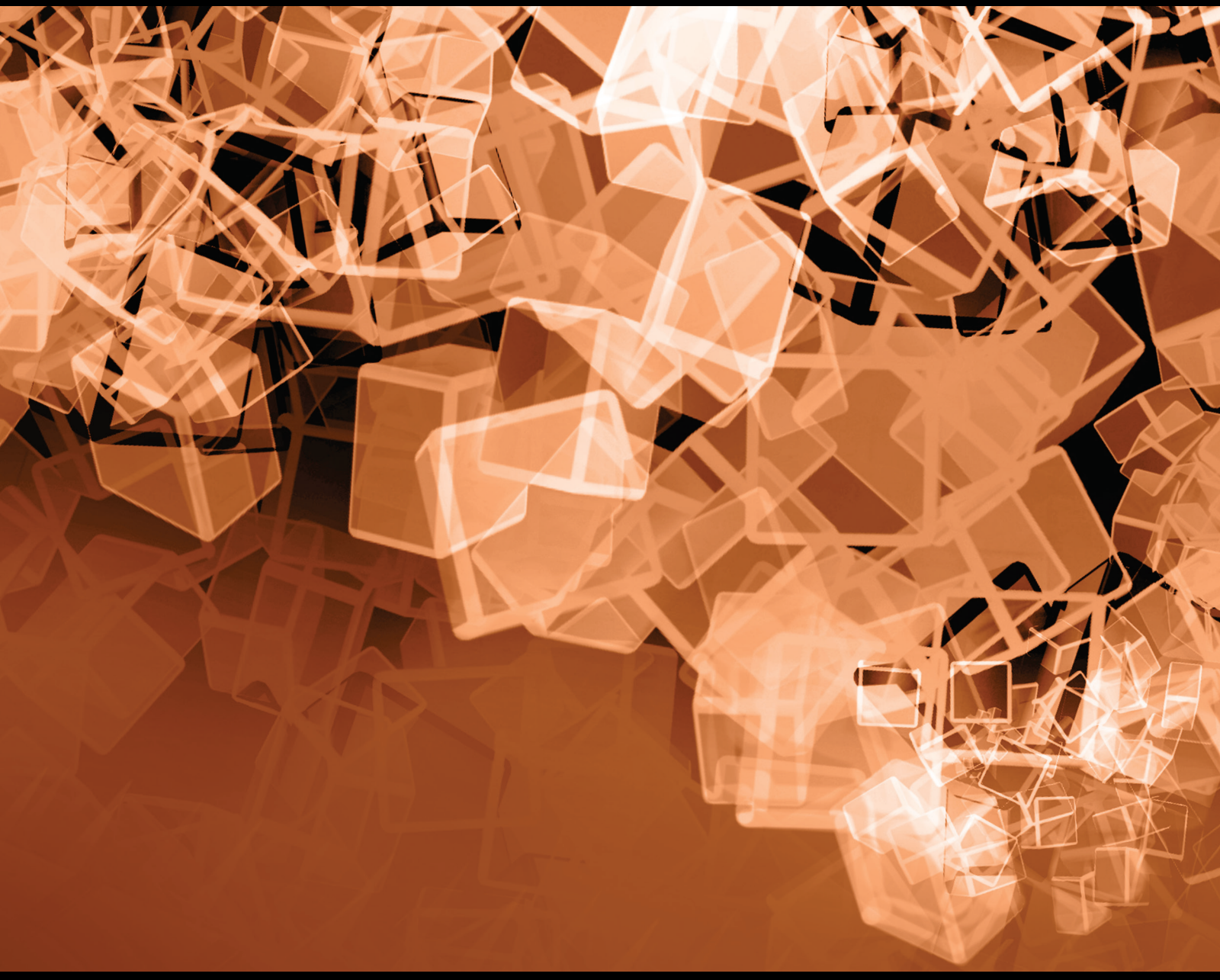
Discrete Dynamics in Nature and Society

Quantitative Methods for Socio-Economic System Research in the Big Data Era

Lead Guest Editor: Lele Qin
Guest Editors: Rashid Maqbool and Xiaoling Huang



Quantitative Methods for Socio-Economic System Research in the Big Data Era

Discrete Dynamics in Nature and Society

Quantitative Methods for Socio-Economic System Research in the Big Data Era

Lead Guest Editor: Lele Qin
Guest Editors: Rashid Maqbool and Xiaoling Huang

Contents

Contents

Contents

Contents

The Prediction of Sports Economic Development Prospect in Different Regions by Improved Artificial Bee Colony Algorithm
Lei Liu and Guangda Song
Research Article (8 pages), Article ID 7720250, Volume 2022 (2022)

IPO Pricing, Investor Behavior, and IPO Underpricing of High-Tech Companies: Evidence from SSE STAR Market and Nasdaq Market
Yu Ma, Guiling Liu, and Chaoping Qi
Research Article (14 pages), Article ID 1711645, Volume 2022 (2022)

Hindawi
Discrete Dynamics in Nature and Society
Volume 2024, Article ID 1055977, 18 pages
https://doi.org/10.1155/2024/1055977

Research Article

Intellectual Structure of Global Value Chain Research: Visualization and Bibliometric Analysis Based on VOSviewer

Jianhua Dai and Shuanglei Xu

Business School, China University of Political Science and Law, Beijing 100088, China

Correspondence should be addressed to Jianhua Dai; daijianhua@cupl.edu.cn

Received 22 March 2022; Revised 24 August 2023; Accepted 12 February 2024; Published 23 February 2024

Academic Editor: Emilio Jiménez Macías

Over the past few decades, numerous scholars have conducted research on global value chains, and the amount of literature in this field has grown rapidly to become "big data." In order to deeply analyze and explore the current research status and development trends in the field of global value chains, this article conducted a systematic and quantitative study on the global value chain. Based on the Web of Science Core Collection SCIE and SSCI databases, this article searched 8273 articles published between 2001 and 2021 with the theme of "Global Value Chain" and used visualization and bibliometric analysis methods. The research field was analyzed using VOSviewer software. Research has shown that the number of papers published in the global value chain field has been continuously increasing over time and has entered a period of rapid development since 2016. The main disciplines are economics and management. A few researchers and research institutions have a strong influence, but the cooperation between scholars and institutions is relatively weak. The United States, the United Kingdom, and China dominate the research field. The complex impact of the natural environment and public health on the global value chain, and the impact of big data and artificial intelligence on the global value chain, has become a new direction for future research. Countries should actively promote the development of the digital economy and green economy, promote the effective allocation of global value chain resources by enterprises, and adhere to the development of good bilateral political relations to reduce the uncertainty of enterprise participation in the global value chain caused by political risks.

1. Introduction

Since the 1980s, with the gradual liberalization of international trade, the rapid development of information and communication technology, and the continuous deepening of international division of labor, the traditional development model of multinational companies has been gradually changed, and global value chains have gradually become the main form of international division of labor. The 2008 financial crisis resulted in global overcapacity, lack of motivation for the expansion of the global value chain, and stagnating. With the improvement of the technological level of enterprises and the level of artificial intelligence, seeking labor advantages around the world is no longer an important goal pursued by the manufacturing industry. Expansion of the value chain is hindered. With the outbreak and epidemic of COVID-19, international trade production and transportation have been suspended, and the global value chain has been hit hard and has faced reshaping.

1.1. Literature Review. Many scholars have conducted research on the global value chain, and according to research methods, literature can be divided into two areas: econometrics and bibliometrics. The study of the value chain originated in the mid-1980s, and Porter pointed out in the book "Competitive Advantage" in 1985: "Every enterprise carries out various activities in the process of designing, producing, selling, dispatching, and assisting its products. Aggregate, all these activities can be represented by a value chain [1]." From the perspective of the value chain, Porter provided a microanalytical framework for industrial economic organization and enterprise strategic management.

He believes that in the era of globalization, the competitiveness of enterprises depends on whether they can operate these value chains and occupy high-value links in the chain. Led by Gereffi, scholars have studied the theoretical framework, dimension expansion, industrial upgrading, and governance types of value chains. In the early 1990s, Gereffi developed the first original framework for explaining the organization of international production networks, based on the economic power of large buyers and producers in driving these commodity chains. He also attempted to go beyond the A country-centered global economic analysis model that reveals macro- and micro-connections scattered across the globe, countries, and regions. To achieve this drive, Gereffi extended the three main dimensions of the commodity chain, namely, input-output structure, territoriality, and interfirm governance. Subsequently, scholars have conducted in-depth research on this dimension of interfirm governance, conceptualizing four types of GVC-related upgrading in industrial clusters [2]. Then, Gereffi et al. designed a theoretical work in economics and sociology, such as production fragmentation, coordination problems, and network analysis. He also constructed a type of supply chain through three supply chain variables, namely, transaction complexity, codeability, and capacity within the supply base, and types of value chain governance [3].

In 2000, the Rockefeller Foundation sponsored a large-scale global value chain conference, marking the beginning of the rapid development of global value chain research. In the field of econometrics, scholars have expanded their research perspectives from micro to macro. At the micro level, Akkermans et al. discussed how bounded rationality expressed by the differing beliefs and goals of supply chain partners enables functional independence and creates barriers to effective value chain management [4]. Lipparini, Lorenzoni, and Lipparini et al. argued that those who benefit most from knowledge transfer between partners are partners who share a common identity and language, acting as a safeguard against the potential threat of opportunism; allowing partners to learn from each other also reduces the risk of knowledge spillover [5]. Kano believes that the bounded rationality and reliability of decision-makers participating in enterprises affect the efficiency of global value chains. Therefore, the role of managers in leading firms is to control bounded rationality and reliability through mixed relational mechanisms, thereby increasing the likelihood that the global value chain (GVC) will be sustainable over time [6]. At the macro level, Griffith and Myers argued that cultural fit can improve performance and that GVC performance can be affected by influencing the ability of leading firms to effectively deploy relational strategies across the network [7]. Sturgeon et al. discussed the impact of the home country's cultural characteristics on the ability of leading American and Japanese firms to successfully engage in relational governance [8]. Barrientos et al. examined the dissemination impact of global and regional supermarkets in the "Global South" and found that the entry of large global retailers provides new opportunities for the most skilled local horticultural producers and workers. This condition is conducive to economic and social upgrading. However, continued economic downward pressure indicates that many less skilled suppliers are excluded from global and regional value chains [9]. Laplume et al. analyzed the potential impact of 3D printing technology on the structure and geographic scope of global value chains [10].

In the field of bibliometrics, Jurowetzki et al. used bibliometric analysis to combine national innovation systems and global value chain literature to study policies related to global economic development [11]. Guan et al. considered measures related to length and location in vertical specialization literature from the perspectives of bibliometrics and economics, measuring the position of the industrial sector in the global value chain [12]. Luo et al. used bibliometric analysis to comprehensively analyze 1811 articles on low-carbon supply chains from 2003 to 2021, exploring the evolution trend and future research directions of low-carbon supply-chain-related literature [13]. They also studied the author distribution, geographical distribution, and cluster situation of literature in this field. Nabi et al. conducted a bibliometric analysis of 212 publications from 2001 to 2020 using VOS viewer, identifying the collaboration network between the main authors, suggesting that emerging country enterprises can enter the international market by reducing value chain activities, and providing direction for supplier downgrade strategies [14]. Wang and Gu used VOS viewer to analyze the main trends in global value-chain-related literature in 2022, showcasing the evolution of value chain theme development, the impact of value chain in different journals and literature, and the impact of keywords and countries on value chain literature publication. Finally, they predicted the trends and directions of future value chain research [15].

Through literature analysis, we found that research on global value chains includes qualitative analysis such as theoretical frameworks and empirical testing of micro basic assumptions. The research level has also expanded from micro to macro levels, analyzing not only the relationship between enterprises and the global value chain but also the impact of the global value chain on political, economic, and environmental systems. However, there are very few direct literature studies on global value chain literature using bibliometrics and visual analysis, and they remain in the descriptive statistical stage after literature visualization, lacking classification and summary, and lacking reference significance for future research. Most of the relevant literature is a combination of global value chains and other directions, rather than research on global value chains.

1.2. Research Questions. This article provides a detailed explanation of the global value chain, and the research questions are as follows: What is the scale and source journal of global value chain research? What are the key and cutting-edge aspects of global value chain research? What is the distribution of global value chain research in terms of countries, institutions, and authors? What is the cocitation status of literature on global value chain research?

1.3. Research Purpose. This article analyzes the research hotspots and trends in the field of global value chains, in order to provide certain guidance for future academic

research and policy formulation. In the post pandemic era, the global value chain is facing reshaping. On the one hand, in the new situation, new research hotspots and trends have emerged in the field of global value chains. This article will analyze the research situation in this field in the past 20 years, explore new research perspectives in this field, and provide guidance for scholars' future research. On the other hand, it provides reference for the effective allocation of global value chain resources and the upgrading of industrial structures in various countries.

1.4. Research Significance. This study analyzes the research hotspots and trends in the global value chain field and divides the existing research content into four major parts, which can provide certain guidance for future academic research and policy formulation. This paper finds that with the increasing global attention to environmental issues and the prevalence of the COVID-19 epidemic, the direction of environment and public health has become a new research direction in the field of global value chain. This article also found that digital trade in the context of the digital economy is increasingly affecting the international trade pattern, and global value chains are facing restructuring. Countries should use the digital economy as a new engine to drive economic development, breaking through the low-end lock-in dilemma in the division of labor in the global value chain. The direction of the digital economy and global value chain has also become a new research direction in the field of global value chains. This article also provides policy recommendations for countries to formulate international trade rules, promote the effective allocation of global value chain resources by enterprises, and promote economic growth.

2. Data Sources and Research Methods

2.1. Data Sources. Web of Science is the world's largest and most interdisciplinary comprehensive database platform, containing a large amount of data on natural sciences and humanities and social sciences worldwide from 1900 to the present. It is rich in information and updates quickly, providing relevant information for scholars around the world to conduct scientific research. The most important thing is to retrieve the history of research literature in a certain field of the lake and track its latest progress by searching the database. Therefore, this article chooses the Web of Science database as the literature source for the global value chain.

This article selects the Web of Science core collection as the data source. In order to obtain a comprehensive literature record and make each year's literature record statistically meaningful, the search time is set to "2001–2021," the dataset is limited to "SCIE" and "SSCI," the language is limited to "English," and the literature type is limited to "Article." The retrieval formula was determined to be (TS=(("global") AND ("value chain") OR ("value chains")), resulting in a total of 8273 records.

2.2. Discharge Standards. Inclusion criteria were as follows: English literature related to the global value chain. Exclusion criteria were as follows: literature with duplicate or incomplete data, conference papers, news, and newspapers.

2.3. Analysis Methods. Bibliometrics is a discipline that studies the distribution structure, quantitative relationships, and changing patterns of literature information using mathematical, statistical, and other econometric methods, focusing on the literature system and bibliometric characteristics. Scientific metrology is the study of the quantitative contribution patterns of the overall development of science and technology and related components using quantitative methods. It is a research field that uses quantitative methods to handle the inputs (such as researchers and research funds), outputs (such as the number of papers and citations), and processes (such as information dissemination and the formation of communication networks) of scientific activities. There is a certain overlap between the two, as one of the main forms of scientific activity output is scientific literature. Therefore, quantitative research on such literature is both scientific metrology research and bibliometric research.

Knowledge graph is a research method that combines the theories and methods of applied mathematics, information visualization technology, and other disciplines with the cooccurrence analysis methods of scientific metrology and bibliometrics and uses a series of graphics to display the process and structural relationship of knowledge development in a certain discipline. Knowledge mapping is used more and more widely as a method of data visualization. Dai and Xu, based on the Web of Science core collection database, used bibliometrics methods and CiteSpace software to conduct a visual analysis of literature in the field of global value chain from 2011 to 2021 [16]. CiteSpace software distinguishes keyword clustering and literature cocitation by clustering blocks to highlight the frontiers of word segmentation and automatically generates titles in clustering blocks, and some information may be omitted. The VOSviewer used in this article is developed using Java programming language and has many analytical functions, such as keyword cooccurrence network analysis, collaborative network analysis, and literature cocitation analysis. It can draw various knowledge graphs, and researchers can use it to analyze research hotspots and trends in the discipline to reveal the knowledge structure of the discipline. This article not only extends the sample period to 2001–2021 but also uses VOSviewer software to distinguish keyword clustering and cocitation of cutting-edge literature by different colors, so it can extract and summarize complete viewpoints on its own.

2.4. Research Limitations. Bibliometrics relies on the quantity and quality of literature as indicators to measure the impact of research, rather than just relying solely on the number of publications to measure the results and level of research. For example, in the analysis of keywords, research authors, research institutions, and research countries, we not only used the number of publications but also used the ratio

of citation to publication to reflect the quality of the literature. However, we have to admit that this may still be influenced by self-citation factors. Meanwhile, all studies are based on the selection of specific keywords and database limitations. Therefore, in order to improve the credibility of the paper and ensure the representativeness of the research topic, we expanded the analysis scope from the Web of Science database to the Scopus database in Chapter 3 of the research content analysis and compared the analysis results under different databases to verify the reliability of the research as much as possible.

3. Research Content

3.1. The Scale Analysis of Global Value Chain Literature. In Figure 1, the historical development of GVC research can be divided into three stages, namely, exploration, preliminary development, and rapid development.

3.1.1. Exploratory Phase (2001–2007). 533 papers were published during this phase. An article entitled "Governance in Global Value Chains" states that governance is at the heart of the global value chain approach, and this article explains its definition and importance for development research and policy. The concept is used to refer to the relationships and institutional mechanisms between firms through which nonmarket coordination of activities in the chain occurs. This coordination is achieved by setting and enforcing the product and process parameters to be satisfied by the actors in the chain. In global value chains, in supply chains typically operated by producers in developing countries, buyers play an important role in setting and enforcing these parameters [17].

3.1.2. Initial Development Stage (2008–2015). 2084 papers were published in this stage. Since 2008, many scholars and institutions have gradually deepened their understanding of exploring the nature of global value chains. They gradually formed the following definition: we define global value chains as a governance arrangement; that is, multiple governance models within a single structure are used to govern different, geographically dispersed, and segmented parts of the value chain. In other words, GVCs are the nexus of interconnected functions and operations whereby goods and services are produced, distributed, and consumed on a global scale [18, 19].

3.1.3. Rapid Development Stage (2016–2021). In this stage, research results emerge rapidly, with 5,656 papers published, averaging more than 900 papers per year. Especially since 2019, the number of documents has increased dramatically. With the advancement of the Internet and computer technology, the global value chain based on big data has received attention. At the same time, studies on sustainability, carbon emissions, and the environment continue to emerge, gradually forming a cross-disciplinary and cross-industry integration.

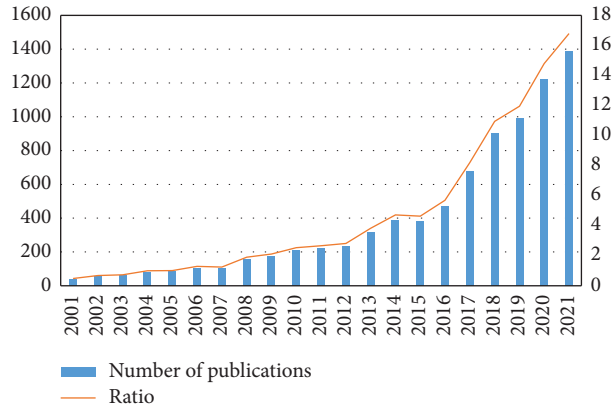


Figure 1: The scale analysis of GVC literature.

3.2. The Source Journal and Disciplinary Analysis of Global Value Chain Literature. Academic journals are an important carrier of academic achievements. By analyzing the source journals of literature in the global value chain field, we can discover the distribution of literature in journals, which also plays an important guiding role for scholars in selecting and submitting articles. We have compiled the journals with the most papers in the global value chain field and listed the top ten journals with the most papers in this field in Table 1. The top three journals in the rankings are Sustainaability, Journal of cleaner Production, and Support chain management an International JOURNAL, with a total of 188, 156, and 90 published papers in the global value chain field, respectively.

Table 2 shows the JCR main subject distribution of the journals listed in Table 1. The top five journals are Management, Green and sustainable science & technology, Environmental studies, Business, and Economics. The research of global value chain is still the main topic of economic management discipline.

3.3. The Research Hotspot Analysis of Global Value Chain Literature. The keywords of the literature are the core viewpoints of the paper and the refined expression of the research topic, which can highlight the core content of the full text. Therefore, the analysis of the keywords is helpful to explore the research hotspots in this research field. Keyword cooccurrence analysis is universal in bibliometric analysis, and it mainly studies the link strength between cooccurring keywords in various studies. Its function is to analyze the internal relationship of an academic field and reveal the research frontier in the field. The larger node and font size indicate higher keyword frequency and higher similarity of keywords with the same color; the thicker connection indicates a closer connection between the two keywords. Figure 2 shows that through the keyword cooccurrence network analysis, the main research topics can be divided into four clusters, and the keywords in the same cluster have a great similarity. In Table 3, we have listed the frequency and connection strength of some keywords. It can be seen that the most frequently appearing keyword is the global value chain, with a frequency of up to 1316 times and a connection strength ranking first at 5118.

Table 1: Distribution of top ten source journals of GVC literature.

Rank	Journals	Total publications	JCR category
1	Sustainability	188	Green & sustainable science & technology Environmental studies Green & sustainable science & technology Environmental sciences
2	Journal of cleaner production	156	Engineering, environmental Environmental sciences Green & sustainable science & technology
3	Supply chain management an international journal	90	Business Management
4	Plos one	61	Multidisciplinary sciences
5	World development	60	Development studies Economics
6	International journal of operations production management	57	Management
7	World economy	56	International relations Economics Business, finance
8	International journal of physical distribution logistics management	54	Management
9	Geoforum	53	Geography
10	International journal of logistics management	48	Management

Table 2: Distribution of top ten disciplines of GVC literature.

Rank	Categories	Total
1	Management	4
2	Green & sustainable science & technology	3
3	Environmental studies	2
4	Business	2
5	Economics	2

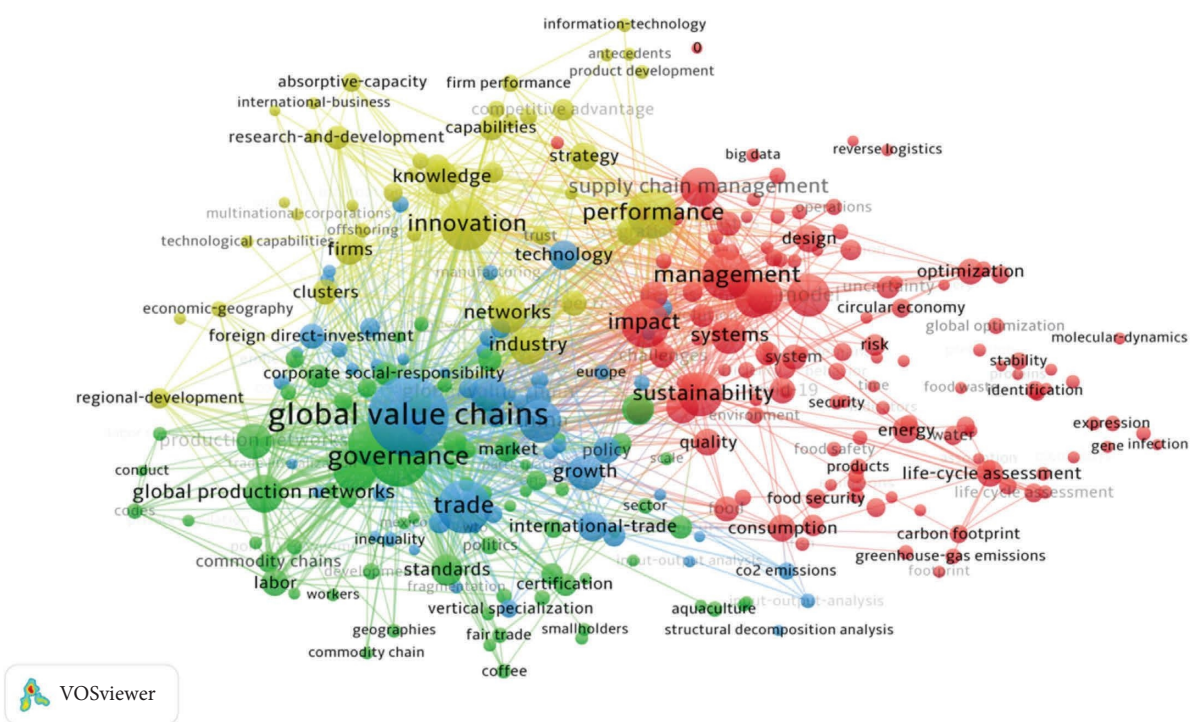


Figure 2: Keyword cooccurrence map of GVC literature (Web of Science).

Table 3: Keyword quantity analysis of GVC literature.

Keyword	Occurrences	Total link strength
Global value chains	1316	5118
Governance	743	3776
Trade	596	2323
Innovation	556	2735
Performance	534	2473
Management	505	2113
Impact	492	2176
Globalization	423	2033
Sustainability	409	1700
Value chains	398	1823

According to the results of the keyword cooccurrence map, we analyze the four clusters formed separately, and the keywords in the same cluster have great similarity. Four aspects of economics, labor economics, value chain composition, and international economics are elaborated.

3.3.1. Cluster 1 (Red): Aspects of Macroeconomics Level. The development of GVCs is affected by a number of macro factors, including intellectual property and foreign direct investment protection regimes [20], trade and tariff regimes, government policies, economic development levels [18], and technological levels. States play a major role in the organization and evolution of global value chains [21]. With the increasing global attention to environmental issues and the outbreak and prevalence of COVID-19, environmental and public health directions have become new research perspectives. The key themes are summarized in the following section.

Institutional direction (cooccurrence keywords include institutions, policies, and management): Institutional factors are a major determinant of the governance attributes of GVCs, and host countries can attract investment from lead firms through policies that promote local supplier linkages but are also skeptical of such investments due to insufficient intellectual property protection and underdeveloped legal systems [22]. However, the impact of the host country's institutional environment on GVCs is heterogeneous, and while we assume that leading firms are attracted to favorable local institutions, it also depends on the specific activities offshore, motivations for internationalization, and the strategies and capabilities at the leading firm level [23, 24]. Institutions strongly impact the ability of GVCs to engage in and profit from innovation, and the lack of local institutions prevents domestic firms from transforming research and development into innovative products and services [25], effectively hindering the supplier catch-up and upgrade. Multinational originates from a developed institutional environment and thus demonstrates technological leadership, a challenge that peripheral players of GVCs can address by engaging in international cooperation and integrating more broadly into international networks to offset local weaknesses [26]. The impact of institutions is dynamic, as trade and liberalization in emerging markets progress, as well as the strategy of suppliers, with internal research and development as the dominant strategy for upgrading [27, 28]. In addition, more technologically advanced suppliers will become the core of the regional network [28]. Green innovation in manufacturing can create economic and social benefits but with risks. It needs to be scientifically and systematically managed based on the perspective of global value chains to promote and protect the value of green innovation [29].

Economic direction (cooccurrence keywords include circular economy, cost, and efficiency): Economic factors can greatly affect the configuration of GVCs and determine the transfer of production in GVCs so suppliers seek higher efficiency and better production capacity [30]. In the global automotive industry, an inverted U-shaped relationship is found between international diversification and performance in manufacturing. The advantages of diversified manufacturing are ultimately offset by increasing organizational complexity and management inefficiencies. Furthermore, location decisions not only aim to reduce costs but are also related to the company's strategic priorities [31]. The simultaneous realization of cost efficiency and production capacity results in a lower cost-to-capacity ratio, which is beneficial to the sustainable development of suppliers. *n* interdisciplinary research agenda with a focus on the Global South is proposed to provide a stronger evidence base to demonstrate how the circular economy can contribute to sustainable global value chain goals for sustainable societies and address degradation and pollution in the Global South [32].

Technology direction (cooccurrence keywords include big data, blockchain, and technology): In the process of intelligent development of the value chain, technology has played a major impact on its life cycle [33]. Thus far, in the 21st century, the development of ICT and the digital economy has enabled "big data" to become the focus of development analysis of dynamic changes, strategic decision-making, and forecasting in urban management [34]. By using the differential panel model with big data in Chinese enterprises, Chinese enterprises' participation in the global value chain can promote their green technology progress and provide a reference for the strategy of solving the dilemma of Chinese enterprises limited by the low-end global value chain [35]. Blockchain technology also has potential implications for all aspects of GVC management, including boundaries, structures, and relationships [36]. 3D printing technology has potential impacts on global value chain structure and geographic scope [10]. While digital connectivity can leverage complementarities between geographically dispersed processes [22], it may limit the participation of suppliers located in less technologically developed regions [37].

Public health direction (cooccurrence keywords include new coronavirus, disease, diagnosis, and health): Amid the COVID-19 pandemic, the shortage of N95 respirators in the U.S. is less a market failure than a policy failure, and the global value chain framework highlights strategic options that could lead to more resilient supply chains and diversified procurement models [38]. The impact of the COVID-19 pandemic on corporate strategies, especially the configuration of corporate global value chains after the

pandemic, is under control. The advantages and disadvantages of alternative location strategies and different governance arrangements for GVC activities are compared [39]. The growing global population also increasingly demands different types of food, especially animal proteins. Research on novel proteins requires not only the development of new value chains but also the impediment of negative environmental impacts and some health concerns [40].

Environmental protection direction (cooccurrence keywords include sustainability, carbon emissions, energy, and environment): Internationally, many scholars have studied the goals of global value chain construction, emphasizing green and environmental protection, and realizing the vision of sustainable economic, social, and environmental development. Sustainability plays an important role in the global economic operation and regulatory structure, and the way that leading companies in the global value chain achieve sustainability has also changed. In the context of achieving environmental sustainability, leading companies in the value chain have captured value [41]. By decomposing the global photovoltaic industry value chain and identifying the main factors affecting the transfer and diffusion of photovoltaic technology, the development history of my country's photovoltaic industry shows that innovation in clean energy technology can be achieved through innovation and knowledge exchange in the global photovoltaic value chain [42]. By combining value-added trade and implied emissions from trade in a consistent manner, the potential environmental costs in GVCs can be estimated from different perspectives, such as production, consumption, and trade [43].

3.3.2. Cluster 2 (Yellow): Aspects of Value Chain Composition. Geographical orientation (cooccurrence keywords include location and cluster): Location decisions determine the most favorable geographic configuration of GVCs, where activities should be located and how they should be allocated to maximize the value created and captured by GVCs. Colocation of manufacturing and sales also allows leading firms to be more responsive to customer needs and offsets the cost of globally dispersed activities by reducing investment in transportation and logistics [31]. An industrial cluster refers to a group of interconnected enterprises, financial institutions, suppliers, and service providers with concentrated geographical locations in a certain industrial environment and is a common feature of industrialization development. The continuous stabilization of the global value chain brought about by economic globalization and trade liberalization has also prompted local industrial clusters to be passively or actively embedded in the global economic system. The literature on industrial clusters emphasizes the role of interfirm cooperation and local institutions in facilitating upgrade, and clusters are inserted in different ways into global value chains. These approaches have implications for enabling or disabling local upgrading efforts, with particular attention to the status of developing country firms [2]. Companies and suppliers seek strategic assets, thereby largely explaining the geographic structure of GVCs, with multinational corporations positioning value chain activities in globally specialized units to take advantage of the international division of labor [44].

Leading enterprise direction (cooccurrence keyword package firm and leading firm): The smooth and effective functioning of GVCs depends to a large extent on the ability of the lead company to build, coordinate, and lead the network. The way GVCs are organized differs not only by the size and productivity of leading firms but also by other heterogeneous firm-level characteristics. GVC researchers should not make assumptions about the uniqueness of large leading firms as a group, looking out for other potential sources of heterogeneity [45]. Through a case study of GVCs of Chinese power companies, we find that power relations in GVCs appear to be more balanced when emerging market countries are in the lead [46, 47].

Knowledge innovation direction (cooccurrence keywords include knowledge, innovation, and ability): Research on industrial clusters using a social network approach shows that, in knowledge-intensive industries, a network structure supported by horizontal linkages of local firms tends to improve innovation performance, while vertical linkages between local firms and multinational can promote labor-intensive cluster innovation [48]. Escalating within established GVCs and developing new ones under local control are difficult, requiring the mobilization of entrepreneurial capacities and the development of complex management skills. Successful upgrades depend not only on suppliers' access to knowledge but also on their ability to absorb knowledge and turn it into innovation, ultimately improving the supplier's position in the global value chain [19].

3.3.3. Cluster 3 (Green): Aspects of Labor Economics. Individual orientation (cooccurrence keywords include labor force and worker): Eriksson et al. believed that the individual-level cognitive and management skills of managers that lead enterprises, such as cultural awareness, global thinking, and analytical skills, can help enterprises to successfully realize cross-border transactions in global value chains [49]. Sinkovics et al. explored the relationship between information complexity, information codification, and supplier capabilities to knowledge connectivity in global value chains, arguing that the risk perception ability of leading enterprise managers can moderate the relationship [50]. Control of global value chains rests with technology leaders, also known as core figures [47].

3.3.4. Cluster 4 (Blue): Aspects of International Economics. Direction of foreign investment (cooccurring keywords include foreign direct investment, international trade, and economic growth): Foreign direct investment enables multinational companies to build a global network under their control, offering a wide range of products with differentiated and low-cost features. Research on Taiwanese electronics firms shows that FDI typically starts close to home, where resources can be drawn from domestic networks, and then, it moves further field as dominant firms develop regional subnetworks to support their further

expansion [51]. A strong relationship exists between GVC participation and a country's network location, with forward participation being associated with more agglomeration but less trade linkages and backward participation with less agglomeration but more trade linkages [52]. Emerging markets should increase high-value-added domestic value chains, reduce foreign-led global value chains, and increase the participation of global value chains in economic growth [53].

Equity and efficiency direction (cooccurrence keywords include developing countries and inequality): In developing countries, the domestic institutional environment, such as the support of national policies and business associations, is more important than the influence of lead companies in shaping network dynamics [26]. Fair value distribution increases partner reliability and enhances the sustainability of global value chains over time [6]. Notably, a fair distribution of value undermines the potential efficiency gains achieved through the externalization of activities, but such sacrifices in efficiency losses may be necessary to ensure the survival of the global factory [54].

3.3.5. The Trend Analysis of Research Hotspots. Figure 3 shows trends in the emergence of keywords in global value chains in recent years. These trends should be studied to explore cutting-edge research. The color change of nodes from blue to yellow in Figure 3 represents the trend of keywords from 2015 to 2021, including: "supply chain, commodity chain, geography, industrial cluster, governance, Internet, global production network, system, vertical division of labor, global value chains, economic growth, sustainability, carbon emissions, and big data." Keywords related to "environmental protection direction" include "sustainability, carbon emissions, environment, and energy." The keywords related to "technical direction" are "big data, blockchain, and technology."

In 2011, global value chain research mainly focused on geography, industrial clusters, and other aspects. An industrial cluster refers to a group of interconnected enterprises, financial institutions, suppliers, and service providers with centralized geographical locations in a certain industrial environment. Groups are a common feature of industrial development. The continuous stabilization of the global value chain brought about by economic globalization and trade liberalization has also prompted local industrial clusters to be passively or actively embedded in the global economic system. Against such a background, industrial clusters must compete for a place in the global market while facing local competition. Therefore, measuring the role of industrial clusters in the global value chain and exploring the impact mechanism of the global value chain on the development of industrial clusters have become the research hotspots of scholars.

In 2015, scholars began to study vertical specialization in global value chains. The division of labor in the global value chain refers to the division of labor and production links that countries or regions are responsible for when participating in the global value chain. At present, the mode of international division of labor has begun to change from horizontal division of labor to vertical division of labor; that is, the enterprises of various countries participating in the international division of labor and cooperation have changed from producing final products to relying on their own factor endowments and only complete a certain link in the final product formation. Developing countries have the opportunity to create and capture higher added value by participating in global value chains. This potential has spawned research on continuous vertical specialization, and development policy and research should delve more deeply into the barriers to vertical division of labor and the development of value-added chains [55]. China participates in the manufacturing and processing links in the global value chain with cheap labor costs and will be locked in the low end of the industry in the long run. Therefore, studying the division of labor model is extremely important for my country to better participate in the division of labor in the global value chain.

In 2018, the research on global value chain and economic growth achieved certain results. GVCs can facilitate developing countries to enter the international market and integrate into the global economic system. They no longer need to develop a complete industry; they can only focus on one link in the industrial chain. Moreover, joining GVCs can create jobs and promote the growth of gross domestic product and national income. GVC-related trade stimulates economic growth. The impact of GVC participation on economic growth is diverse. Policies that promote GVC participation and strengthen domestic fundamentals should be the goal of countries to further benefit from trade [56].

In 2020, CO_2 emission and COVID-19 have become new topics of research. Carbon emissions generally refer to greenhouse gas emissions, which cause the greenhouse effect to increase global temperatures. On August 9, 2021, the IPCC released a report stating that due to global warming, extreme weather conditions, such as heat waves, heavy rains, and droughts, have become more frequent, clearly blaming greenhouse gas emissions for rising temperatures and pointing out that the solution to slow and reverse global warming is to reduce greenhouse gas emissions to zero. With the increasing attention to the environment, the research on the value chain and the environment become a new hotspot. Multiregional structural decomposition analysis technology is used to quantify the global value chain determinants of China's carbon dioxide emission intensity from the perspectives of production and consumption and to analyze whether global value chain participation decouples China's development from carbon dioxide emissions. The study shows that global value chains are still major barriers to environmental sustainability in China [57]. COVID-19 has brought global production to a standstill, shrinking international trade. Downstream countries and industries are more affected by China's production disruption than upstream countries and industries. The United States, South Korea, and Japan are the most affected, as well as the electronics, textile, machinery, manufacturing, and wholesale trade industries. China's position in the global value chain is very important [58].

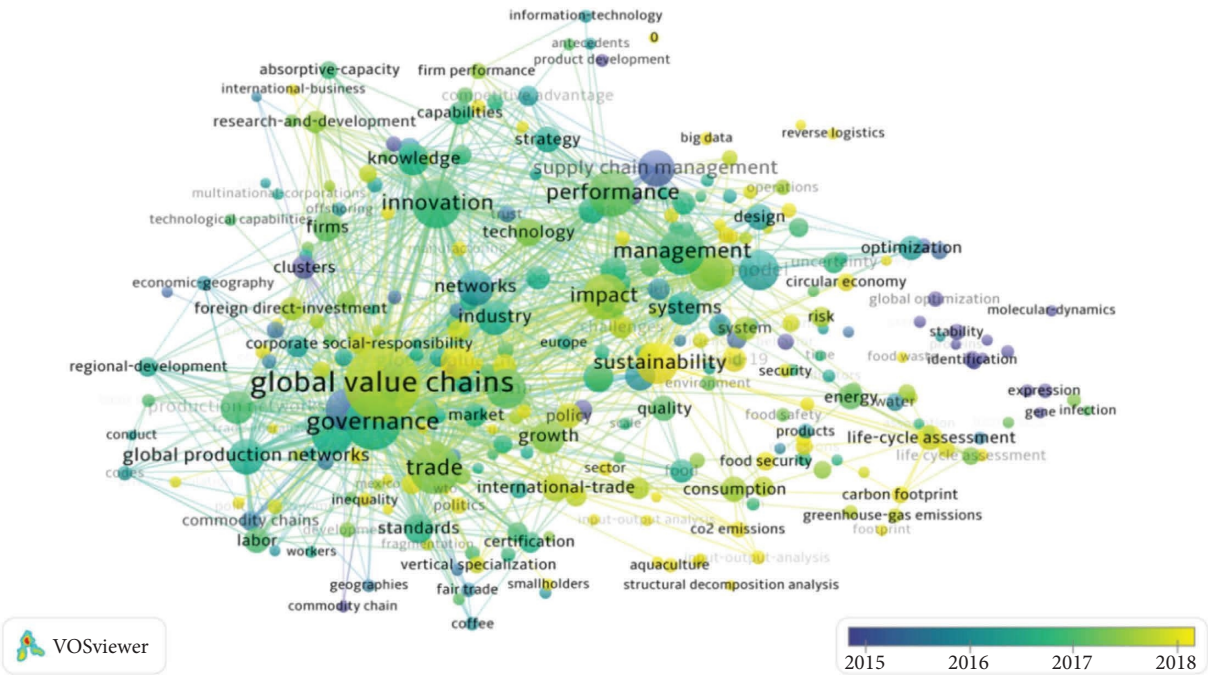


Figure 3: Keyword trend map of GVC literature (Web of Science).

3.3.6. Research Hotspots and Trend Analysis Based on Scopus Database. This article further selects the Scopus database as the data source for comparative analysis with the previous text, in order to demonstrate the reliability of the basic research in this article to some extent. The search criteria are consistent with the previous text. We set the search time to "2001–2021," language to "English," and literature type to "Article" and determine the search formula as (TS = ("global") AND ("value") AND ("chain")). The search time was August 22, 2023, and a total of 8595 records were obtained. In Figure 4, we can see that through keyword cooccurrence network analysis, the main research topics can still be divided into four clusters, and the keywords in the same cluster have great similarity. The keyword with the highest frequency of occurrence is still the global value chain, with a frequency of up to 815 times and a connection strength ranking first at 1392.

Similar to the previous analysis, in the direction of environmental protection, common keywords include sustainable development, carbon dioxide, and environmental impact. In the direction of public health, key words such as COVID-19, virology, epidemiology, diagnosis, and fever are still the key contents of analysis based on the Scopus database. In addition, the cost and economy of the economic direction, as well as the institutional and supply chain management of the institutional direction, are also the same as the above.

Based on the Scopus database, we further analyzed the trend changes of research hotspots, as shown in Figure 5, where the color changes of nodes from blue to yellow represent the trend of keyword appearance from 2001 to 2021. We can clearly see the latest two types of research directions. The keywords in the bottom right corner of Figure 5 are mostly green, including sustainable development, carbon dioxide, environmental impact, and environmental protection. There are a lot of yellow keywords in the upper left corner of Figure 5, including COVID-19, virology, epidemiology, diagnosis, and fever, which belong to the direction of public health. With the increasing attention paid to the environment by countries around the world, the study of value chain and environment will become a new research hotspot. With the outbreak and prevalence of COVID-19 and the suspension of international trade, production, and transportation, the global value chain is facing remodeling, and public health has become a new research direction in the field of the global value chain. This research finding is consistent with the previous findings. The analysis of global value chain research hotspots and trends based on the Scopus database is similar to the research findings based on the Web of Science database, which to some extent demonstrates the reliability of the basic research in this article.

3.4. The Research Author Distribution of Global Value Chain Literature. The coauthorship map of the published authors can reflect the cooperative relationship between the published authors in this field. Table 4 provides the information of the ten authors, who have published the most papers in this field. Gereffi has the highest number of papers (29 papers), followed by Ponte (27 papers) and then by Lund-Thomsen (21 papers). In Figure 6, each node represents an author, the size of the node represents the number of his published articles, the color of the node represents the group the author belongs to based on the default clustering method, and the thickness of the line represents the strength of the partnership between authors. From the perspective of the author group as a whole, GVC research is in a state of

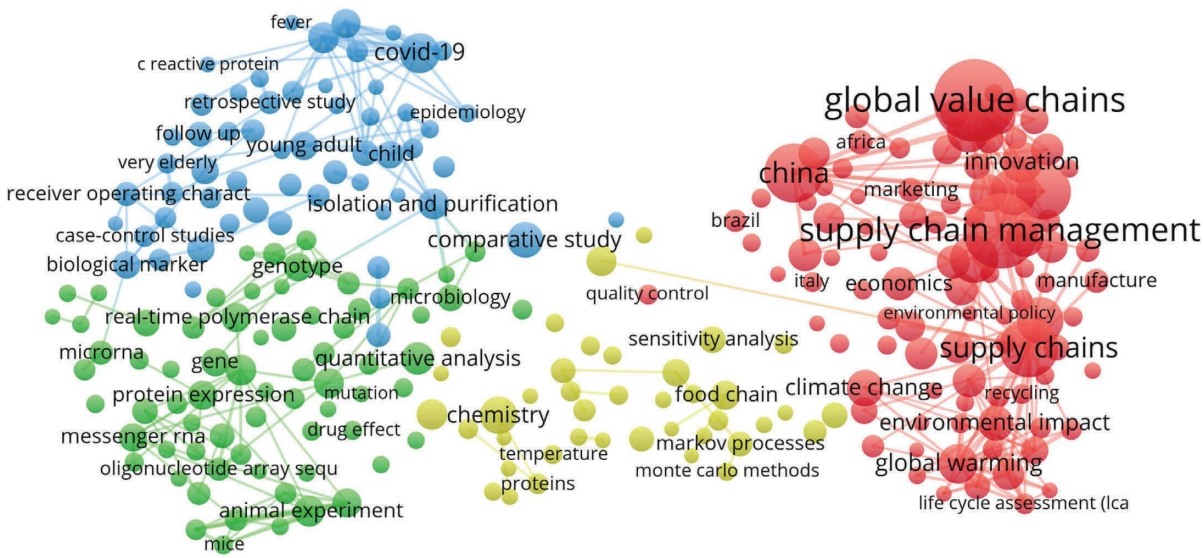


Figure 4: Keyword cooccurrence map of GVC literature (Scopus).

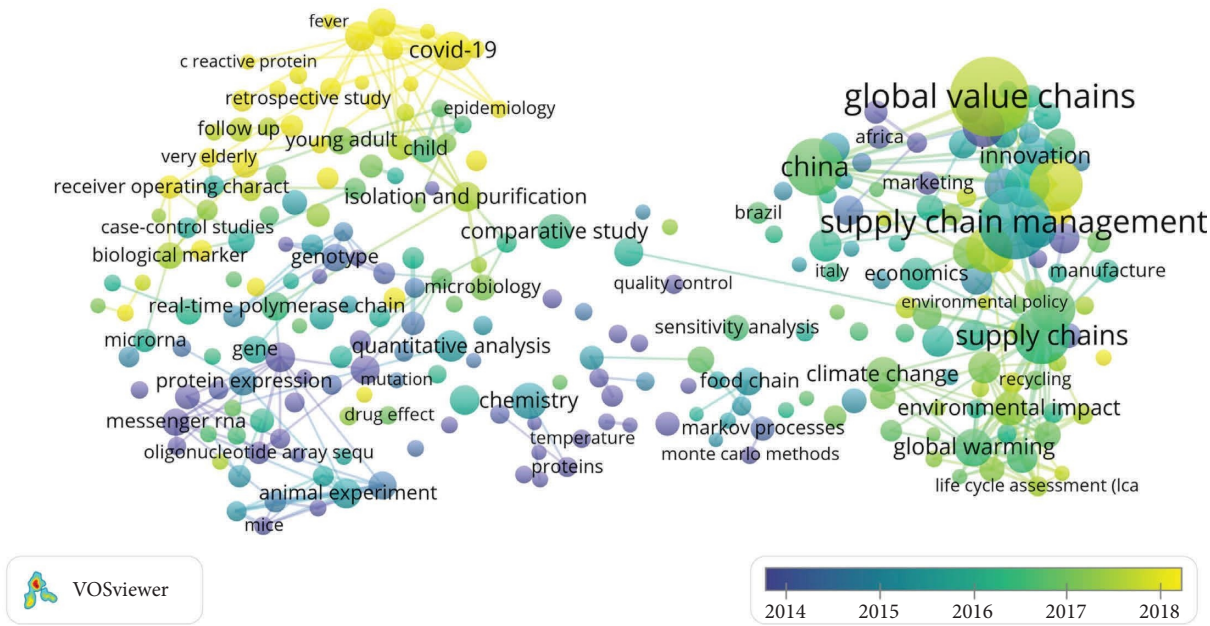


Figure 5: Keyword trend map of GVC literature (Scopus).

"partial concentration and overall dispersion," and the mutual citation relationship between most research teams is weak. Common research teams are usually composed of authors from the same institution. They are not closely related to each other, such as the red clustering team headed by Gereffi, the yellow clustering team headed by Ponte, the blue clustering team headed by Lund-Thomsen, and the Fuchsia clustering team headed by Mudambi. In the long run, this approach is not conducive to the theoretical development of the value chain field.

3.5. The Research Institution Distribution of Global Value Chain Literature. Table 5 shows the top 10 institutions by the number of papers published. The top three institutions by volume of papers are the University of Manchester, Copenhagen Business School, and Chinese Academy of Science, with 122, 91, and 86 papers, respectively. Among the top 10 institutions with the most publications, the UK ranks first with four universities.

In Figure 7, each node represents an organization, and its size represents the number of GVC-related documents it generates. The color of the nodes indicates the group to which the organization based on the default clustering method belongs, and the connections in the network diagram represent the cooperation between the organizations. The wider the line, the stronger the cooperation. The teams headed by the top four institutions with the largest number of publications, shown in dark blue, light blue, green, and

Table 4: The research author analysis of GVC literature.

Author	Total production	Total citation	Total citation/total production
Gereffi, Gary	29	2164	75
Ponte, Stefano	27	1393	52
Lund-Thomsen, Peter	21	729	35
Nadvi, Khalid	17	868	51
Mudambi, Ram	17	1477	87
Di Maria, Eleonora	16	308	19
Bush, Simon R	15	329	22
De Marchi, Valentina	15	302	20
Maertens, Miet	15	468	31
Xing, Lizhi	14	60	4

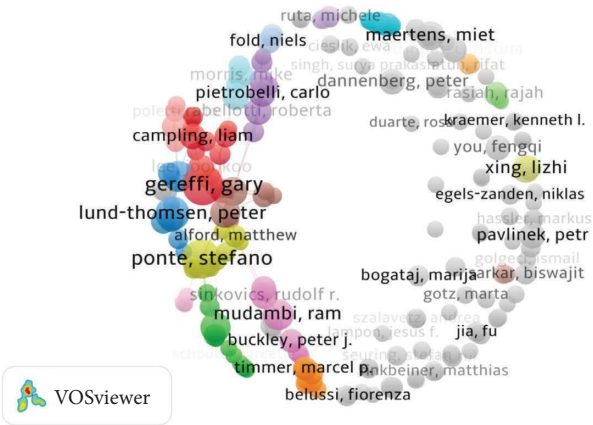


Figure 6: The research author map of GVC literature.

Table 5: The research institution analysis of GVC literature.

Organization	Country	Total production	Total citation	Total citation/total production
University of Manchester	England	122	5540	45
Copenhagen Business School	Denmark	91	2750	30
Chinese Academy of Science	China	86	1699	20
Wageningen University	Netherlands	76	2423	32
Duke University	USA	66	6183	94
University of Sussex	England	66	6652	101
University of Cambridge	England	59	1421	24
University of Sao Paulo	Brazil	58	938	16
National University of Singapore	Singapore	57	2382	42
University of Oxford	England	55	1667	30

red, are not closely related and are relatively independent, and need to strengthen cooperation. The University of Chinese Academy of Sciences ranked third with 86 publications, indicating that Chinese scholars are more interested in the field of global value chains. The ratio of the number of citations to the number of publications reflects the quality of the literature to a certain extent. According to the TC/TP value, the University of Sussex ranks first with 101, and Duke University ranks second with 94, indicating that the quality of its literature is relatively high. However, the TC/TP value of China is at a low level of 20, indicating that the quality of Chinese scholars' papers still has a lot of room for improvement.

3.6. The Research Country Distribution of Global Value Chain Literature. Table 6 shows the top 10 countries by the number of published papers. The top three countries by the number of published papers are USA, England, and China, with 1,748, 1,124, and 1,019 papers, respectively. In this research field, countries with relatively high levels of economic development, such as the United States, the United Kingdom, China, Germany, and Italy, are currently dominant.

In Figure 8, each node represents a country, and its size represents the number of GVC-related documents it generates. The color of the nodes represents the group to which the organization based on the default clustering method

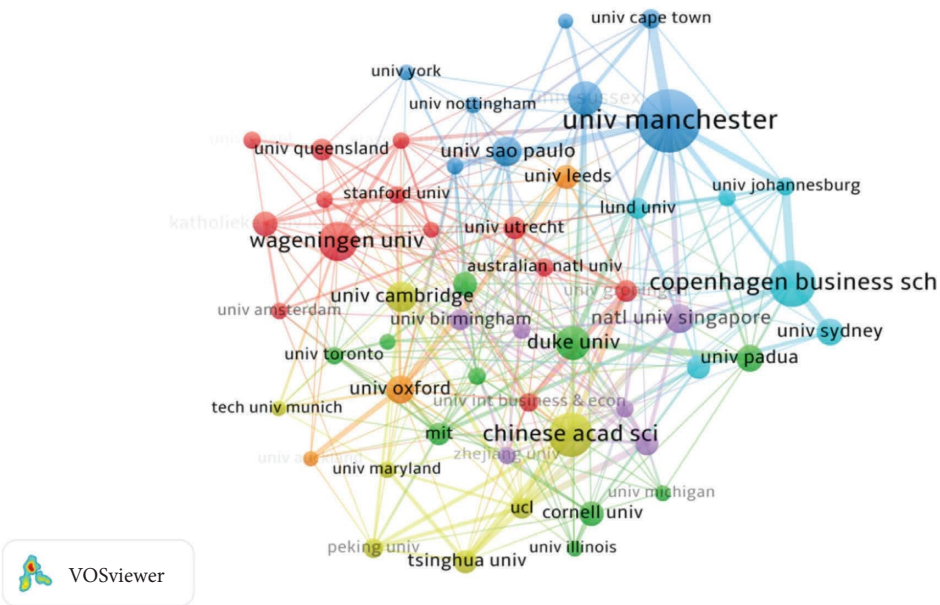


Figure 7: The research institution map of GVC literature.

Table 6: The research country analysis of GVC literature.

Country	Total production	Total citation	Total citation/total production
USA	1748	59120	34
England	1124	34847	31
China	1019	15630	15
Germany	724	15743	22
Italy	508	11447	23
France	452	8983	20
Australia	437	8511	19
Netherlands	420	11761	28
Spain	410	7461	18
India	385	5177	13

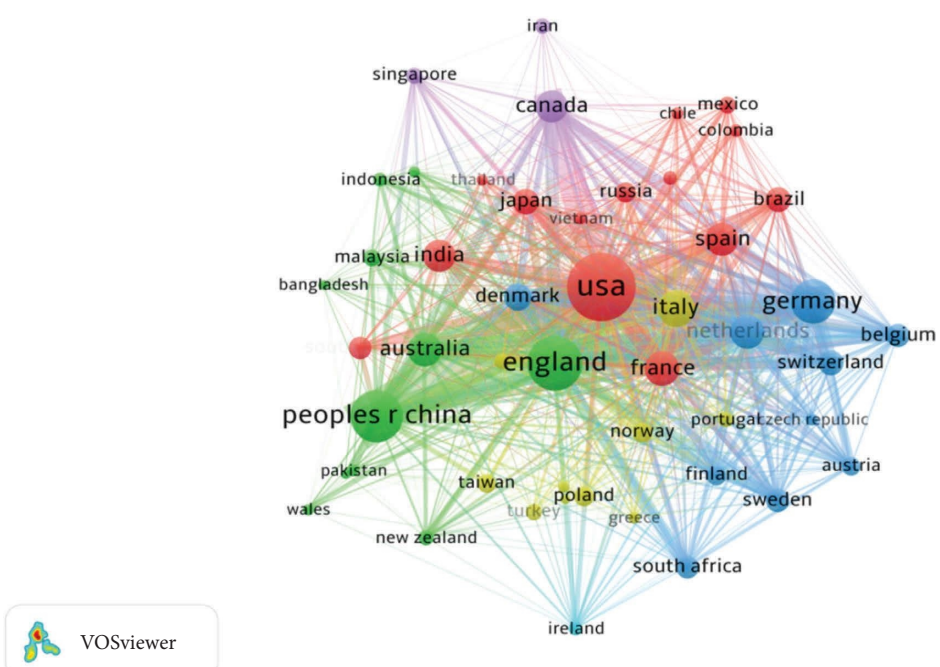


Figure 8: The research country map of GVC literature.

belongs, and the connections in the network diagram represent cooperation between countries. The wider connection indicates a stronger degree of cooperation. The group of countries headed by the top three countries with the highest number of publications is displayed in red and green. The United States has a low degree of connection with the United Kingdom and China, and the nodes with Japan, Spain, France, and India are red. The connecting lines are also thicker, indicating that they are more closely related. The lines connecting the UK and China are thicker, and the nodes are green, indicating that the two are closely connected. Countries with strong ties are ranked higher, indicating that progress and development in new areas require exchanges between different countries to cooperate for development. China ranks third with 1,019 publications, indicating that Chinese scholars are more interested in the field of global value chains. However, according to the TC/TP value, the USA ranks first with 34, and England ranks second with 31, indicating that the quality of its literature is high, whereas the TC/TP value of my country is at a low level of 15, indicating that Chinese scholars have much room for improvement in the quality of the papers.

In the United States, in 2008, Sturgeon, Sturgeon et al. applied global value chain analysis to the latest development status of the global automotive industry, taking North America as an example, using the three main elements of global value chain enterprises, governance, power, and institutions to highlight some defining characteristics of the automotive industry [8]. The U.S. outsources product production to foreign companies and earns significant revenue from intellectual property and services embedded in physical products sold to consumers around the world, yet traditional trade statistics are compiled based on the value of goods declared to customs across borders; intellectual property and service-related added value embedded in goods are not recorded as exports. Current trade statistics vastly underestimate U.S. exports, and if the added value of Apple's intellectual property and services embedded in all Apple products sold to foreign consumers were included in U.S. exports, then the total U.S. exports would have grown and the trade deficit will decrease [59].

In England, on January 31, 2020, the United Kingdom officially left the European Union after 47 years of membership, a historic turning point that will accelerate the shift in the economic trajectory. The impact of "Brexit" on UK trade is not only a change in the surface figures but also leads to the adjustment of the UK's global value chain structure. From the perspective of development trends, the UK's global value chain cooperation focus shows signs of gradually shifting to Asian countries in line with the development trend of globalization. From 2000 to 2018, the UK's total trade with Asian countries increased by 185%, whereas trade with European countries only increased by 125%.

In China, Chinese companies enter the field of photovoltaic manufacturing through technology acquisition and then gradually establish global competitiveness through vertical integration strategies and the photovoltaic value chain [42]. The U.S. antidumping policy toward China has accelerated and shortened the length of production based on backward linkages and ultimately improved the position of "Made in China" in the global value chain. Therefore, China should continue to adhere to opening up and strengthening linkages with the world economy to gain new development prospects [60]. In the context of the digital economy, the global value chain is facing restructuring. How China can use the digital economy as a new engine to drive economic development and break through the low-end-lock dilemma in the division of labor in the global value chain is a key research direction in the future.

3.7. The Cocitation Analysis of Global Value Chain Literature. Reference cocitation analysis mainly studies key documents and research hotspots in the field, and document cocitation clustering reflects the hot topics and research directions of common concern among clustered documents. When two documents appear in the references of the third document at the same time, the cocitation of documents occurs. Mining the cocitation relationship of documents through big data is called literature cocitation analysis. Based on a large number of cited references, the analysis can efficiently and rapidly understand the core literature in the research field and can also analyze the correlation between the studies.

Cocitation analysis was performed on the literature using VOSviewer, and the results were obtained as shown in Table 7 and Figure 9. As shown in Table 7, the top three cited papers are "The Governance of Global Value Chains," "The Organization of Buyer-driven Global Commodity Chains: How US Retailers Shape Overseas Production Networks," "Global Production Networks and the Analysis of Economic Development"; the citations are 1103, 611, and 510 times, respectively. As shown in Figure 9, through literature cocitation analysis, research in the field of global value chains has formed three literature clusters around key nodes. Global value chain research networks are highly centralized and have a high degree of network overlap. A strong degree of correlation exists between node documents, and they have strong explanatory power. The key node documents with high citations are located at the junction of knowledge groups, which play a linking role between the groups and provide theoretical support and direction guidance for follow-up research.

The red cluster is located in the center of the network and is closely related to the surrounding area. It is the theoretical basis of the entire global value chain research field. The main theme of this clustering is the theoretical framework. Gereffi et al. built a theoretical framework to explain governance patterns in GVCs, the complexity of transactions, the ability to encode transactions, and the ability to supply bases play an important role in determining how GVCs are governed and changed; grades, captive, relational, modular, and market are the five types of GVC governance [3]. Based on the cross-border activities and development results of early enterprises, a global production network framework is proposed to analyze the asymmetric relationship between economic integration and economic and social development [61].

Table 7: The cocitation analysis of GVC literature.

Cluster	Cited reference	Total citation	Title	Author
Red	Gereffi G, 2005, rev int polit econ, v12, p78	1103	The governance of global value chains	Gereffi G
	Gereffi G, 1994, commodity chains glo	437	The organization of buyer-driven global commodity chains: How US retailers shape overseas production networks	Gereffi G
	Henderson J, 2002, rev int polit econ, v9, p436	370	Global production networks and the analysis of economic development	Henderson, J
Green	Humphrey J, 2002, reg stud, v36, p1017	611	How does insertion in global value chains affect upgrading in industrial clusters?	Humphrey, J
	Gereffi G, 1999, j int econ, v48, p37	510	International trade and industrial upgrading in the apparel commodity chain	Gereffi G
	Giuliani E, 2005, world dev, v33, p549	261	Upgrading in global value chains: Lessons from Latin American clusters	Giuliani, E
Blue	Hummels D, 2001, j int econ, v54	288	The nature and growth of vertical specialization in world trade	Hummels, D
	Koopman R, 2014, am econ rev, v104, p459	287	Tracing value-added and double counting in gross exports	Koopman, Robert
	Johnson RC, 2012, j int econ, v86, p224	268	Accounting for intermediates: Production sharing and trade in value-added	Johnson, Robert C

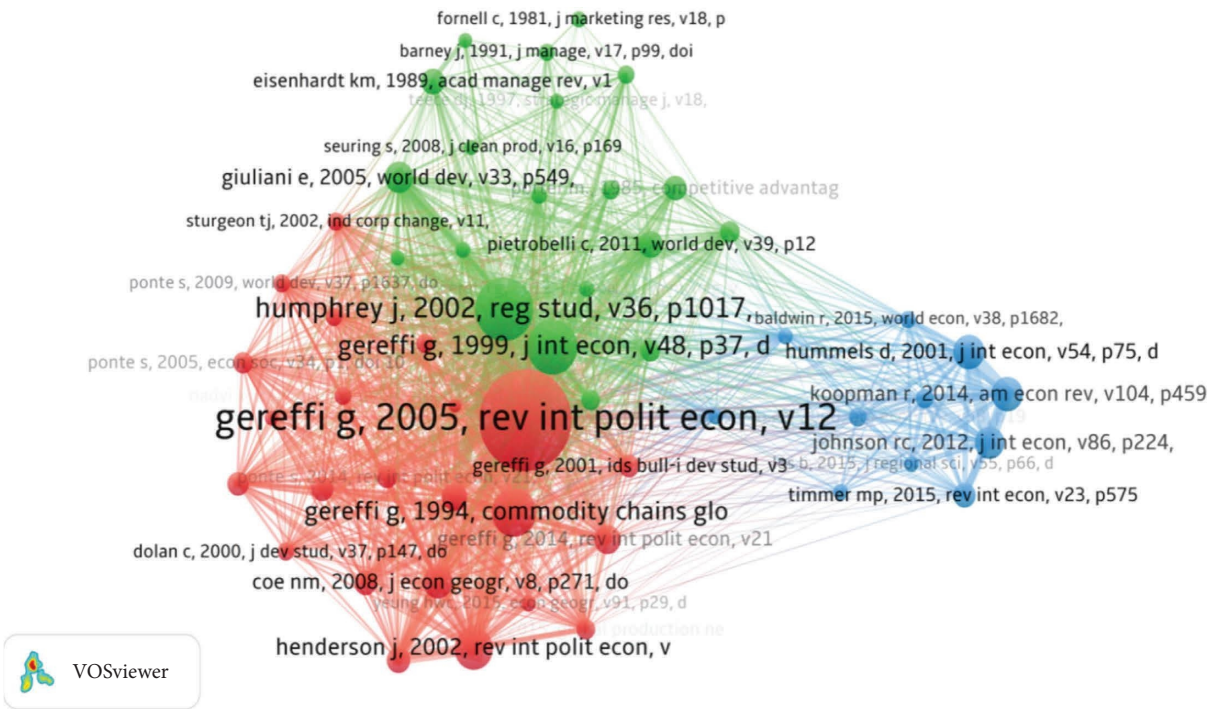


Figure 9: The cocitation map of GVC literature.

The green cluster is at the center of the network and is closely related to its surroundings. It is also the theoretical basis of the entire global value chain research field. The main themes of this cluster are industrial clusters and industrial upgrading. Most industrial cluster literature emphasizes the role of business-government cooperation in promoting development and upgrading. The value chain literature focuses on consumers worldwide and their role in value chain upgrading. Clusters are combined with global value chains in different ways. It also has a certain impact on the value chain [2]. From the perspective of the global commodity chain, the national trade network and the conditions for promoting the upgrading of the garment industry are analyzed [62]. By analyzing the relationship among clusters, GVCs, upgrading, and sectoral innovation patterns in Latin America, we find that sectoral characteristics have a significant impact on the upgrading patterns of clusters in GVCs [63].

The blue cluster is at the edge of the network, showing a certain degree of independence, and it is not strongly related to other studies. To become a frontier branch of value chain research is an extension of the group's theory and its application in practice. The main research themes of this cluster are vertical specialization and a new method of statistical trade data, the value-added method. Using input-output tables for the OECD and four emerging countries, we find that growth in vertical specialization accounts for one-third of export growth in these countries. This condition illustrates that the nature of international trade is changing; the trade chain tends to be vertical when production processes tend to span many countries [64]. Koopman et al. proposed an accounting framework that divides a country's gross exports into various value-added components by source and additional double-counting clauses, bridging the gap between gross-value and value-added trade data [65]. By combining input-output and bilateral trade data to calculate the value-added bilateral trade, we find that the ratio of value added to total exports in manufacturing is lower than in services, and bilateral production linkages are responsible for the change in this ratio [66].

4. Conclusion and Recommendation

4.1. Conclusion. This article uses bibliometric analysis to analyze the research hotspots and trends in the field of global value chains, which has reference significance for countries to better participate in the global value chain in the post pandemic era. Research has shown that the number of papers published in the global value chain field has been continuously increasing over time and has entered a period of rapid development since 2016; the main disciplines are economics and management; a few researchers and research institutions have strong influence, but the cooperation between scholars and institutions is relatively weak; the United States, the United Kingdom, and China dominate the research field; the research directions with high attention include governance, innovation, globalization, and sustainability; new research directions include CO_2 emission, COVID-19, economic growth, and big data.

4.2. Recommendation. This article analyzes the research hotspots and trends in the field of global value chains, which can provide certain guidance for future academic research. On the one hand, with the increasing global attention to environmental issues and the prevalence of the COVID-19

epidemic, the direction of the environment and public health has become a new research perspective. In the future, scholars can further study the complex impact of the natural environment and public health on the global value chain, especially the impact of carbon emissions on the global value chain and the change of the value chain in the post epidemic era.

On the other hand, the global value chain in the context of the digital economy is facing restructuring, and digital trade is increasingly affecting the international trade pattern. How countries can use the digital economy as a new engine to drive economic development and break through the low-end lock-in dilemma in the global value chain division of labor is a key research direction in the future. Scholars can analyze the impact of big data and artificial intelligence on the global value chain and explore the interaction between digital trade and traditional trade and its impact on the status and division of labor of economies in the global value chain.

The conclusion of this article also has important reference value for policy makers. At present, with the prevalence of unilateralism and trade protectionism, the global economy is facing the challenge of antiglobalization. In addition to the impact of COVID-19, the global economic recovery is facing great challenges, and the global value chain may be reshaped. Green development and digital economy are the focus of future research in the value chain field and are also important driving forces for achieving modernization. China can actively promote the development of the digital economy and green economy, guide the upgrading of industrial structure, and promote the effective allocation of global value chain resources by enterprises while the rules are not yet finalized. At the same time, we adhere to the development of good bilateral political relations with countries around the world, reduce the uncertainty of corporate participation in the global value chain division of labor caused by political risks, and provide strong support for enterprises to go global.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was funded by the Research and Innovation Project of China University of Political Science and Law (23ZFG79002) which was supported by "the Fundamental Research Funds for the Central Universities" and the National Social Science Foundation Art Project (17BC059). We thank Steven Pagel of Philadelphia, USA, for his help in writing this paper. We are also grateful for the comments and criticisms of an early version of this manuscript by our colleagues.

References

[1] P. Michael, "Competitive advantage: creating and sustaining superior performance," *Harvard Business Review*, pp. 73–93, Free Press, New York, NY, USA, 1998.

[2] J. Humphrey and H. Schmitz, "How does insertion in global value chains affect upgrading in industrial clusters?" *Regional Studies*, vol. 36, no. 9, pp. 1017–1027, 2002.

[3] G. Gereffi, J. Humphrey, and T. Sturgeon, "The governance of global value chains," *Review of International Political Economy*, vol. 12, no. 1, pp. 78–104, 2005.

[4] H. Akkermans, P. Bogerd, and B. Vos, "Virtuous and vicious cycles on the road towards international supply chain management," *International Journal of Operations and Production Management*, vol. 19, no. 5/6, pp. 565–582, 1999.

[5] A. Lipparini, G. Lorenzoni, and S. Ferriani, "From core to periphery and back: a study on the deliberate shaping of knowledge flows in interfirm dyads and networks," *Strategic Management Journal*, vol. 35, no. 4, pp. 578–595, 2014.

[6] L. Kano, "Global value chain governance: a relational perspective," *Journal of International Business Studies*, vol. 49, no. 6, pp. 684–705, 2018.

[7] D. A. Griffith and M. B. Myers, "The performance implications of strategic fit of relational norm governance strategies in global supply chain relationships," *Journal of International Business Studies*, vol. 36, no. 3, pp. 254–269, 2005.

[8] T. Sturgeon, J. Van Biesebroeck, and G. Gereffi, "Value chains, networks and clusters: reframing the global automotive industry," *Journal of Economic Geography*, vol. 8, no. 3, pp. 297–321, 2008.

[9] S. Barrientos, P. Knorringa, B. Evers, M. Visser, and M. Opondo, "Shifting regional dynamics of global value chains: implications for economic and social upgrading in African horticulture," *Environment and Planning a-Economy and Space*, vol. 48, no. 7, pp. 1266–1283, 2016.

[10] A. O. Laplume, B. Petersen, and J. M. Pearce, "Global value chains from a 3D printing perspective," *Journal of International Business Studies*, vol. 47, no. 5, pp. 595–609, 2016.

[11] R. Jurowetzki, R. Lema, and B. A. Lundvall, "Combining innovation systems and global value chains for development: towards a research agenda," *European Journal of Development Research*, vol. 30, no. 3, pp. 364–388, 2018.

[12] J. Guan, Y. Li, L. Xing, Y. Li, and G. Liang, "Closeness centrality for similarity-weight network and its application to measuring industrial sectors' position on the Global Value Chain," *Physica A: Statistical Mechanics and its Applications*, vol. 541, Article ID 123337, 2020.

[13] J. L. Luo, M. M. Huang, and Y. H. Bai, "Visual analysis of low-carbon supply chain: development, hot-spots, and trend directions," *Frontiers in Environmental Science*, vol. 10, p. 21, 2022.

[14] M. N. U. Nabi, S. M. Misbauddin, and U. Dornberger, "Downgrading as a strategy from the suppliers' perspective in global value chain: towards a conceptual framework and directions for future research," *Transnational Corporations Review*, p. 16, 2022.

[15] S. Y. Wang and Z. Y. Gu, "Mapping the field of value chain: a bibliometric and visualization analysis," *Sustainability*, vol. 14, no. 12, p. 7063, 2022.

[16] J. Dai and S. Xu, "Analysis of the research trend of global value chain based on literature metrology and visualization technology," *Technical Journal*, vol. 30, no. 5, pp. 1357–1365, 2023.

[17] J. Humphrey and H. Schmitz, "Governance in global value chains," *Ids Bulletin-Institute of Development Studies*, vol. 32, no. 3, p. 19, 2001.
[18] R. Mudambi, "Offshoring: economic geography and the multinational firm," *Journal of International Business Studies*, vol. 38, no. 1, p. 206, 2007.
[19] P. J. Buckley, "The impact of the global factory on economic development," *Journal of World Business*, vol. 44, no. 2, pp. 131–143, 2009.
[20] L. Johns and R. L. Wellhausen, "Under one roof: supply chains and the protection of foreign investment," *American Political Science Review*, vol. 110, no. 1, pp. 31–51, 2016.
[21] A. Smith, "The state, institutional frameworks and the dynamics of capital in global production networks," *Progress in Human Geography*, vol. 39, no. 3, pp. 290–315, 2015.
[22] J. Gooris and C. Peeters, "Fragmenting global business processes: a protection for proprietary information," *Journal of International Business Studies*, vol. 47, no. 5, pp. 535–562, 2016.
[23] A. Ascani, R. Crescenzi, and S. Iammarino, "Economic institutions and the location strategies of European multinationals in their geographic neighborhood," *Economic Geography*, vol. 92, no. 4, pp. 401–429, 2016.
[24] M. Morris and C. Staritz, "Industrialization trajectories in Madagascar's export apparel industry: ownership, embeddedness, markets, and upgrading," *World Development*, vol. 56, pp. 243–257, 2014.
[25] P. J. Buckley and X. W. Tian, "Transnationality and financial performance in the era of the global factory," *Management International Review*, vol. 57, no. 4, pp. 501–528, 2017.
[26] S. Pipkin and A. Fuentes, "Spurred to upgrade: a review of triggers and consequences of industrial upgrading in the global value chain literature," *World Development*, vol. 98, pp. 536–554, 2017.
[27] A. Kumaraswamy, R. Mudambi, H. Saranga, and A. Tripathy, "Catch-up strategies in the Indian auto components industry: domestic firms' responses to market liberalization," *Journal of International Business Studies*, vol. 43, no. 4, pp. 368–395, 2012.
[28] G. Suder, P. W. Liesch, S. Inomata, I. Mihailova, and B. Meng, "The evolving geography of production hubs and regional value chains across East Asia: trade in value-added," *Journal of World Business*, vol. 50, no. 3, pp. 404–416, 2015.
[29] Y. Y. Sun, L. Wu, and S. Yin, "Green innovation risk identification of the manufacturing industry under global value chain based on grounded theory," *Sustainability*, vol. 12, no. 24, Article ID 10270, 2020.
[30] S. Azmeh and K. Nadvi, "Asian firms and the restructuring of global value chains," *International Business Review*, vol. 23, no. 4, pp. 708–717, 2014.
[31] J. Lampel and C. Giachetti, "International diversification of manufacturing operations: performance implications and moderating forces," *Journal of Operations Management*, vol. 31, no. 4, pp. 213–227, 2013.
[32] P. Schroeder, P. Dewick, S. Kusi-Sarpong, and J. S. Hofstetter, "Circular economy and power relations in global value chains: tensions and trade-offs for lower income countries," *Resources, Conservation and Recycling*, vol. 136, pp. 77-78, 2018.
[33] B. L. MacCarthy, C. Blome, J. Olhager, J. S. Srai, and X. Zhao, "Supply chain evolution-theory, concepts and science," *International Journal of Operations and Production Management*, vol. 36, no. 12, pp. 1696–1718, 2016.
[34] J. Massana, C. Pous, L. Burgas, J. Melendez, and J. Colomer, "Identifying services for short-term load forecasting using data driven models in a Smart City platform," *Sustainable Cities and Society*, vol. 28, pp. 108–117, 2017.
[35] M. L. Song and S. H. Wang, "Participation in global value chain and green technology progress: evidence from big data of Chinese enterprises," *Environmental Science and Pollution Research*, vol. 24, no. 2, pp. 1648–1661, 2017.
[36] H. Treiblmaier, "The impact of the blockchain on the supply chain: a theory-based research framework and a call for action," *Supply Chain Management-an International Journal*, vol. 23, no. 6, pp. 545–559, 2018.
[37] C. Foster, M. Graham, L. Mann, T. Waema, and N. Friederici, "Digital control in value chains: challenges of connectivity for east african firms," *Economic Geography*, vol. 94, no. 1, pp. 68–86, 2018.
[38] G. Gereffi, "What does the COVID-19 pandemic teach us about global value chains? The case of medical supplies," *Journal of International Business Policy*, vol. 3, no. 3, pp. 287–301, 2020.
[39] R. Strange, "The 2020 Covid-19 pandemic and global value chains," *Journal of Industrial and Business Economics*, vol. 47, no. 3, pp. 455–465, 2020.
[40] M. Henchion, M. Hayes, A. Mullen, M. Fenelon, and B. Tiwari, "Future protein supply and demand: strategies and factors influencing a sustainable equilibrium," *Foods*, vol. 6, no. 7, p. 53, 2017.
[41] S. Ponte, "The hidden costs of environmental upgrading in global value chains," *Review of International Political Economy*, vol. 29, p. 26, 2020.
[42] F. Zhang and K. S. Gallagher, "Innovation and technology transfer through global value chains: evidence from China's PV industry," *Energy Policy*, vol. 94, pp. 191–203, 2016.
[43] B. Meng, G. P. Peters, Z. Wang, and M. Li, "Tracing CO2 emissions in global value chains," *Energy Economics*, vol. 73, pp. 24–42, 2018.
[44] C. G. Asmussen, T. Pedersen, and B. Petersen, "How do we capture global specialization when measuring firms' degree of globalization?" *Management International Review*, vol. 47, no. 6, pp. 791–813, 2007.
[45] M. P. Dallas, "'Governed' trade: global value chains, firms, and the heterogeneity of trade in an era of fragmented production," *Review of International Political Economy*, vol. 22, no. 5, pp. 875–909, 2015.
[46] S. W. He, Z. Khan, and O. Shenkar, "Subsidiary capability upgrading under emerging market acquirers," *Journal of World Business*, vol. 53, no. 2, pp. 248–262, 2018.
[47] M. G. Jacobides and C. J. Tae, "Kingpins, bottlenecks, and value dynamics along a sector," *Organization Science*, vol. 26, no. 3, pp. 889–907, 2015.
[48] E. Turkina and A. Van Assche, "Global connectedness and local innovation in industrial clusters," *Journal of International Business Studies*, vol. 49, no. 6, pp. 706–728, 2018.
[49] T. Eriksson, N. Nummela, and S. Saarenketo, "Dynamic capability in a small global factory," *International Business Review*, vol. 23, no. 1, pp. 169–180, 2014.
[50] N. Sinkovics, U. S. Choksy, R. R. Sinkovics, and R. Mudambi, "Knowledge connectivity in an adverse context: global value chains and Pakistani offshore service providers," *Management International Review*, vol. 59, no. 1, pp. 131–170, 2019.
[51] T. J. Chen, "Network resources for internationalization: the case of Taiwan's electronics firms," *Journal of Management Studies*, vol. 40, no. 5, pp. 1107–1130, 2003.

[52] H. Yanikkaya, H. Karaboga, and A. Altun, "Implications of participation in global value chains for international trade network," *Applied Economics Letters*, vol. 28, no. 14, pp. 1169–1173, 2021.
[53] Z. Q. Mao, "Global value chains (gvcs) and economic growth: a nonlinear analysis," *Singapore Economic Review*, vol. 67, p. 20, 2021.
[54] M. Yamin, "A commentary on peter buckley's writings on the global factory," *Management International Review*, vol. 51, no. 2, pp. 285–293, 2011.
[55] Y. S. Tong, "Vertical specialisation or linkage development for agro-commodity value chain upgrading? The case of Malaysian palm oil," *Land Use Policy*, vol. 68, pp. 585–596, 2017.
[56] B. P. Jangam and B. N. Rath, "Do global value chains enhance or slog economic growth?" *Applied Economics*, vol. 53, no. 36, pp. 4148–4165, 2021.
[57] H. Wang, C. Pan, B. Ang, and P. Zhou, "Does global value chain participation decouple Chinese development from CO2 emissions? A structural decomposition analysis," *Energy Journal*, vol. 42, no. 2, pp. 183–204, 2021.
[58] M. Qin, X. Y. Liu, and X. X. Zhou, "COVID-19 shock and global value chains: is there a substitute for China?" *Emerging Markets Finance and Trade*, vol. 56, no. 15, pp. 3588–3598, 2020.
[59] Y. Q. Xing, "Global value chains and the missing exports of the United States," *China Economic Review*, vol. 61, Article ID 101429, 2020.
[60] Y. B. Ding, H. Y. Zhang, and S. T. Tang, "The impact of US anti-dumping against China on China's manufacturing global value chains status," *Transnational Corporations Review*, vol. 11, no. 4, pp. 323–331, 2019.
[61] J. Henderson, P. Dicken, M. Hess, N. Coe, and H. W. C. Yeung, "Global production networks and the analysis of economic development," *Review of International Political Economy*, vol. 9, no. 3, pp. 436–464, 2002.
[62] G. Gereffi, "International trade and industrial upgrading in the apparel commodity chain," *Journal of International Economics*, vol. 48, no. 1, pp. 37–70, 1999.
[63] E. Giuliani, C. Pietrobelli, and R. Rabellotti, "Upgrading in global value chains: lessons from Latin American clusters," *World Development*, vol. 33, no. 4, pp. 549–573, 2005.
[64] D. Hummels, J. Ishii, and K. M. Yi, "The nature and growth of vertical specialization in world trade," *Journal of International Economics*, vol. 54, no. 1, pp. 75–96, 2001.
[65] R. Koopman, Z. Wang, and S. J. Wei, "Tracing value-added and double counting in gross exports," *The American Economic Review*, vol. 104, no. 2, pp. 459–494, 2014.
[66] R. C. Johnson and G. Noguera, "Accounting for intermediates: production sharing and trade in value added," *Journal of International Economics*, vol. 86, no. 2, pp. 224–236, 2012.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9823083, 1 page
https://doi.org/10.1155/2023/9823083

Retraction

Retracted: An Empirical Study on the Influencing Factors of the Returning Intention of Overseas Talents

Discrete Dynamics in Nature and Society

Received 3 October 2023; Accepted 3 October 2023; Published 4 October 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] L. Liu and F. Tian, "An Empirical Study on the Influencing Factors of the Returning Intention of Overseas Talents," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2778287, 7 pages, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9812891, 1 page
https://doi.org/10.1155/2023/9812891

Retraction

Retracted: An Empirical Study of Blended Teaching Mode Based on SPOC in the Postpandemic Era

Discrete Dynamics in Nature and Society

Received 22 August 2023; Accepted 22 August 2023; Published 23 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] X. Chen, J. Guo, and H. Xu, "An Empirical Study of Blended Teaching Mode Based on SPOC in the Postpandemic Era," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7094272, 8 pages, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 8696858, 12 pages
https://doi.org/10.1155/2023/8696858

Research Article

The Dynamic Effects of the Foreign Economic Shocks on the Korean Port Industry

Sung-A. Kim,[1] Kapje Park,[2] and Chan-Ho Kim[1]

[1]*Korea Maritime Institute, Seoul, Republic of Korea*
[2]*Department of Economics and Finance, Kyungnam University, Changwon, Republic of Korea*

Correspondence should be addressed to Kapje Park; park0318@kyungnam.ac.kr

Received 2 September 2022; Revised 6 November 2022; Accepted 24 November 2022; Published 28 February 2023

Academic Editor: Lele Qin

Although the port industry is very important in the Korean economy, there are few literature studies that shed light on the macroeconomic implications of the business cycles in this industry. This paper examines the roles played by foreign economic factors in the business cycle in the Korean port industry. Specifically, it aims to estimate the impulse response of the seaborne freight volume in the port industry due to the shocks of the foreign economy and analyze the contributions of each shock considered on the variation in the freight volume. The structural FAVAR (SFAVAR) model was employed to extract the unobserved foreign economic factors. This paper estimates the four foreign economic factors and the parameters of the model using the one-step Bayesian Gibbs sampling method. The findings of this study show that foreign economic activity statistically affects the freight volume of the Korean ports. Specifically, the shocks to the foreign real economic activity increased freight transportation for nearly one year. Following the world inflation shocks, the freight transportation was enhanced. However, this impact disappeared after a year. Similarly, the rise in global liquidity was shown to encourage transportation activity; nevertheless, this activity declined after five quarters. Moreover, the increase in the world interest rates exerted a negative effect on the volume of transportation. Furthermore, the variance decomposition analysis shows that 49.2% of the variation in the transportation volume could be attributed to foreign economic activity. This analysis can contribute to drawing useful implications in establishing the port industry policy in response to the change in the economic environment such as the foreign economy.

1. Introduction

The port industry has grown to be a vital sector of the Korean economy, especially given the country's high level of economic openness, geographic advantages, and growing significance of seaborne freight transportation in global supply chains. Accordingly, there have been many studies that analyze the Korean port industry in the microeconomic perspective. However, there are few literature studies that shed light on the macroeconomic implication through the systematic analysis of this industry. For instance, despite the fact that the port sector in Korea has become more significant, the relationship between the Korean port industry and the country's business cycle has not been adequately evaluated. According to the previous study, the transportation industry, including the port industry, plays an important role in the propagation of the nation-wide business cycles [1]. Thus, the business cycle studies have important implications in the decision-making processes of government agencies and private sectors.

This study examines the business cycles in the Korean port industry triggered by foreign economic fluctuations. Specifically, the dynamic effects of shocks to foreign economic factors on the transportation volume of the Korean port industry are studied. In particular, in the Korean economy, where there is no alternative except for the port transportation channel, the port industry is a vital channel for export and import. It can be easily postulated that the business cycle in the port industry is related to that of the national and global economies.

However, there are many difficulties in undertaking a quantitative study of the dynamic impact of global

economic shocks on the domestic port industry, the most significant of which is the way to measure foreign economic activity. This problem is further related to other issues such as the empirical model to be employed and the method to identify the shocks to the foreign economy.

This paper focuses on the role played by foreign economic activity in the business cycle of the domestic port industry. Consequently, we hope that the existence of a one-to-one relationship between the foreign economy and the trade volume by the Korean port can be exploited. Traditionally, the VAR type model has traditionally been employed as the framework for analyzing the dynamic impact of economic shocks on the macroeconomy. However, the shocks must be identified for analyzing the effects using the VAR model. Incorrect identification of the shocks results in misleading inferences regarding the causality of the business cycle. The literature indicates that one important reason that the shocks cannot be accurately recognized is that the small-scale traditional VAR does not adequately account for an individual's economic activities while making decisions.

This difficulty in identifying the shocks remains a challenge when analyzing the effect of foreign economic shocks on small, open economies. In previous studies, foreign economic shocks have been measured as the unexpected movement of specific variables such as GDP. For example, Cushman and Zha [2] analyzed the economy of Canada considering the unexpected fluctuation in the U.S. GDP as shocks to the foreign economy. Further, Kim and Roubini [3] examined the effect of the U.S. monetary policy on other economies but not the dynamic effect of the foreign economy. This study uses the Structural FAVAR model to identify the foreign economic factor and shed light on the dynamic effects of foreign shocks on the Korean port industry.

The FAVAR model combines the VAR model typically used in the analysis of the macroeconomy with factor analysis [4]. As the FAVAR model offers the advantage of incorporating a large amount of information obtained from a large set of economic series into a VAR model, it is considered useful in modeling the central bank's reaction function or analyzing the international business cycles. However, it has a drawback in the sense that it does not provide an economic interpretation of the estimated factors. This problem can be overcome by using the Structural FAVAR (SFAVAR) model [5, 6]. The industry-level economy has not yet been studied using the SFAVAR model, which has been used to study the broader economy. However, this model can be applied to studying the dynamic effect of shocks to the foreign economy on a specific industry. Lee and Ni [7] studied the relationship between oil price shocks and the U.S. industry based on the VAR model, and Jo et al. [8] employed the FAVAR model to study the same subject.

The SFAVAR model adopted in this study offers the advantage of examining the transmission mechanism through the port industry by identifying the factor economically. In addition, this analysis can contribute to drawing useful implications for establishing port industry policy. To perform these purposes, we estimate the dynamic effect of the foreign economic shocks on the Korean port industry via the impulse response analysis and measure the relative importance of the domestic and foreign factors through the variance decomposition of forecast errors.

The remainder of the paper is organized as follows: Section 2 reviews the literature related. Section 3 presents the empirical methods adopted in this paper. Section 4 presents the estimation results and discussion. Section 5 concludes the paper.

2. Literature Reviews

This section provides a brief assessment of earlier studies on the relationship between foreign economy and seaborne freight transportation. The methodology for estimating the foreign economic factor that was described in the literature is also discussed.

2.1. Relationship between the Foreign Economy and the Port Industry. There are three economic aspects that imply the importance of the freight economy to the business cycles of the port industry. First, there is a direct relationship between the transportation industry and general economic activity. In their seminal paper on the relationship between economic activity and transportation, Lahiri and Yao [1] examined the business cycle in the U.S. transportation sector since the 1990s. They found a close relationship between the business cycle of the U.S. macroeconomy and the transportation service. Muller et al. [9] emphasized the strong relationship between economic activity and transportation. Consequently, they developed new economic indicators to study the business cycles in this industry. Pastowski [10] showed the strong interdependence between freight transport and GDP growth. Meersman and de Vande [11] analyzed the relationship between the general economic activity and the volume of seaborne transportation but concluded that the GDP measure is not a suitable variable for the determinant of freight transportation based on the cointegration analysis. Angelopoulos and Chlomoudis [12] examined the business cycle of the U.S. port industry using the dynamic factor model.

Second, the Korean economy is a small open economy, which helps to understand the relevance of the foreign economy to the business cycles of the Korean port industry. According to the OECD, the proportion of the sum of imports and exports in the Korean economy was 72.9% of the GDP in 2020. However, the relative contribution was 74% to the GNI, 35.5% to the U.S., and 34.1% to Japan. Thus, the importance of the foreign economy can be assessed as the driving force of the Korean economy. For example, many Korean economic analysts have stressed commerce with other nations as the driving force behind the Korean 10 industry. Consequently, the potential role played by the foreign economy in the port industry can be inferred. In addition, Pallis and de Langen [13] analyzed the effect of the economic recession on the port industry and concluded that the 2008 credit crunch and the subsequent economic crisis

generated the volume of freight transport and led to a significant reduction in the volume.

Finally, since the 1990s, the globalization of the economy or global value chain (GVC) has intensified, making international commercial activity increasingly significant for the variety of domestic port transportation. Thus, the proliferation of the global supply chain increased the link of the domestic economy to the foreign economy, thereby resulting in an increase in the production of the countries through the supply chain [14, 15]. Also, it was reported that the globally integrated international supply chain increased the interdependence between economies and the importance of trade economies [16]. It was showed that the demand for port transportation significantly affects the maritime industry and indicated the lack of quantitative studies on the role of the variation of the world economy [17]. In addition, based on the vector autoregression analysis, the study found that shocks to global GDP had a favorable impact on all freight transportation categories.

2.2. Identifications of Foreign Economic Factors. As mentioned earlier, the objective of this paper is to examine the dynamic effect of the foreign economy on the Korean domestic port industry. This study specifically seeks to evaluate the influence of foreign economic activity shocks on domestic freight transportation utilizing the impulse response function and the variance decomposition based on the VAR type framework. However, the important thing to tackle is measuring foreign economic activity. In many cases in the previous literature, the U.S. economy has been traditionally treated as the world economy [2, 3]. However, these identification methods are only applicable to the Canadian economy or when studying the international transmission mechanism originating from the U.S. economy. Hence, we cannot employ this idea for measuring the foreign economic activity as the world economy does not comprise only the U.S. economy. Moreover, the Chinese economy is very important to the Korean economy in terms of explaining the variation of the Korean economy. In this paper, we understand foreign economic activity as the economic factors that underlie the comovements of the aggregates across the different foreign countries.

In the literature, the dynamic factor model has been used to estimate the unobserved foreign economic factors in the empirical literature. Gregory et al. [18] used the Kalman filtering and dynamic factor model to identify the common factors across macroeconomic aggregates in G7 countries. They showed that fluctuations in all aggregates contain world common components that are both statistically significant and quantitatively important. Kose et al. [19] employed a Bayesian dynamic factor model to estimate the common components in macroeconomic aggregates in 60 countries. Their results indicate that a common world factor is an important source of volatility for aggregates in most countries. D'Agostino and Surico [20] constructed a measure of global liquidity using the first dynamic principal component of the growth rates of broad money across the G7 economies. They found that the global liquidity produces forecasts of U.S. inflation that are significantly more accurate than the forecast based on U.S. money growth. Their results support the fact put forward by Rogoff [21] that national inflation rates in several industrialized economies share a common significant international component. Also, the result shows the importance of the foreign economic factor in explaining the fluctuation of the national economy. Mumtaz and Surico [22] used a large panel of data for 17 industrialized countries to investigate the international transmission mechanism. In their analysis, the FAVAR model, which is a modification of the dynamic factor model, was used to show the dynamic effects on the U.K. economy of an unanticipated fall in the international interest rate factor and the world liquidity factor. They extracted four common foreign factors: real-world economic activity, world inflation, world liquidity, and world interest rate factors. For instance, they estimate the international real activity factor from all international real activity series in the data set. Similarly, the foreign inflation factor is identified as the only factor that is loaded by international inflation series in their analysis. The present study follows the methodology of that study [22].

3. Open Economy FAVAR Model

This section explains the empirical model adopted in this paper, SFAVAR, and the estimation method. As noted earlier, the SFAVAR model is an extension of the FAVAR model in which the estimated factor can have economic interpretations. Since the FAVAR model is an application of the dynamic factor model, the model can also be represented by the state-space form which consists of two equations, i.e., measurement equations and transition equations. The model explanation is as follows.

3.1. SFAVAR Model. This subsection describes the SFAVAR model. First, we discuss the measurement equation in the model. Let Y_t and X_t be the two vectors of economic variables. Y_t is an $M \times 1$ vector and X_t is a large dataset of economic variables, whose dimension is $N \times 1$, and$t = 1, 2, \cdots, T$ is the time index. Y_t includes the Korean GDP, the volume of the sum of Korea economy's import and export, and volume of seaborne freight transportation. Further, X_t is assumed to be explained by a variety of unobserved factors, which can be summarized by a $K \times 1$ vector of factors F_t, and error terms. Thus, we can write the model of X_t as

$$X_t = \Lambda F_t + e_t, \tag{1}$$

where e_t is the error term with $E(e_t) = 0$ and $\mathrm{Cov}(e_{m,t}, e_{n,t}) = 0$, $m, n = 1,2,., N$. Also, it is assumed that $e_t \sim i.i.d\ N(0, R)$ and that its covariance matrix, R, is the diagonal. Further, Λ is factor loading and its dimension is the $N \times K$ matrix. Here, assume that the series of observable datasets X_t can be grouped into $X_t^1, X_t^2, \cdots, X_t^I$ based on the approximate economic category, where X_t^i is an $N_i \times 1$ vector and $\sum_{i=1}^{I} N_i = N$. This study assumes that an arbitrary segment of X_t, for example, X_t^i, can be explained by F_t^i. This

implies that F_t is also partitioned by F_t^1, F_t^2, $\cdots$, and F_t^I, which correspond to various economic concepts. Here, F_t^i is the $K_i \times 1$ vector. In addition, $\sum_{i=1}^{I} K_i = K$ holds. Moreover, it is assumed that $K_i < N_i$. Thus, the above observation (measurement) equation (1) can be rewritten as

$$\begin{bmatrix} X_t^1 \\ X_t^2 \\ \vdots \\ X_t^I \end{bmatrix} = \begin{bmatrix} \Lambda_1^f & 0 & \cdots & 0 \\ 0 & \Lambda_2^f & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \Lambda_I^f \end{bmatrix} \begin{bmatrix} F_t^1 \\ F_t^2 \\ \vdots \\ F_t^I \end{bmatrix} + \mathrm{e}_t. \tag{2}$$

Second equation to be discussed is the transition equation. The foreign economic variables that are included in X_t are grouped to have a clear economic meaning. In addition, we assume that each subgroup of X_t is explained by only one factor; that is, $K_i = 1$. Next, the dynamics of $(F_t^1, F_t^2, \cdots, F_t^I, Y_t)$ is assumed to be the following vector autoregression model (VAR model):

$$\begin{bmatrix} F_t^1 \\ F_t^2 \\ \vdots \\ F_t^I \\ Y_t \end{bmatrix} = \Phi(\mathrm{L}) \begin{bmatrix} F_{t-1}^1 \\ F_{t-1}^2 \\ \vdots \\ F_{t-1}^I \\ Y_{t-1} \end{bmatrix} + \mathrm{v}_t, \tag{3}$$

where $\Phi(L)$ is a matrix of the polynomial of lag operator d and v_t is the error terms with conditional mean $E(v_t) = 0$. In addition, it is assumed that $v_t \sim i.i.d\ N(0, Q)$. As will be explained below, we assume that $d = 2$.

As evident from the above specification, the key difference between the FAVAR model of equations (2) and (3) and the standard VAR model is that the above equations include the unobserved factor while the standard VAR does not. Particularly, this model offers the advantage of having the economically interpreted factors because we impose the restrictions that F_t^i is related to X_t^i. In other words, the drawback of the original FAVAR model can be addressed. That is, while the estimated components of the FAVAR model cannot have a structural economic interpretation, our SFAVAR model may have it [4]. Thus, the factor that possesses an economic interpretation can be estimated. This can be achieved by first categorizing the variables in X_t based on the economic meaning and subsequently estimating each factor based on the categorized economic variables.

Following the previous study [22] that analyzed the U.K. economy in the context of a small open-open economy, this study categorized the foreign economic factors that affect the domestic port economy into four categories: world real economic activity, foreign inflation, world liquidity, and world interest rate factors. Specifically, the foreign real economic activity factor F_t^Y can be extracted from the subset X_t^1, the foreign inflation factor F_t^S from X_t^2, liquidity factor F_t^L from X_t^3, and finally the world interest rate factor F_t^M from X_t^4.

3.2. Estimation Method. In the previous subsection, we discussed the SFAVAR model used here in the dynamic factor model framework. Here, we explain the method for estimating the model parameters and the unobserved foreign economic factors. In general, two estimation strategies can be used to estimate the SFAVAR model introduced in the previous section. One is the principal component estimation method and the other is the Bayesian estimation based on the Gibbs sampling. Although the principal components method is more convenient than Bayesian estimation, this study implements the latter. This is because the principal component method estimates the unobserved factor using only equation (2), implying that the dynamics of the factor are not considered [23]. We use the dynamics of the factors formalized by equation (3) when estimating the factors.

To carry out the likelihood-based Gibbs sampling, we need to transform the model discussed in the previous section into the state-space form. As it is well known, the state-space model has two equations. One is the measurement equation and the other is transition equation. The measurement equation can be written as

$$\begin{bmatrix} X_t \\ Y_t \end{bmatrix} = \begin{bmatrix} \Lambda & 0 \\ 0 & I_M \end{bmatrix} \begin{bmatrix} F_t \\ Y_t \end{bmatrix} + \begin{bmatrix} e_t \\ 0 \end{bmatrix}. \tag{4}$$

The above equation can be expressed by using the notations $\mathbf{X_t} = (X_t', \mathbf{Y_t'})'$ and $\mathbf{F}_\mathrm{t} = (\mathrm{F_t'}, \mathrm{Y_t'})'$.

$$\mathbf{X}_t = \Lambda \mathbf{F}_t + e_t. \tag{5}$$

The transition equation, another component of the model, is obtained as

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_t \\ Y_t \end{bmatrix} + v_t. \tag{6}$$

Equation (6) can also be expressed as

$$\mathbf{F}_t = \Phi(L)\mathbf{F}_{t-1} + v_t, \tag{7}$$

where v_t and e_t are independent of each other.

It can be concluded that equations (5) and (7) represent the state-space form system. We follow the estimation procedure based on the Bayesian estimation which can be found in Belviso and Milani [5] and Fonseca and Pereira [6].

Following the Bayesian approach, we treat the model parameters $\theta = (\Lambda, R, Q, \Phi)$ and the factors F_t as random variables. Let $\widetilde{X}_T = (X_1, .., X_T)$ and $\widetilde{F}_T = (F_1, .., F_T)$ be the histories of X and F. We need to derive the posterior of F and θ, $p(\widetilde{F}_T|\theta, \widetilde{X}_T)$ and $p(\theta|\widetilde{F}_T, \widetilde{X}_T)$, respectively, to obtain the estimates of $\widetilde{F}_T$ and θ. The Gibbs sampling method proceeds as follows. First, we set the starting values for the parameter θ, say θ^0. We set the first element of Λ_i^f, $i = 1, .., I$, to 1 and other elements to 0. Also, R is the residual covariance matrix from the regression of X on an arbitrary proxy variable for F. We set $\mathrm{vec}(\Phi)$ and $Q = I$. Second, conditional on θ^0 and the data $\widetilde{X}_T$, draw values for $\widetilde{F}_T$ from the conditional density $p(\widetilde{F}_T|\widetilde{X}_T, \theta^0)$ based on the Kalman filter algorithm [24]. Third, conditional on the sampled values of $\widetilde{F}_T$ and the data, draw the parameter θ from the conditional distribution $p(\theta|\widetilde{X}_T, \widetilde{F}_T)$. In this step, we need the prior and the posterior for θ. We will use the prior and

the posterior shown in the Bernanke et al. [4]. The final two steps are one iteration and are repeated until the empirical distribution of $\widetilde{F}_T$ and θ converges. After that, we can obtain the empirical distribution to calculate the estimate of θ and $\widetilde{F}_T$.

4. Estimation and Interpretation

This section describes the data used in this paper and gives an interpretation of the obtained empirical results of the SFAVAR model developed in Section 3 based on the impulse response analysis and variance decomposition analysis.

4.1. Data. As mentioned earlier, this study assumes four common foreign economic factors that affect the Korean economy. Furthermore, it is assumed for expository purposes that the foreign economy may be represented by the economies of the G7 countries and China. The first foreign factor is the foreign real economic activity factor. The real economic growth of these nations can be utilized to identify and estimate this factor. Rogoff [21] used a variety of variables including real economic growth to estimate this factor. However, only one variable, that is, economic growth, is used to identify the factor.

Seaborne freight transportation volume can also be affected by world inflation in both directions. The number of exports rises and the volume of imports falls when world inflation rises because the increase in the price of products produced abroad relative to those of local goods indicates an increase in the domestic good's price competitiveness. In certain studies, the common factor in the inflation of the countries is often interpreted as the supply side. This study shows that this is not always the case since inflation can sometimes rise along with rising aggregate demand as a result of a rise in economic activity.

The inflation based on the CPI of the countries considered is used to identify the world inflation factor. Further, the M3 monetary aggregate of the U.S., U.K., and Canada, wherein the data are available to estimate the world liquidity factor, is used. Finally, the call rate of each country is used to estimate the world interest rate factor.

The domestic variables in the model comprise the quarterly real economic growth and the sum of the real export and real import. Furthermore, the nominal volume of imports and exports combined, divided by the CPI, is used to compute the real trade. In addition, the real trade volume is transformed into the growth of that relative to the same period of the previous year.

The relationship between seaborne freight transportation and US GDP growth, which plays the most significant role in the global economy, is necessary to understand before assessing the results estimated using the SFAVAR model. Figure 1 shows the variation of the log-transformed quarterly GDP around the trend calculated using the HP filter and the variation of the domestic freight transportation calculated using the same method. It indicates that the variation in transportation is larger than that of U.S. economic growth. In addition, it is evident that domestic transportation is correlated with the U.S. growth during the same period. Particularly, during the 2008–2009 financial crisis and the 2019–2020 COVID-19 epidemic eras, both values decreased significantly. However, even before the 2007 financial crisis, U.S. growth and domestic transportation increased constantly, while domestic transportation exhibited greater volatility. The figure suggests that there may be a possible correlation between the two values, even if it is not adequate to draw the conclusion that it is proof of the causal impact of global economic activity on domestic transportation.

4.2. Estimation of the Foreign Economic Factors. The foreign economic factors were extracted from a variety of foreign economic variables based on the SFAVAR model in this subsection. The estimated foreign real economic activity factor is associated with the existence of the international business cycle proposed by Kose et al. [19], which drives many countries in the world. The literature implies close comovements among the many countries' industrial productions [27, 28]. In addition, the evidence of a similar pattern in the business cycles was presented in many countries [29].

This research took Rogoff [21]'s insight into account while analyzing the effects of the international liquidity factor. It was shown that the industrialized countries shared the common components of these inflation fluctuations to the extent that there are high correlations between money growth and inflation and that world liquidity can affect world inflation. D'Agostino and Surico [20] showed that the world's liquidity is useful for explaining the inflation phenomenon in many countries. Figure 2 shows a plot of the four common foreign factors extracted using the SFAVAR model. It is evident that a certain portion of the pattern is almost consistent with conventional wisdom.

The 2001-2002 period, the 2007 financial crisis, and the COVID-19 outbreak all resulted in a severe economic downturn for the nations taken into consideration in this analysis. The pattern of these time series almost corresponds to the existence of the international business cycles [18]. The overall decreasing trend in the world inflation factor is consistent with the global disinflation [28]. The estimated liquidity factor, which is shown in the left-upper corner, also climbed from late 2004 to mid-2008, fell after that, and subsequently rapidly surged during the COVID-19 pandemic period. The right-upper corner shows the world interest rate factor identified by short-run interest rates in the countries considered in this study.

Since 2000-2001, the factor has shown a progressively falling tendency, followed by a rise until 2007. Consequently, this factor has been constantly decreasing since the 2008 financial crisis. The common factor for the interest rates is to show the approach to the recent historically low level.

4.3. Impulse Response Function Analysis. An essential feature of the globalization of the economy since the 1990s has been the growing importance of the seaborne container trade for supply chains. With 90% of nonbulk dry cargo globally being

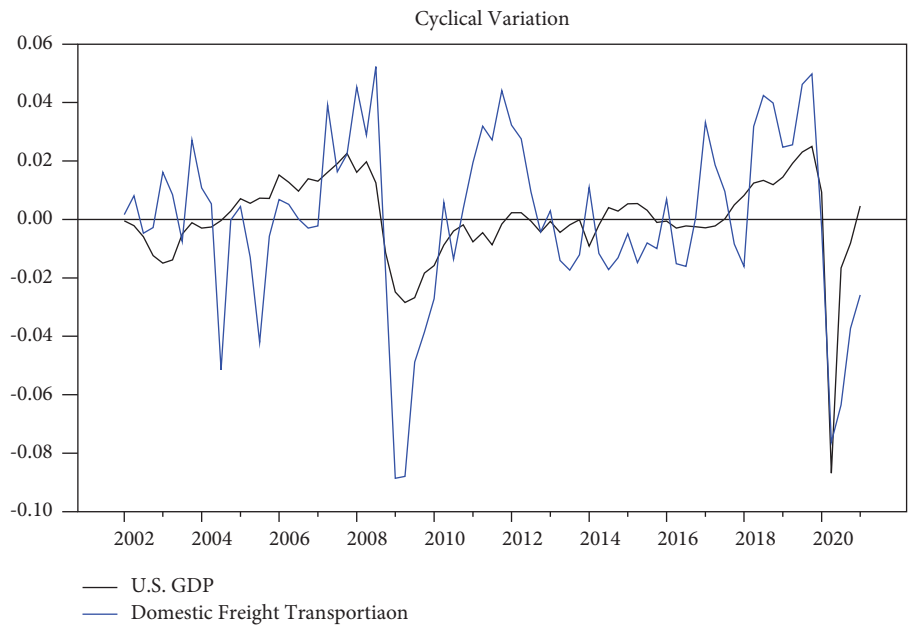


Figure 1: The cyclical variation of U.S. GDP and seaborne freight volume. Source: U.S. FRED and Korea Port-mis [25, 26].

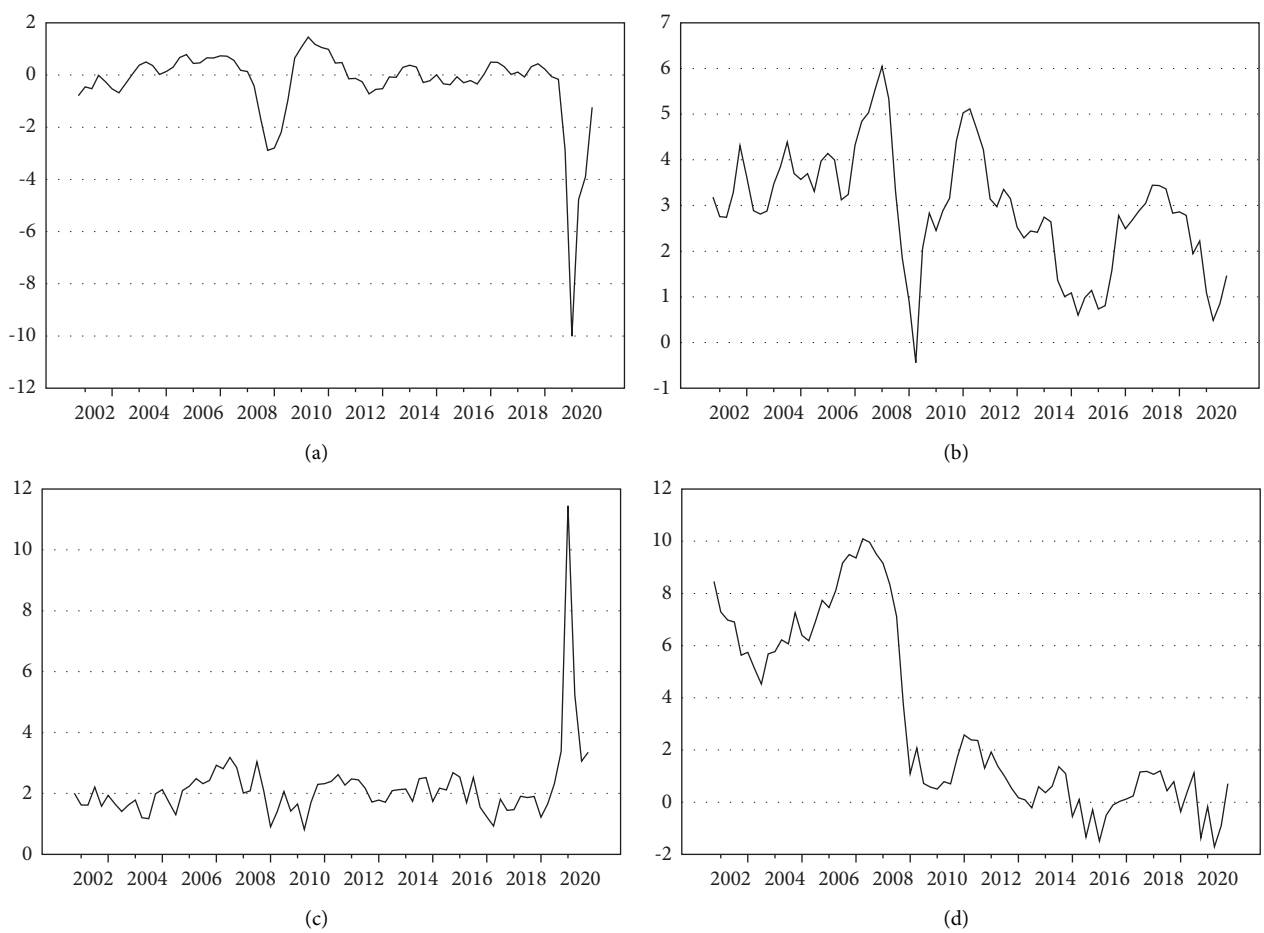


Figure 2: Estimated factors. (a) Foreign real economic factor. (b) Foreign inflation factor. (c) Global liquidity factor. (d) World interest rates factor. Note: the unit of the vertical line is % (percent).

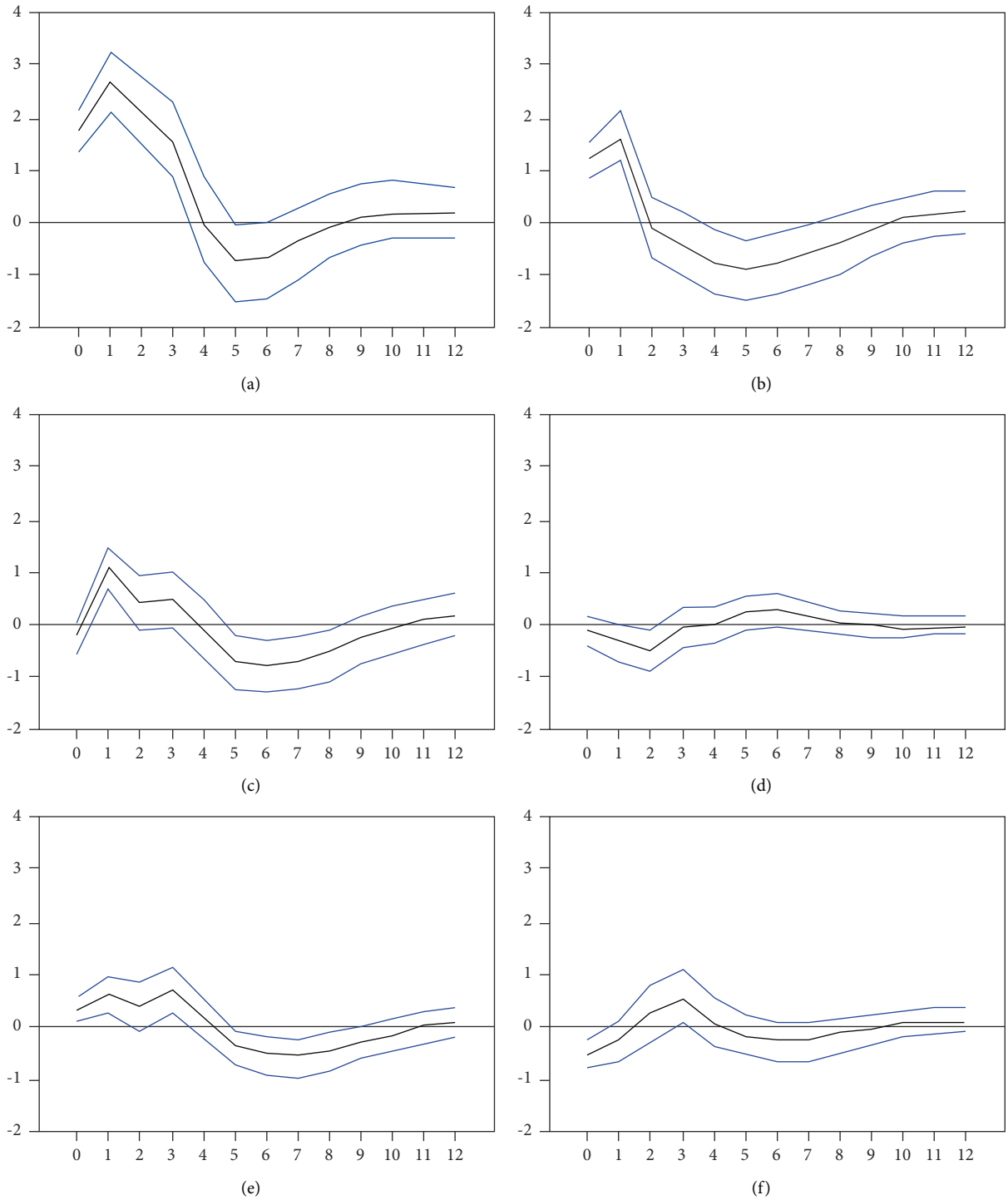


Figure 3: Impulse response function (IRF) of the seaborne freight volume. (a) Foreign real economic shocks. (b) Foreign inflation shocks. (c) Foreign liquidity shocks. (d) Foreign rates shock. (e) Domestic GDP shocks. (f) Import-export trade volume shocks. Note: the blue line represents the 90% confidence interval. The unit of the vertical line is % (percent).

shipped via containers, there exists a close relationship between the volume of container trade and domestic economic activity. For example, domestic manufacturing firms rely on imports of raw materials and intermediate goods transported through containers as well as exports of finished products through containers, which consumers routinely purchase.

The left-upper part of Figure 3 displays the estimate of the dynamic effects of shocks to the foreign real economic activity on domestic seaborne freight transportation. It is

Table 1: The variance of decomposition of the forecast errors.

Step	Real economic activity factor	Inflation factor	World liquidity factor	World interest factor	Domestic growth	Import-export	Seaborne freight
1	31.85	16.02	0.81	0.12	1.35	2.87	46.98
2	47.52	19.81	5.71	0.55	2.41	1.55	22.45
3	55.38	15.88	5.30	1.32	2.57	1.55	17.99
4	56.57	14.58	5.42	1.16	3.87	2.56	15.84
5	55.44	16.05	5.31	1.14	3.96	2.57	15.52
6	53.71	17.55	6.45	1.26	4.18	2.46	14.39
7	51.95	18.10	7.74	1.43	4.81	2.53	13.46
8	50.38	18.26	8.88	1.43	5.51	2.67	12.87
9	49.51	18.25	9.53	1.42	5.95	2.69	12.64
10	49.31	18.19	9.70	1.42	6.09	2.68	12.62
11	49.28	18.19	9.70	1.42	6.10	2.69	12.62
12	49.21	18.27	9.70	1.41	6.09	2.72	12.60

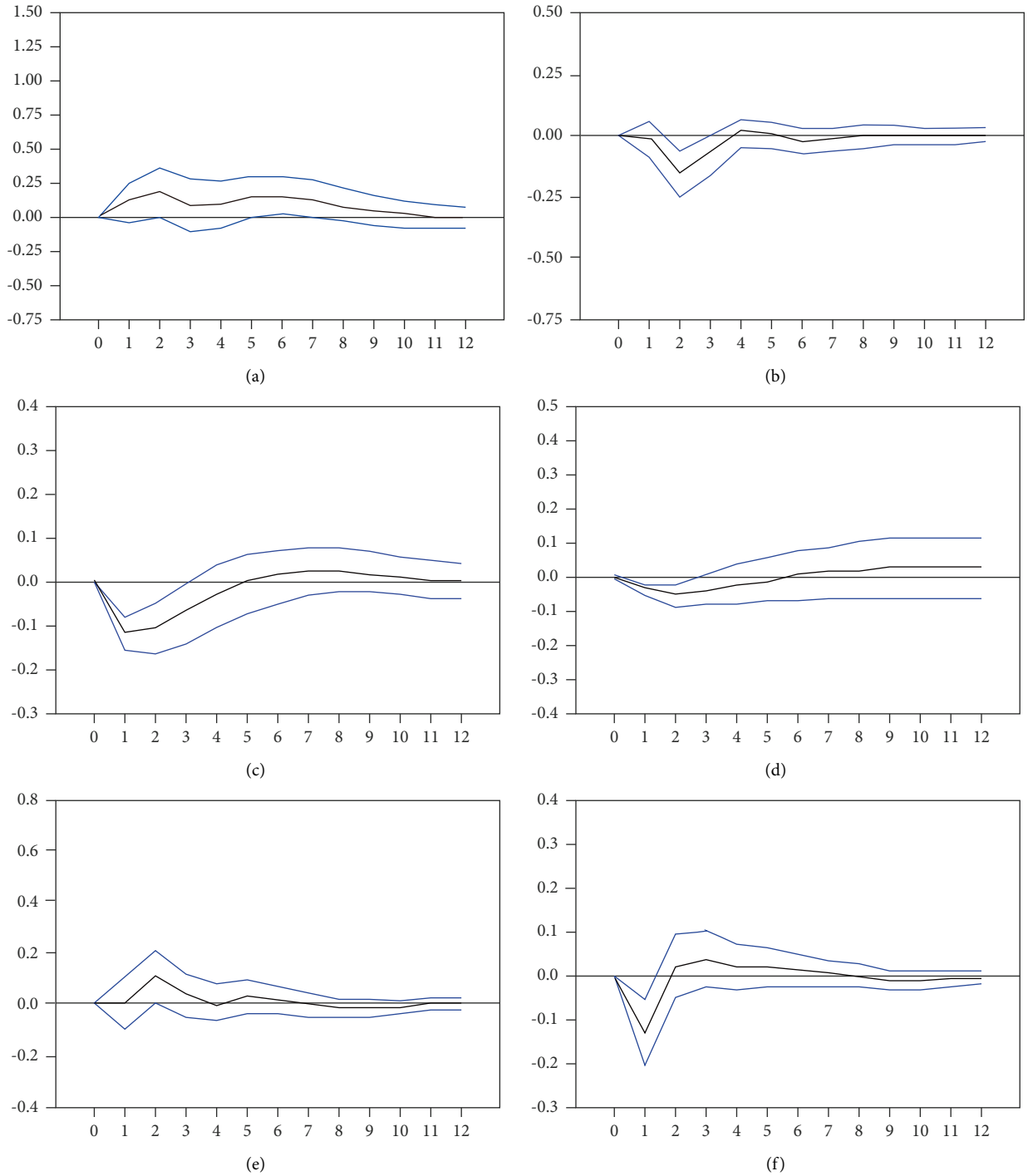


Figure 4: IRF of the seaborne freight volume based on the alternative aggregation. (a) Foreign real economic shocks. (b) Foreign inflation shocks. (c) Foreign liquidity shocks. (d) Foreign rates shocks. (e) Domestic GDP shocks. (f) Import-export trade volume shocks. Note: the blue line represents the 90% confidence interval. The unit of the vertical line is % (percent).

clear that an unanticipated growth in the world industrial production is projected to have a considerable impact on domestic freight transportation. Specifically, one standard increase in the foreign GDP growth results in a 2% increase in domestic freight transportation.

The variation in inflation can originate from a variety of sources. For example, the increases in the expectation of the consumer and business can trigger the variation in consumption and investment, resulting in higher inflation. In addition, the low level of interest rate owing to the higher liquidity can cause an increase in the aggregate demand. Moreover, the supply shocks originating from the increase in the oil price and wages can be a cause of the international inflation phenomenon. As this study only considered the

Table 2: The variance of decomposition based on the alternative aggregation.

Step	Real economic activity factor	Inflation factor	World liquidity factor	World interest factor	Domestic growth	Import-export	Seaborne freight
1	28.663	0.059	5.516	0.236	1.674	2.466	61.385
2	47.827	0.066	9.941	1.28	4.792	1.696	34.398
3	52.041	0.127	8.855	1.905	4.606	2.826	29.64
4	50.431	0.158	11.837	2.97	4.607	3.087	26.911
5	46.519	0.151	17.126	3.143	4.385	2.847	25.828
6	43.597	0.278	20.145	2.867	5.774	2.869	24.469
7	42.045	0.723	20.883	2.719	7.332	3.031	23.268
8	41.097	1.069	20.893	2.881	8.318	3.142	22.6
9	40.591	1.273	20.697	3.166	8.739	3.173	22.36
10	40.406	1.384	20.628	3.373	8.793	3.16	22.257
11	40.351	1.42	20.736	3.458	8.744	3.159	22.132
12	40.32	1.418	20.87	3.46	8.748	3.192	21.992

resulting values of inflation, it is possible to determine whether the cause originated from the demand or supply side. The left-middle part of Figure 3 shows that freight transportation exhibits positive responses following the global inflation shocks. Although the impact of shocks on freight transportation diminished with time, the effects were reversed five quarters after the shock.

In general, world liquidity can positively affect the world economy in the short run. However, the rise and subsequent crash in asset prices, as well as the drop in demand brought on by the weight of liabilities, may cause the economy to go through an adjustment phase and cause a decline in investment and consumption. Thus, if the liquidity increase is based on the credit from the bank, following the growth of the economy in a certain period, the economy exhibits an adjustment period and a certain recession. Moreover, this adjustment phase can affect the port industry negatively. The left-bottom part of Figure 3 shows the estimated response of domestic freight transportation to shocks to the world M3 growth. The domestic freight movement rose after the shocks by more than 1%, as is clear, and the reaction was statistically significant. However, the positive effect of the early phase reversed in five quarters following the shocks.

The world interest rate factor is interpreted as the common factor of all interest rates across countries. This factor originates from the behavior of the central banks; thus, the unexpected fluctuation of the factor can be regarded as shocks that cause central banks across the world to deviate from the path implied by the systematic component of their monetary policy. The right-upper part of Figure 3 shows the dynamic response of the volume of freight transportation to shocks to the world's interest rates based on the recursive identification scheme. The increase in world interest rates is estimated to reduce freight transportation in the early period of shocks. It is generally recognized that a contractionary monetary policy, in which the interest rate rises, reduces investment and consumption, which shocks industrial production. The results obtained were statistically significant. However, the effect of the shocks to world interest rates on the Korean port industry was proven to be smaller than that of the world's real economic activity.

The positive shocks to domestic real GDP growth were estimated to raise domestic freight transportation. According to the right-middle part of Figure 3, one standard increase in domestic real economic activity significantly increases freight transportation. In general, the variation in the trade is understood through a one-to-one relation with freight transportation. However, it was predicted that early in the trade shocks, the positive shocks would boost the amount of freight transported via ports. However, after 3 quarters following the shocks, the response to freight transportation became positive.

4.4. Variance Decomposition. In general, the forecast error variance decomposition indicates the proportion of the movement in a variable owing to its own shocks versus shocks to the other variables. Table 1 presents the results of the forecast error variance decomposition of freight transportation. It is evident that 49.2% of the variation in the seaborne transportation can be driven by the shocks to the real-world economic activity, 18.27% by the shocks to the world inflation factor, 9.7% by the shocks to the world factor, 9.7% by the shocks to the world liquidity factor, and only 6.09% by the shocks to the domestic economic growth.

4.5. VAR Model Analysis (Robust Analysis). This section presents the estimation results and provides the interpretation based on the factors constructed using the weighted mean over the estimation period of the time series taken into consideration in the earlier subsection. This is different from the econometric approach that was thought of before in this study. While there are certain advantages to estimating the common factor using this approach, there are limitations to weighing each series equally. For example, the degree to which the U.S. and UK economies can affect the Korean economy is different. Thus, the influence of each foreign economy on the Korean economy has to be correctly assessed when constructing the common factors.

In this mean method, the proportion of each country's GDP was used as the weight, and the estimation result of the VAR model was obtained using these alternative methods. Figure 4 shows the estimated impulse response of the variable. As evident, the increase in the world real activity increased domestic freight transportation. This result is the same as that of the previous analysis. The increase in world inflation is estimated to lower the volume of freight transportation. Furthermore, the transportation volume was also reduced by the global interest rate impact.

Table 2 presents the variance decomposition analysis results. Here, 40.32% of the variation in the transportation volume was driven by the world GDP shocks, 20.87% by the world liquidity shocks, and 8.75% by the domestic GDP shocks.

5. Conclusion

The port industry in Korea has grown in importance because of a high level of economic openness, the advantages of geographical positioning, and the increasing importance of sea freight transportation in the global supply chain. Thus, it is useful for correct decision-making by the related private agents and policy-making by the port authority to estimate the business cycle in this industry. This paper estimated the business cycles in the Korean port industry, focusing on the dynamic effect of shocks to the foreign economy on this port industry based on the SFAVAR model using the Bayesian Gibbs sampling method.

The major findings of this paper show that the Korean port industry is affected by the business cycle of the global economy. This study is the first to use the SFAVAR model to extract foreign economic factors and shocks; therefore, it can add methodologically to the literature on marine economics in addition to providing estimation findings. The results of this paper can be useful in establishing the correct policy in response to the fluctuations in the global economy.

However, this paper has some limitations. First, it considered the G-7 countries and the Chinese economy as the global economy for computational convenience. Second, this paper did not incorporate the business cycles of other countries' port industries. In fact, the volume of seaborne freight in the Korean port industry is related to that of other countries. In the future, we will be able to use a larger dataset, including the world economy and the data of other countries' port industries, to make the estimation results more robust.

Data Availability

The whole data used to support the findings of this study can be obtained from (1) https://Fred.stlouisfed.org/ for G7 and China data, (2) https://new.portmis.go.kr/ for Korea port data, and (3) https://ecos.bok.or.kr for Korea macroeconomic data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the Academic-Research Cooperation Program in Korea Maritime Institute (KMI).

References

[1] K. Lahiri and V. W. Yao, "Economic indicators for the US transportation sector," *Transportation Research Part A: Policy and Practice*, vol. 40, no. 10, pp. 872–887, 2006.

[2] D. O. Cushman and T. Zha, "Identifying monetary policy in a small open economy under flexible exchange rates," *Journal of Monetary Economics*, vol. 39, no. 3, pp. 433–448, 1997.

[3] S. Kim and N. Roubini, "Exchange rate anomalies in the industrial countries: a solution with a structural VAR approach," *Journal of Monetary Economics*, vol. 45, no. 3, pp. 561–586, 2000.

[4] B. S. Bernanke, J. Boivin, and P. Eliasz, "Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach," *Quarterly Journal of Economics*, vol. 120, no. 1, pp. 387–422, 2005.

[5] F. Belviso and F. Milani, "Structural factor-augmented VARs and the effects of monetary policy," *Topics in Macroeconomics*, vol. 6, no. 3, pp. 1–44, 2006.

[6] M. Fonseca and P. L. V. Pereira, "Credit shocks and monetary policy in Brazil: a structural FAVAR approach," *Brazilian Review of Econometrics*, vol. 32, no. 2, pp. 169–200, 2012.

[7] K. Lee and S. Ni, "On the dynamic effects of oil price shocks: a study using industry level data," *Journal of Monetary Economics*, vol. 49, no. 4, pp. 823–852, 2002.

[8] S. Jo, L. Karnizova, and A. Reza, "Industry effects of oil price shocks: a re-examination," *Energy Economics*, vol. 82, pp. 179–190, 2019.

[9] S. Muller, J. Klauenberg, and A. Wolfermann, "How to Translate Economic Activity into Freight Transportation?" *Transportation Research Procedia*, vol. 8, pp. 1–13, 2015.

[10] A. Pastowski, "Decoupling economic development and freight for reducing its negative impacts," *Wuppertal papers*, vol. 79, 1997.

[11] A. C. Meersman and E. Van de Voorde, "Decoupling of road freight transport and economic growth trends in the UK: an exploratory analysis," *Transport Reviews*, vol. 27, no. 1, pp. 37–64, 2013.

[12] J. Angelopoulos and C. Chlomoudis, "A generalized dynamics factor model for the U.S. Port sector," *Journal of Economics and Business*, vol. 67, no. 1, pp. 22–37, 2017.

[13] A. A. Pallis and P. W. de Langen, "Seaports and the structural implications of the economic crisis," *Research in Transportation Economics*, vol. 27, no. 1, pp. 10–18, 2010.

[14] M. P. Timmer, A. A. Erumban, B. Los, R. Stehrer, and G. J. de Vries, "Slicing up global value chains," *The Journal of Economic Perspectives*, vol. 28, no. 2, pp. 99–118, 2014.

[15] E. Blanchard, "Renegotiating NAFTA the role of global supply chains," in *Economics and Policy in the Age of Trump*, C. P. Bown, Ed., pp. 175–183, CEPR Press, Washington, DC, USA, 2017.

[16] L. Klllan, N. Nomikos, and X. Zhou, "Container shipping and US business cycle fluctuations," *VoxEU*, vol. 15, 2021.

[17] N. A. Michail, "World economic growth and seaborne trade volume: quantifying the relationship," *Transportation Research Interdisciplinary Perspectives*, vol. 4, Article ID 100108, 108 pages, 2020.

[18] A. W. Gregory, A. C. Head, and J. Raynauld, "Measuring world business cycles," *International Economic Review*, vol. 38, no. 3, pp. 677–701, 1997.

[19] M. A. Kose, C. Otrok, and C. H. Whiteman, "International business cycles: world, region, and country-specific factors," *The American Economic Review*, vol. 93, no. 4, pp. 1216–1239, 2003.

[20] A. D'Agostino and P. Surico, "Global liquidity help to forecast U.S. inflation?" *Journal of Money, Credit, and Banking*, vol. 41, no. 2-3, pp. 479–489, 2009.

[21] K. Rogoff, *Globalization and Global Disinflation*, International Monetary Fund, Washington, DC, USA, IMF Working Paper, 2003.

[22] H. Mumtaz and P. Surico, "The transmission of international shocks: a factor-augmented VAR approach," *Journal of Money, Credit, and Banking*, vol. 41, no. 1, pp. 71–100, 2009.

[23] P. Eliasz, *Likelihood-Based Inference in Large Dynamic Factor Models Using Gibbs Sampling*, Princeton University, Princeton, NJ, USA, 2002.

[24] C. Kim and C. Nelson, *State-Space Models with Regime Switching*, The MIT Press, Cambridge, MA, USA, 1999.

[25] Economic research, "Fred economic data," 1991, https://fred.stlouisfed.org/Korea.

[26] Portmis, "Shipping and port logistics information system," 2019, https://new.portmis.go.kr/.

[27] D. Backus, P. Kehoe, and F. Kydland, "Internal business cycles: theory and evidence," in *Frontier of Business Cycle Research*, T. F. Cooley, Ed., pp. 331–357, Princeton University Press, Princeton, NJ, USA, 1995.

[28] M. Baxter, "Internal trade and business cycles," *Handbook of International Economics*, vol. 3, pp. 1801–1864, 1995.

[29] V. Zarnowitz, *Business Cycles: Theory, History, Indicators, and Forecasting*, University of Chicago, Chicago, Illinois, 1992.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 6500191, 10 pages
https://doi.org/10.1155/2023/6500191

Research Article

Analysis of the Impact of County-Levelization on Economic Growth and Public Service Development Based on Panel Data

Wangteng Xu[1] **and Shaojian Wang**[2]

[1]*Xi'an University of Architecture and Technology, Xi'an 710055, Shaanxi, China*
[2]*Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, China*

Correspondence should be addressed to Wangteng Xu; xuwangteng@xauat.edu.cn

Received 2 September 2022; Revised 8 November 2022; Accepted 24 November 2022; Published 4 February 2023

Academic Editor: Lele Qin

County-levelization has become an important vane and propeller of urban spatial development, which is closely related to economic development and public service development. County-levelization can effectively broaden the geographic scope of urban areas, enhance urban functions, and implement strategic planning measures for metropolitan areas. But what impact will such reform have on economic growth and public service development? What is the effect of the current policy of "abolishing counties and establishing districts" in the implementation process? Should the policy of "abolishing counties and establishing districts" be promoted or not? Based on a panel of 453 counties in China, this paper uses DID to analyze the impact of county zoning on county economic growth and public service development and uses PSM-DID to test the robustness. The study shows that county-levelization in China has had a positive effect on economic growth, but in the areas of education and health/public services, such reforms have only had a "squeeze effect" with minimal effect.

1. Introduction

In recent years, the policy of turning counties into districts (TCID) has been successively implemented in Shanghai, Xi'an, Zhengzhou, Chengdu, Hangzhou, and other big cities. The regional reform of the city has caused strong public concern. Some people speculate that China will enter an era of "no counties" in the future, and the municipal district will replace the county as the mainstream vehicle for administrative divisions [1]. Looking back at the objective reality of urban development in recent years, there has been rapid economic growth and a rising level of urbanization, while the imbalance between regional economic and social development has become increasingly prominent, and the profile of public services, such as education and medical care, is also rising rapidly [2]. Discussion of the real impact of TCID reforms on regional economic and social development, and whether they can promote growth and benefit the people's livelihood, will help to further reveal the laws of urban development and ensure that such reforms better serve the people.

The data show that in the context of vigorously building a new pattern of urban development, TCID reform has become an important measure of regional development strategies. Taking Zhengzhou as an example, in the process of building a national central city, local officials in Zhengzhou have been actively promoting the reform of administrative divisions. From 2016 to 2018, in the process of implementing the TCID project in Zhongyu, Xiangyang, Xinzheng, Xinmi, and other places around Zhengzhou City, the official experienced a process of discourse transformation from "recommendation" to "struggle" to "acceleration." The TCID reform has become an important weather vane and accelerator for Zhengzhou to expand its urban development space and build its status as an international commercial capital [3].

Throughout the country, the concept of TCID has become a new style of urban development. Figure 1 provides

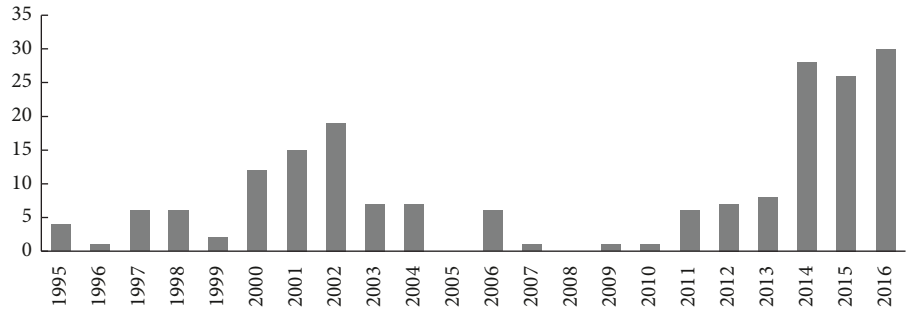


Figure 1: The number of TCIDs implemented in China from 1995 to 2016.

further statistics on the number of cities implementing TCID reforms in China from 1995 to 2016. Between 2000 and 2004, the number of cities implementing TCID reforms reached the peak of the first phase. During this period, a total of 60 cities implemented such reforms. In recent years, the momentum of TCID reforms has further increased, and such policies were implemented 84 times in the three years from 2014 to 2016.

For the administrative division to reform policies with high frequency and wide coverage, multiangle and all-round evaluation can effectively improve the scientificity and effectiveness of policy operations. The TCID reform has undoubtedly broadened the spatial scope of the central city, which is conducive to the formulation and implementation of the development plan of the metropolitan area [4]. However, questions remain as to whether the implementation of such reforms has accelerated economic growth in targeted counties, especially in terms of improving local public services such as education and health care. Exploring these issues is of great significance for ensuring and improving people's livelihoods in urban development [5].

Based on the panel data of 453 counties in China from 1999 to 2010, this paper uses the difference-in-difference (DID) method to conduct counterfactual causal analysis with reference to natural experiments and explore the effect of TCID reforms on economic growth and the development of public services. The main contributions of this paper are as follows:

(1) Discussed the dual impact of such reforms on county-level economic growth and the development of public services, as well as demonstrated the economic and social effects of TCID policies.

(2) Based on the construction of the dual model, the PSM-DID method is further introduced to test the robustness of the results, which can effectively avoid the sample selection bias and confounding deviation of the traditional DID method.

(3) Improved the analysis of the mechanism of TCID reforms on economic growth and public service development, and discussed the interaction between such reforms and economic and social drivers, enriching the relevant results of the evaluation of TCID policies.

The other parts of this paper are organized as follows: The second part sorts out the background of the administrative division system of TCID reforms in China and reviews related literature; the third part explains the empirical model, research scope, and data source; the fourth part introduces the variable selection and descriptive statistics of the sample; the fifth part includes the evaluation results and robustness test; and the sixth part is the conclusion.

2. Literature Review

China's administrative division is the primary means for the central government to pursue economic and social causes across the nation, and, to some extent, it is the shadow cast by state power in geographic spaces [6]. Back in early times, China established an administrative system characterized by a central government, regions, provinces, prefectures, and counties. In 1982, an early reform of regional administrative divisions was introduced. In China's 6th five-year plan, central leadership called for the use of cities, especially large- and medium-sized ones, as central places to organize and manage economic activities and to stimulate rural economic growth, with the hope that economic regions of different geographic sizes and administrative levels based on central cities could be formed eventually [7]. In 1983, a "city administering county" system was established across the country, with the governance hierarchy consisting of the central government, provinces, prefecture-level cities, counties, and townships.

Unlike the Western world, where the reform of administrative divisions is determined by civil autonomy, such reform is government-oriented in China. Since the country's reform and opening up, this effort has grown in strength. Of the reforms put in place, turning counties into cities (TCIC) and turning counties into districts (TCID) pertains to the city level. To prioritize small- and medium-sized cities and towns in the wake of national reform, TCIC reforms became a nationwide trend. Afterward, as of 1996, county cities had increased to 445 from 92 in 1978 [8]. The campaign, however, failed to fulfill hopes for economic growth and urban reform. Instead, such reform led to a surge in the number of cities, an ambiguous conceptualization of cities, and an abnormal type of urbanization [9]. Unsurprisingly, subsequent attempts were met with disapproval by the central government in 1997.

TCID reforms were initiated in the 1980s when counties and county-level cities were approved to transition to prefecture-level municipal districts. This trend has seen

rapid growth since the abortion of TCIC policies in 1997. Generally speaking, areas that want to implement TCID policies must go through the following process from application to implementation: First, the county-level government presents an application for reform, and the provincial and municipal governments agree to report to the Ministry of Civil Affairs and the State Council for approval; after a field visit, TCID reforms can be officially implemented. TCID reforms are a means of adjusting regional administrative relations. This type of reform has the following two distinctive features:

(1) According to the ongoing jurisdiction system in China, a city consists of municipal districts and counties. A municipal government has direct jurisdiction over municipal districts but has limited jurisdiction over counties [10, 11]. With the implementation of TCID reforms, such administrative divisions are broken, allowing counties and municipal districts to coordinate in matters of urban planning, industry layout, and infrastructure construction [12].

(2) This type of reform breaks the institutional barrier between cities and counties. Urban resources are channeled to counties as it is easier to access resources, which contributes to the migration of urban industries and the integrity and redistribution of public resources between regions.

There are volumes of insightful documents concentrating on the causes of the TCID boom. Decentralization is among the primary merits of reform and opening up. The M-structure resulting from decentralization in local governments has also catalyzed the economic miracle unleashed by China since reform and opening up [13]. Nevertheless, such a decentralization in China is not down to earth, which leads to a Chinese style "administration region economy" due to excessive intervention from local governments in terms of capital, labor, and land use [14, 15]. To inject vitality into local economies, allocate resources among cities, and improve urbanization, TCID policies have been introduced by the central government nationwide since the 1980s.

In China's rigid administrative hierarchy, administrative rank is related to the status and power of key officials, as well as preferential policies and resources given to local governments; because of this, lower-level administrators are eager to advance their management ranks [16]. Research results show that county-level cities receive more favorable support than county-level cities in terms of taxation, land policy, and administration, which explains why county-level governments have a strong desire to implement TCIC policies [17]. Likewise, county-level officials are half a rank higher than the county in the administrative hierarchy and thus have more initiative to implement these policies. As a result, county officials tend to be very enthusiastic about TCID policies. Chinese officials' inherent desire for promotion and power in the country's urbanization process is reflected in the prosperous administrative division reform.

Disagreements remain regarding the practical significance of the TCID policies. Some argue that this pursuit leads to an array of problems: targeted counties lose control over their development, spurious, passive, and incomplete urbanization can occur [18]. Others point out that the targeted counties become more independent and enjoy economic growth without any sign of spurious urbanization [19]. Such reforms also contribute to the increased mobility of the population, with an increasing number of migrants pouring into cities [20]. In general, the debate on TCID policies mainly focuses on the economy and urbanization, with little discussion of the impact on public services. As the principal social contradiction and the philosophy of governance have changed, measuring the effect of TCID policies is conducive to their comprehension and evaluation.

3. Research Model

3.1. Empirical Model. When examining the impact of TCID policy on economic growth and public service development, it is necessary to control the interference of other factors as much as possible, especially the impact of macroeconomic trends on the regression results. The difference-in-difference (DID) method is usually used to solve this problem. The DID method is a commonly used strategy evaluation and analysis tool. The basic idea is to divide the sample into an experimental group and a control group. After feeling the impact of the policy, the net effect of the policy shock can be obtained by comparing the differences between the experimental group and the control group [21].

The county-level samples that have experienced TCID reform are taken as the experimental group of this study; then construct the research control group by selecting county-level samples that have not yet experienced TCID reform. In the subsequent processing of DID, the study samples were further divided into four subsamples: the experimental group before TCID, the experimental group after TCID, the control group before TCID, and the control group after TCID. Set the regression equation by introducing two dummy variables, du and dt; see (1). Among them, $du = 1$ represents the county-level sample that has experienced TCID, $du = 0$ represents the county-level sample that has not experienced TCID, $dt = 1$ represents the sample after TCID, and $dt = 0$ represents the sample before TCID.

$$h_{it} = \alpha_0 + \alpha_1 du_{it} + \alpha_2 dt_{it} + \alpha_3 dt_{it} \times du_{it} + \sum_{i=1}^{n} \beta_i X_{it} + \varepsilon_{it}. \quad (1)$$

In equation (1), the subscripts i and t represent the ith county-level sample and the tth period, respectively, X represents a series of control variables affecting a county's economic growth or public service development, ε is a random disturbance term, and h is the dependent variable. The interaction term $dt_{it} \times du_{it}$ is a DID variable. By assigning variables to the two dummy variables du and dt in equation (1), it can be seen that α_3 is the net effect of TCID policies on economic growth or public service development.

An important premise of using the DID model is that the experimental and control groups do not have other characteristics that affect economic growth or public service development, respectively. Obviously, in practice, the above assumptions are difficult to fully hold. In order to ensure the similarity of the sample characteristics of the experimental group and the control groups in various dimensions, this paper adopts the DID propensity score matching method (PSM-DID) for the robustness test [22, 23]. The core idea of the PSM-DID method is to make the two groups as close as possible by comparing the experimental group and the control group one by one from the perspective of various characteristics. The paired control group constitutes the counterfactual state of the experimental group. Comparing the differences between the experimental and control groups provides a clearer picture of the precise policy effects [24].

3.2. Research Scope

3.2.1. Time Range of the Study. The time range of this study was from 1999 to 2010, with a focus on county-level TCID samples from 2000–2004. The basis for selecting this time frame is that (i) exploring the short- and medium-term effects of TCID: that is, the policy effects of one year (short-term) and two-to-six years (medium-term). Since the period from 2000 to 2004 overlaps with the peak period of this type of reform, the inclusion of the TCID sample from this period as the experimental group ensures that there are sufficient data to discuss the development of economic effects and public services before and after such reforms. (ii) It can be seen from Figure 1 that the second peak in TCID policy implementation occurred in 2011. It is not easy to analyze the medium-term effects of TCID policies. Therefore, this paper does not consider the research samples at this stage. (iii) The existing studies surrounding Chinese TCID policies also include TCID samples from the period 2000–2004 [6, 25].

3.2.2. Sample Range of the Study. The county-level samples in this study are mainly divided into two groups: the experimental group and the control group. The former mainly consists of county-level samples that experienced TCID reforms from 2000 to 2004. The latter mainly includes subordinate counties that have not undergone TCID in the same cities and subordinate counties of 70 large- and medium-sized metropolitan areas in China. Incorporating the subordinate counties of 70 large- and medium-sized cities into the control group is mainly based on the fact that the probability of occurrence of TCID policy implementation in large- and medium-sized cities is relatively high. Adding these samples draws the characteristics of the control and experimental group samples closer. This both effectively reduces the selective bias of DID analysis and improves the accuracy of PSM-DID analysis.

It should be noted that during the actual data analysis, areas and flags parallel to the county in the selection of the control sample were not considered in order to ensure the consistency of sample characteristics, and a large number of missing data that occurred during the sample period was excluded, and interpolation was used to fill in records with obvious anomalies and a small amount of missing data.

3.3. Data Sources. The data used in the study mainly includes administrative division reform data and economic and social statistics. Among them, the administrative division reform data come from the official website of the Ministry of Civil Affairs (https://xzqh.mca.gov.cn/description?dcpid=1) and the administrative division network (https://www.xzqh.org). These two websites record in detail the relevant information on the administrative changes of county-level units in China each year. The county-level economic and social statistics mainly come from the government's public statistical yearbook, including the "China County Statistical Yearbook" (2000–2011) and the "China Statistical Yearbook for Regional Economy" (2002–2011), as well as local economic and social statistics [26].

3.4. Variable Selection and Descriptive Statistics. This study uses China's 453 county-level panel data from 1999 to 2010 to evaluate the impact of TCID policies, controlling for various economic factors that affect county economic growth and public service development. The detailed calculation method for all variables is shown in Table 1.

In order to measure regional economic growth and the level of public service development, according to the common practice in the literature, take the per capita GDP (pergdp) of a county, the number of students enrolled per 10,000 people (education), and the number of beds in hospitals and health centers per 10,000 people (medical) as dependent variables. One of the core indicators used in this paper is the dummy variable of the TCID (reform). In the scope of the sample in this paper, if a county carried out TCID reform during the period 2000–2004, then the dummy variable is assigned a value of 1 for 2005 and beyond; otherwise, the value is 0. In the process of using the PSM-DID method for the subsequent robustness test, the specified regional variable is the individual ID, and the logit model is used to estimate the propensity score and perform kernel matching [27, 28].

Since the economic growth and development of public services of a county are affected by many factors, to control the interference of other unobservable factors, control variables are required. The size of the administrative scale (adm) and the size of the population (lnpop) reflect the size and volume of a county, which is an important exogenous variable that affects the economic and social development of the region and, therefore, must be controlled [25]. Agriculture is a major industry at the county level. The level of modernization and output capacity of agriculture in each county are quite different, as is the impact on economic and social development. Therefore, the focus is on controlling the effects of several agricultural variables (agri-mod, agri-dev, lnagri-output, and lnhusbandry-output) on regression. Differences in the economic structure are an important cause of regional differences in the rates of economic growth. The level of industrialization (industry) can test the role of

Table 1: Main variables and calculation method.

Variable	Meaning	Calculation method
pergdp	Economic growth level	Per capita GDP
education	Education level	Number of students enrolled per 10,000 people
medical	Medical level	Number of beds in hospitals and health centers per 10,000 people
reform	TCID	Dummy variable (0, 1)
adm	Administrative scale	Per capita administrative area
lnpop	Population size	Logarithm of the total population
agri-mod	Agricultural modernization level	Total power of agricultural machinery
agri-dev	Agricultural development level	The added value of the primary industry accounts for the proportion of GDP
Lnagri output	Agricultural output capacity	Logarithm of total grain output
Lnhusbandry output	Husbandry output capacity	Logarithmic value of meat production
industry	Industrialization level	The added value of the secondary industry accounts for the proportion of GDP
revenue	Government income level	Fiscal revenue as a percentage of GDP
expenditure	Government expenditure level	Fiscal expenditure as a share of GDP
sav	Savings rate	Urban-rural deposit balance as a percentage of GDP
finance	Financial operation level	Urban-rural loans as a percentage of GDP

structural factors in a county's economic and social development. Second, in the development of a county's economy in China's transitional period, the government plays an important role. The government's income and expenditures are closely related to regional economic growth and public service provision. Therefore, fiscal revenue and fiscal expenditure as a percentage of GDP (revenue and expenditure) were chosen to measure the government's impact on economic and social development at the county level. In addition, savings rates (sav) and loan levels (finance) affect the level of investment and consumption in society and show strong correlations with regional economic growth and public service development, so the impact of these financial variables on the regressions needed to be controlled for. Descriptive statistical results for each variable are shown in Table 2.

4. Evaluation Results and Robustness Test

4.1. A Preliminary Examination of the Effect of TCID Reforms on Economic Growth and Public Service Development. As an important measure of China's urban development strategy, the implementation of TCID reforms provides a quasi-natural experiment. This paper uses the DID method to evaluate the net effect of TCID reform on a county's economic growth and public service development. The regression results are shown in Table 3.

Columns (1), (2), and (3) in Table 3 are estimates of pergdp, education, and medical, respectively. It can be found that, in the short term, and the interaction term $dt1 \times du1$ of pergdp is a positive value of 6102.4, which is significant at the 5% statistical level, indicating that TCID reform can promote the growth of a county's economy in the short term. As the years progress, the value of the interaction term and the level of significance also increase (from two to three stars), indicating that, over a longer time frame, the positive effect of TCID on a county's economic growth is stable. From the interactive items of education, it can be found that $dt1 \times du1$ to $dt6 \times du6$ are not significant, indicating that TCID reform has no obvious positive effect on the improvement of a county's education level. In the results of the medical interaction items, the values of $dt1 \times du1$ to $dt\,6 \times du\,6$ are positive and are significant only in some years (2006, 2008, and 2009), indicating that TCID reform has a weak effect on promoting improvements in medical services. From these estimates, it is not difficult for us to conclude that TCID brings economic benefits to a county and that it has no effect on the development of public services, or that it has a weak positive impact.

The dynamic and robust estimation results of each control variable are shown in Table 4. It can be found that agri-mod, agri-dev, revenue, expenditure, and lnagri-output have a significant effect on the per capita GDP of a targeted county. Among them, agri-mod and revenue have a positive effect on the per capita GDP, and the rest are negative. From the dynamic effects of education and medical services, it can be found that agri-mod, agri-dev, and sav have a significant positive effect on the improvement of a county's education level, and lnagri-output has a significant negative effect on education. The variables agri-mod and sav have a significant positive effect on the improvement of medical services, and lnpop, agri-dev, and lnagri-output have a significant negative effect on medical. The impact of the remaining variables on county-level economic growth and public service development is not significant or robust.

4.2. Further Robustness Test. The DID method can effectively eliminate the bias caused by unobservable factors that do not change with time, but there are still endogeneity problems caused by selective bias. To overcome systematic differences between the experimental and control groups and to reduce the bias in the DID estimates, further robustness tests were performed using the PSM-DID method. First, logit regression is performed on the control variables through reform, and the weight matrix is constructed using the predicted propensity score; then, the policy's effect is estimated according to the kernel matching method. In this process, it is also necessary to check whether the distribution of each variable in the experimental and control groups becomes balanced after such matching and whether the mean value of the covariate is still significantly different

Table 2: Descriptive statistical results.

Variable	Obs	Mean	Std. dev	Min	Max
pergdp	5436	14643.25	15405.77	263.423	154000
education	5436	1461.722	360.222	103.83	5043.04
medical	5436	20.475	9.962	1	96.453
reform	5436	0.056	0.229	0	1
adm	5436	46.174	58.409	0.889	1240.633
lnpop	5436	3.942	0.619	1.386	6.746
agri-mod	5436	36.584	34.059	0.6	300
agri-dev	5436	0.248	0.204	0.006	0.974
lnagri-output	5436	12.198	0.992	2.197	14.922
lnhusbandry-output	5436	10.388	0.978	2.944	13.416
industry	5436	0.466	0.319	0	0.982
revenue	5436	0.045	0.033	0.003	1.012
expenditure	5436	0.111	0.086	0.006	1.987
sav	5436	0.611	0.41	0.001	14.724
finance	5436	0.52	0.419	0	12.35

Table 3: DID dynamics test results of TCID on economic growth and public service development.

Variable	(1) pergdp	(2) education	(3) medical
$dt1$	5112.8***	−314.0***	−0.894
	(709.7)	(31.19)	(0.795)
$dt2$	3827.8***	−359.5***	−1.393*
	(609.9)	(30.84)	(0.802)
$dt3$	11353.2***	−431.2***	0.551
	(1260.5)	(35.08)	(0.949)
$dt4$	15297.2***	−488.2***	1.657*
	(1539.0)	(35.98)	(0.962)
$dt5$	18433.2***	−551.7***	2.140**
	(1842.6)	(35.83)	(0.999)
$dt6$	24241.9***	−590.0***	4.010***
	(2205.2)	(37.55)	(1.119)
$du1$	3147.8***	10.32	2.068
	(754.5)	(71.61)	(1.374)
$du2$	3897.3***	−65.24	3.925***
	(835.1)	(63.74)	(1.319)
$du3$	3112.8***	−50.85	2.426**
	(896.0)	(65.94)	(1.220)
$du4$	2541.4***	−47.09	2.337*
	(978.9)	(65.70)	(1.259)
$du5$	2817.6***	−56.10	2.240*
	(1083.8)	(63.89)	(1.209)
$du6$	3217.5**	−48.12	2.419**
	(1249.1)	(63.83)	(1.219)
$dt1 \times du1$	6120.4**	21.78	3.103
	(2454.9)	(93.97)	(2.694)
$dt2 \times du2$	13203.6***	−3.864	6.453**
	(3080.0)	(93.03)	(2.803)
$dt3 \times du2$	8774.3**	46.15	3.438
	(3472.9)	(89.44)	(2.426)
$dt4 \times du4$	10923.1***	22.38	4.356*
	(4090.0)	(92.94)	(2.408)
$dt5 \times du5$	12555.1***	8.710	4.353*
	(4093.0)	(82.61)	(2.358)
$dt6 \times du6$	15442.6***	5.327	3.953
	(4820.2)	(83.92)	(2.492)

Table 3: Continued.

Variable	(1) pergdp	(2) education	(3) medical
Other control variables	Yes	Yes	Yes
_cons1	48256.5***	2641.0***	45.81***
	(7939.1)	(318.8)	(9.120)
_cons2	38958.4***	2908.3***	45.86***
	(6195.0)	(234.5)	(6.849)
_cons3	73093.3***	2472.6***	43.73***
	(11715.6)	(370.5)	(8.326)
_cons4	80665.0***	2398.0***	41.97***
	(13029.7)	(348.7)	(7.433)
_cons5	91320.5***	2647.8***	46.69***
	(17012.1)	(271.1)	(8.230)
_cons6	102539.9***	2526.8***	49.61***
	(17630.2)	(257.0)	(8.548)
N	906	906	906
R_1^2	0.622	0.238	0.349
R_2^2	0.535	0.275	0.308
R_3^2	0.629	0.322	0.326
R_4^2	0.632	0.363	0.341
R_5^2	0.635	0.420	0.343
R_6^2	0.646	0.463	0.353

Standard errors in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

between the experimental and control groups. If there is no significant difference, the application of the PSM-DID method is supported. After the covariate test, there was no significant difference between the experimental and control groups in our study[3]. The distribution of each variable in the experimental and control groups became balanced, indicating that it was appropriate to use the PSM-DID method. A kernel matching approach was used to estimate and test the robustness of the TCID effect. The estimated results are shown in Table 5.

The data results show that the short-term interaction coefficient pergdp is 6757.8, which is highly significant, and has a little difference from the results of ordinary DID. From the medium-term effect, the corresponding results of PSM-DID pergdp and DID are not very different in terms of coefficients and significance. The per capita GDP of the

Table 4: DID dynamics test results of various control variables on economic growth and public service development.

Variable	lnpop	agri-mod	agri-dev	revenue	expenditure	sav	lnagri-output	lnhusbandry-output
Per capita GDP		+	−	+	−		−	
Education		+	+			+	−	
Medical	−	+	−			+	−	+

"+" in the table represents positive action and "−" represents negative effect.

Table 5: PSM-DID dynamics test results of TCID on economic growth and public service development.

Variable	(1) pergdp	(2) education	(3) medical
$dt1$	8243.7*** (1180.7)	−309.5*** (38.11)	2.010* (1.025)
$dt2$	3270.0** (1278.1)	−362.3*** (40.04)	3.408*** (1.102)
$dt3$	15235.6*** (1737.2)	−409.1*** (40.98)	4.386*** (1.070)
$dt4$	20137.7*** (2104.9)	−456.0*** (41.73)	4.975*** (1.032)
$dt5$	23424.2*** (2228.7)	−501.9*** (37.96)	6.575*** (1.064)
$dt6$	30250.9*** (2552.4)	−551.0*** (38.12)	8.857*** (1.107)
$du1$	2866.6** (1167.5)	−53.78 (37.69)	3.339*** (1.013)
$du2$	2010.3 (1271.3)	−78.55** (39.83)	2.363** (1.096)
$du3$	2010.3 (1728.0)	−78.55* (40.77)	2.363** (1.064)
$du4$	2010.3 (2093.7)	−78.55* (41.51)	2.363** (1.027)
$du5$	1879.8 (2215.3)	−104.1*** (37.73)	2.303** (1.057)
$du6$	1847.9 (2536.6)	−83.61** (37.88)	2.162** (1.100)
$dt1 \times du1$	6757.8*** (1660.5)	37.44 (53.60)	2.493* (1.441)
$dt2 \times du2$	14770.9*** (1802.8)	65.80 (56.47)	2.517 (1.555)
$dt3 \times du3$	8204.9*** (2450.3)	72.08 (57.81)	2.071 (1.509)
$dt4 \times du4$	9867.2*** (2968.9)	71.63 (58.86)	3.035** (1.456)
$dt5 \times du5$	10516.3*** (3142.4)	34.94 (53.52)	2.387 (1.500)
$dt6 \times du6$	11105.0*** (3598.5)	30.78 (53.75)	1.521 (1.561)
Other control variables	Yes	Yes	Yes
_cons1	8370.9*** (825.6)	1760.9*** (26.65)	19.39*** (0.717)
_cons2	8380.4*** (899.0)	1723.5*** (28.16)	19.65*** (0.775)
_cons3	8380.4*** (1221.9)	1723.5*** (28.83)	19.65*** (0.753)
_cons4	8380.4*** (1480.5)	1723.5*** (29.35)	19.65*** (0.726)
_cons5	8450.8*** (1566.5)	1737.5*** (26.68)	19.59*** (0.748)
_cons6	8364.6*** (1793.6)	1730.5*** (26.79)	19.41*** (0.778)
$N1$	645	645	645
$N2$	641	641	641
$N3$	641	641	641
$N4$	641	641	641
$N5$	637	637	637
$N6$	655	655	655
R_1^2	0.298	0.158	0.091
R_2^2	0.332	0.180	0.087
R_3^2	0.310	0.211	0.104
R_4^2	0.334	0.246	0.150
R_5^2	0.367	0.349	0.173
R_6^2	0.394	0.383	0.205

Standard errors in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

counties that implemented the TCID reform was 10,892.9 yuan/person higher than that of the counties without the TCID reform (averaged by the $dt2 \times du2$ to $dt6 \times du6$ coefficients). In the educational interaction project, the coefficients of $dt1 \times du1 \sim dt6 \times du6$ are still insignificant, indicating that the result that the TCID reform has no significant impact on the improvement of county education levels is stable. Among the medical interaction items, only the $dt1 \times du1$ (2005) and $dt4 \times du4$ (2008) coefficients were significant. Compared with the previous DID dynamic test results, the medium-term effects of TCID reforms were further weakened, verifying that such reforms have limited effects on improving medical services.

4.3. Inspection of the Impact Mechanism of TCID Reforms. From the results of various types of inspections in the previous article, it can be found that TCID reforms can promote the growth of a county's economy, but they fail to accelerate the development of public services. So, what factors have led to this reality? To this end, the causes of the TCID reforms were identified by examining their role in the various drivers of economic and social growth. Table 6 shows the test results of the impact mechanism of TCID reforms.

In Table 6, the interaction term, which represents the net impact of TCID reforms on the growth drivers of major economies and societies, is the key observation object of this paper. The regression results in Table 6 show that TCID reforms are significantly positive for revenue and are

Table 6: PSM-DID dynamic test results of TCID impact mechanism.

Variables	(1) lnpop	(2) agri-mod	(3) agri-dev	(4) revenue	(5) expenditure	(6) sav	(7) lnagri-output	(8) lnhusbandry-output
$dt1$	0.00353	10.54***	−0.0487***	0.00458**	0.0232***	0.0394	−0.176*	0.637***
	(0.0521)	(3.047)	(0.0102)	(0.00202)	(0.00605)	(0.0310)	(0.0977)	(0.0875)
$dt2$	0.0204	12.87***	−0.00855	0.0459***	0.0767***	0.563***	0.679***	0.679***
	(0.0506)	(3.097)	(0.0105)	(0.00436)	(0.00666)	(0.0495)	(0.0740)	(0.0740)
$dt3$	0.0272	14.59***	−0.0724***	0.0117***	0.0393***	0.0212	−0.117	0.586***
	(0.0507)	(3.172)	(0.0101)	(0.00245)	(0.00621)	(0.0294)	(0.0995)	(0.0803)
$dt4$	0.0296	17.39***	−0.0819***	0.0133***	0.0481***	0.0461	−0.0920	0.576***
	(0.0507)	(3.257)	(0.00981)	(0.00254)	(0.00651)	(0.0312)	(0.132)	(0.0777)
$dt5$	0.0374	20.84***	−0.0920***	0.0153***	0.0561***	0.0905***	−0.0824	0.635***
	(0.0511)	(3.379)	(0.00966)	(0.00250)	(0.00721)	(0.0317)	(0.102)	(0.0782)
$dt6$	0.0418	26.28***	−0.0998***	0.0193***	0.0612***	0.0749**	−0.0789	0.671***
	(0.0511)	(3.584)	(0.00952)	(0.00256)	(0.00698)	(0.0324)	(0.101)	(0.0775)
$du1$	−0.0130	−0.646	−0.0110	−0.0000935	0.00783	0.168***	0.0757	0.188**
	(0.0514)	(2.976)	(0.0101)	(0.00200)	(0.00601)	(0.0307)	(0.0968)	(0.0849)
$du2$	−0.0324	−5.974*	−0.0192*	−0.000219	0.00716	0.134***	0.272***	0.272***
	(0.0503)	(3.080)	(0.0104)	(0.00434)	(0.00663)	(0.0490)	(0.0740)	(0.0740)
$du3$	−0.0324	−5.974*	−0.0192*	−0.000219	0.00716	0.134***	0.0819	0.272***
	(0.0505)	(3.155)	(0.0100)	(0.00244)	(0.00618)	(0.0291)	(0.0989)	(0.0803)
$du4$	−0.0324	−5.974*	−0.0192*	−0.000219	0.00716	0.134***	0.0819	0.272***
	(0.0505)	(3.240)	(0.00976)	(0.00253)	(0.00648)	(0.0309)	(0.131)	(0.0777)
$du5$	−0.0188	−8.092**	−0.0211**	−0.00103	0.00766	0.138***	0.123	0.276***
	(0.0509)	(3.357)	(0.00959)	(0.00249)	(0.00717)	(0.0314)	(0.102)	(0.0782)
$du6$	−0.0159	−6.546*	−0.0168*	−0.000501	0.00833	0.132***	0.137	0.251***
	(0.0508)	(3.557)	(0.00941)	(0.00254)	(0.00695)	(0.0321)	(0.100)	(0.0775)
$dt1 \times du1$	−0.00540	−8.056*	−0.0480***	0.00648**	0.00199	−0.0639	−0.398***	0.0552
	(0.0732)	(4.239)	(0.0143)	(0.00283)	(0.00848)	(0.0434)	(0.137)	(0.120)
$dt2 \times du2$	−0.0345	−7.466*	−0.0914***	−0.0324***	−0.0473***	−0.548***	0.0553	0.0553
	(0.0710)	(4.368)	(0.0148)	(0.00613)	(0.00940)	(0.0694)	(0.105)	(0.105)
$dt3 \times du3$	−0.0164	−8.160*	−0.0325**	0.00947***	−0.000283	−0.0598	−0.368***	−0.0500
	(0.0713)	(4.474)	(0.0142)	(0.00345)	(0.00876)	(0.0412)	(0.140)	(0.114)
$dt4 \times du4$	−0.00536	−9.381**	−0.0300**	0.00972***	−0.00285	−0.0566	−0.507***	−0.0898
	(0.0713)	(4.594)	(0.0138)	(0.00357)	(0.00919)	(0.0437)	(0.185)	(0.110)
$dt5 \times du5$	0.00411	−10.19**	−0.0271**	0.0106***	0.00246	−0.0898**	−0.387***	−0.0625
	(0.0719)	(4.763)	(0.0136)	(0.00353)	(0.0102)	(0.0445)	(0.144)	(0.111)
$dt6 \times du6$	0.0268	−14.22***	−0.0274**	0.0105***	0.000720	−0.0765*	−0.368***	−0.0863
	(0.0720)	(5.030)	(0.0134)	(0.00361)	(0.00985)	(0.0454)	(0.142)	(0.110)
_cons1	4.072***	32.65***	0.227***	0.0365***	0.0573***	0.526***	12.43***	9.959***
	(0.0363)	(2.124)	(0.00712)	(0.00141)	(0.00425)	(0.0219)	(0.0684)	(0.0617)
_cons2	4.198***	35.06***	0.236***	0.0355***	0.0557***	0.522***	9.984***	9.984***
	(0.0356)	(2.178)	(0.00739)	(0.00307)	(0.00469)	(0.0349)	(0.0523)	(0.0523)
_cons3	4.198***	35.06***	0.236***	0.0355***	0.0557***	0.522***	12.51***	9.984***
	(0.0357)	(2.231)	(0.00710)	(0.00173)	(0.00437)	(0.0207)	(0.0699)	(0.0568)
_cons4	4.198***	35.06***	0.236***	0.0355***	0.0557***	0.522***	12.51***	9.984***
	(0.0357)	(2.291)	(0.00690)	(0.00179)	(0.00458)	(0.0220)	(0.0925)	(0.0549)
_cons5	4.209***	36.41***	0.236***	0.0357***	0.0541***	0.518***	12.52***	9.977***
	(0.0360)	(2.374)	(0.00678)	(0.00176)	(0.00507)	(0.0224)	(0.0721)	(0.0553)
_cons6	4.205***	36.98***	0.237***	0.0351***	0.0530***	0.521***	12.54***	10.01***
	(0.0359)	(2.515)	(0.00665)	(0.00180)	(0.00492)	(0.0228)	(0.0710)	(0.0548)
$N1$	663	657	659	656	674	667	634	575
$N2$	666	681	679	662	681	677	674	674
$N3$	666	681	679	662	681	677	639	674
$N4$	666	681	679	662	681	677	639	674
$N5$	646	681	681	653	675	687	620	670

Table 6: Continued.

Variables	(1) lnpop	(2) agri-mod	(3) agri-dev	(4) revenue	(5) expenditure	(6) sav	(7) lnagri-output	(8) lnhusbandry-output
$N6$	665	686	681	673	697	683	640	673
R_1^2	0.000	0.026	0.176	0.060	0.053	0.059	0.063	0.193
R_2^2	0.003	0.056	0.200	0.184	0.195	0.178	0.244	0.244
R_3^2	0.002	0.063	0.216	0.140	0.109	0.040	0.042	0.148
R_4^2	0.002	0.076	0.251	0.153	0.134	0.037	0.038	0.142
R_5^2	0.002	0.104	0.287	0.191	0.163	0.036	0.036	0.173
R_6^2	0.004	0.121	0.318	0.233	0.187	0.032	0.032	0.179

Standard errors in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

significantly negative for agri-mod and agri-dev. According to the previous regression results, agri-mod and revenue have positive effects on a county's economic growth, while agri-dev has a negative effect. The results show that, in addition to suppressing the positive effect of agricultural modernization on economic growth[4], TICD reforms can increase government revenue, slow down the negative impact of agricultural development on economic growth, and thus benefit the county's economic growth overall. The regression results of the previous article on education show that agri-mod and agri-dev have a significant positive effect on the improvement of a county's education level. It should be noted that TCID not only inhibits the positive effect of agricultural modernization on education but also reduces the positive effect of agricultural development on it. The previous regression results of the impact on medical services show that agri-mod has a significant positive effect on the improvement of medical services and that agri-dev has a negative effect on it. Combined with the results from Table 6, the TCID reforms not only reduce the positive effect of agricultural modernization on the improvement of medical services, but they also inhibit the adverse effects of agricultural development on it. Therefore, TCID reforms have only a weak and unsteady positive impact on the improvement of a county's medical services.

The analysis of the above mechanism shows that the impact of TCID reforms on the economic growth of a county is robust and powerful, and that major economic drivers are developing in a direction that is conducive to economic growth after such reforms are implemented. In the areas of education and medical/public services, such reforms have only produced an "extrusion effect," and there are trade-offs between various drivers. The actual effect of TCID reforms on the development of public services is minimal.

5. Conclusion

In recent years, in the construction of a new pattern of urbanization dominated by urban agglomerations, major cities have promoted the implementation of TCID reforms. Whether they can bring economic growth to a targeted county, especially in terms of the improvement of public services, is an important issue that should be studied at present. Using panel data from 453 counties in China from 1999–2010, this study analyses the short- and medium-term impacts of TCID reforms on economic growth and public service development using the DID methodology. The main conclusions of the study are as follows: (1) TCID reforms have a significant and stable positive effect on a county's economic growth. The GDP of a county that has experienced TCID reforms is 6757.8 yuan per person higher than that of a county that has not experienced them in the short term, and the average value is 10892.9 yuan per person in the medium term. (2) TCID reforms do not significantly increase a county's education level. They have a significant positive effect on the level of medical services only in some years, and the regression results are not stable. (3) Further results of mechanism identification show that TCID reforms can promote the development of major economic drivers in the direction of economic growth. In terms of education and medical or public services, such reforms have only produced an "extrusion effect."

This paper provides empirical evidence for the comprehensive evaluation of the actual effects of the reform of administrative divisions under TCID policies. At present, under the strong influence of new urban development patterns, counties have become more integrated into the development of metropolitan areas through TCID reforms. Such measures can be either good or bad for the development of a county. The analysis in this paper finds that TCID reforms are beneficial to counties at least in terms of economic growth, but TCID reforms have not played a positive role in improving the level of education or medical/public services. This conclusion warns us that in future TCID reforms, local governments should pay special attention to introducing this "policy dividend" in a way that improves public services.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] H. Chung, "State regulation and China's administrative system: a spatial perspective," *China Review*, vol. 8, no. 2, pp. 201–230, 2008.

[2] C. Gu, C. Kesteloot, and I. G. Cook, "Theorising Chinese urbanisation: a multi-layered perspective," *Urban Studies*, vol. 52, no. 14, pp. 2564–2580, 2015.

[3] J. Zhu and Y. Guo, "Fragmented peri-urbanisation led by autonomous village development under informal institution in high-density regions: the case of Nanhai, China," *Urban Studies*, vol. 51, no. 6, pp. 1120–1145, 2013.

[4] G. C. Lin, X. Li, F. F. Yang, and F. Z. Hu, "Strategizing urbanism in the era of neoliberalization: state power reshuffling, land development and municipal finance in urbanizing China," *Urban Studies*, vol. 52, no. 11, pp. 1962–1982, 2014.

[5] W. Tang and Y. Wang, "Administrative boundary adjustment and urbanization of population: evidence from city-county merger in China," *Economic Research Journal*, vol. 50, no. 09, pp. 72–85, 2015.

[6] L. Zhang, J. Pi, and G. Song, "Government competition and preference for productive expenditure: the political economy in county to district reforms in China," *Finance & Trade Economics*, vol. 39, no. 03, pp. 65–78, 2018.

[7] L. Zhang and S. X. B. Zhao, "Re-examining China's "urban" concept and the level of urbanization," *The China Quarterly*, vol. 154, no. 154, pp. 330–381, 1998.

[8] K. W. Chan, "Misconceptions and complexities in the study of China's cities: definitions, statistics, and implications," *Eurasian Geography and Economics*, vol. 48, no. 4, pp. 383–412, 2007.

[9] S. Fan, L. Li, and X. Zhang, "Challenges of creating cities in China: lessons from a short-lived county-to-city upgrading policy," *Journal of Comparative Economics*, vol. 40, no. 3, pp. 476–491, 2012.

[10] S. S. Chien, "New local state power through administrative restructuring–A case study of post-mao China county-level urban entrepreneurialism in Kunshan," *Geoforum*, vol. 46, pp. 103–112, 2013.

[11] E. Maskin, Y. Qian, and C. Xu, "Incentives, information, and organizational form," *The Review of Economic Studies*, vol. 67, no. 2, pp. 359–378, 2000.

[12] C. Cartier, "Urban growth, rescaling, and the spatial administrative hierarchy," *Provincial China*, vol. 3, no. 1, pp. 9–33, 2011.

[13] A. Young, "The razor's edge: distortions and incremental reform in the People's Republic of China," *Quarterly Journal of Economics*, vol. 115, no. 4, pp. 1091–1135, 2000.

[14] C. Zeng, A. Zhang, and S. Xu, "Urbanization and administrative restructuring: a case study on the Wuhan urban agglomeration," *Habitat International*, vol. 55, pp. 46–57, 2016.

[15] C. Zeng, A. L. Zhang, L. Liu, and Y. Liu, "Administrative restructuring and land-use intensity—a spatial explicit perspective," *Land Use Policy*, vol. 67, pp. 190–199, 2017.

[16] K. W. Chan, "Fundamentals of China's urbanization and policy," *China Review*, vol. 10, no. 1, pp. 63–93, 2010.

[17] L. Li, "The incentive role of creating "cities" in China," *China Economic Review*, vol. 22, no. 1, pp. 172–181, 2011.

[18] X. Li and X. Xu, "Impact analysis of turning counties (cities) into districts to the urban economic growth in China," *Acta Geographica Sinica*, vol. 70, no. 08, pp. 1202–1214, 2015.

[19] L. J. C. Ma, "Urban transformation in China, 1949-2000: a review and research agenda," *Environment and Planning: Economy and Space*, vol. 34, no. 9, pp. 1545–1569, 2002.

[20] Y. Zhou and L. J. C. Ma, "Economic restructuring and suburbanization in China," *Urban Geography*, vol. 21, no. 3, pp. 205–236, 2000.

[21] G. Zhang and C. Gu, "Passive urbanization in rapid urbanization," *City Planning Review*, vol. 5, pp. 48–54, 2006.

[22] X. Luo, J. Yin, and D. Tian, "Administrative boundary reorganization in Nanjing metropolitan region," *Geographical Research*, vol. 29, no. 10, pp. 1746–1756, 2010.

[23] L. Zhang and J. Zhang, "Rethinking the regional merger effect of turning counties into districts-Taking Dantu District of Zhenjiang city as an example," *Urban Problems*, vol. 1, pp. 36–40, 2007.

[24] Y. Liu, Z. Li, and J. Jin, "Pseudo-urbanization or real urbanization?: urban China's mergence of administrative regions and its effects: a case study of Zhongshan City, Guangdong province," *China Review*, vol. 14, no. 1, pp. 37–59, 2014.

[25] Y. Lin and P. Liu, "Chinese development strategy and economic convergence," *Economic Research Journal*, vol. 3, pp. 19–25, 2003.

[26] R. H. Dehejia and S. Wahba, "Propensity score-matching methods for nonexperimental causal studies," *The Review of Economics and Statistics*, vol. 84, no. 1, pp. 151–161, 2002.

[27] C. Shao, D. Su, and Q. Bao, "Growth performance evaluation of city-county merger under the Chinese style decentralization," *The Journal of World Economy*, vol. 41, no. 10, pp. 101–125, 2018.

[28] R. Liu and R. Zhao, "Western development: growth drive or policy trap-an analysis based on PSM-DID method," *China Industrial Economics*, vol. 6, pp. 32–43, 2015.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6123348, 9 pages
https://doi.org/10.1155/2022/6123348

Research Article

Research on the Classification of Policy Instruments Based on BERT Model

Jiani Zhao [1,2] **and Cheng Li** [1]

[1] *College of Air Transportation, Shanghai University of Engineering Science, Shanghai, China*
[2] *School of Information Management & Engineering, Shanghai University of Finance and Economics, Shanghai, China*

Correspondence should be addressed to Jiani Zhao; zhaojiani@sues.edu.cn

Received 31 July 2022; Revised 4 September 2022; Accepted 30 September 2022; Published 14 October 2022

Academic Editor: Lele Qin

Currently, policy instruments are classified mainly by means of manual encoding and checking, which is highly subjective and inefficient, which greatly hinders the development of policy research. The research tries to apply the automatic classification algorithm based on BERT (Bidirectional Encoder Representation from Transformer) to the policy instruments to improve the efficiency and accuracy of policy instruments classification. An entrepreneurship policy instrument classification model was established on the basis of the pretraining language model to realize the automatic classification of entrepreneurship policy instruments. The research showed that through optimization and improvement of the model, the F1 value was 0.86 on the test set, indicating a good classification effect; through the comparative experiment, it was further proved that the classification effect of this model was far superior to other three commonly used text classification models. The model greatly improves the efficiency and objectivity of policy instrument classification and provides a new idea for investigating entrepreneurship policies and more generalized policy instruments.

1. Introduction

As a common way of governing a state's social public affairs, policy instruments serve as a vital bridge that connects policy targets and policy results. Regarding the interpretation of specific policies, the selection and application of policy instruments reflect the diversity of public policies [1]. When public policies are implemented, different policy instruments may lead to varying policy objects. Moreover, the standards for assessing a policy instrument's effect also influence the final policy goal [2]. Policy instruments influence the goals and status of implementing policies. Beyond that, the government conducts several combination designs of policy instruments according to the circumstances of each industry to reach high adaptability. On the whole, policies cannot do without support from policy instruments in the entire process, ranging from formulation to proper execution. Sufficient and detailed data on the classification of policy instruments will provide a solid foundation for the follow-up research on policy instrument coordination analysis and policy evaluation and provide a basis for further expanding the depth of policy instrument research. Currently, there are no unified standards in academia for classifying policy instruments. Hence, public policy researchers have proposed distinctive classification standards based on the respective research problems, interests, and areas. Consequently, policy instruments come in a diverse range of categories [3]. However, few studies in the theory circle have focused on the way to classify policy instruments. Instead, manual encoding and rechecks are employed [4–6]. Not only is manual classification strongly subjective but also it considerably lowers the efficiency of researching policy instruments. Despite this, the automatic classification algorithm based on text analysis has not been used with research policy instruments.

Therefore, the research proposes a BERT-based deep learning model to study the policy instrument classification of entrepreneurial policy texts referring to predecessors'

research. In recent years, the mode of pretraining-parameter fine-tuning has been a new pattern in the natural language processing realm [7]. Generally speaking, most deep learning models must be trained by vast data [8]. Unfortunately, this study only collected 470 pieces of entrepreneurial policy text, which can be divided into about 10,000 units for policy instrument analysis. This volume is smaller than other corpora, and the number of manually marked policy instruments is less than 2,000. Such a small sample size is unfit for training deep learning models with many parameters [9]. Nevertheless, the pretraining language models represented by BERT can conduct pretraining in a super-large corpus and start fine-tuning in samples with few downstream tasks. Thus, it can achieve an outstanding effect without many samples [10]. Owing to this trait, the BERT model achieves a satisfactory effect even in sample tasks with a small size of text, which is very suitable for the research scenario of this paper.

2. Literature Review

Text classification is devoted to classifying diverse levels of text, including sentences, paragraphs, and documents, making it a critical research orientation for natural language processing [11]. Currently, there have been many successful cases of applying text analysis to the question answering system, conversation system, and analysis of public opinions [12]. Existing mainstream text analysis methods can be divided into two categories: methods based on traditional machine learning and those based on deep learning. The latter is attracting growing favor from researchers.

Feed-forward network (FFN) is one of the earliest deep neural networks. This model regards the text as one "bag-of-words," namely, a set of words, without considering the dependence relationship between different words and the sequence of words [13]. Recurrent neural network (RNN) [14] regards the text as a group of word sequences, to extract the relationship between words, text structure, and other information. However, the original RNN fails to achieve the same effect as the FFN model in the actual application of text classification. It is mainly because the original RNN brings a varnishing gradient and gradient explosion in back-propagation, which results in a catastrophic impact on optimizing the model's parameters. Subsequently, the researchers optimized the original RNN and proposed an LSTM model. The convolution neural network (CNN) [15] is mainly used to process images. Unlike the time sequence information between the input sequences extracted by RNN, CNN excels in extracting the spatial position of input features [16].

When humans read, they pay varying degrees of attention to each word in the text, and the attention mechanism was brought forth under the inspiration of this phenomenon. Transformer [17] is a self-attention network structure and has overcome the defect that RNN and its variants cannot be trained. Compared with CNN, this model can be used to directly calculate the relationship between two words separated by a long distance and is not limited by the length of the convolution core in CNN. Due to these merits, transformer achieves an outstanding effect in actual application. Thus, it has emerged as the most mainstream network structure in natural language processing. As the natural language processing technology advances, the model of pretraining-parameter fine-tuning becomes a new pattern in this realm [7]. This pattern works in specific procedures. (1) the pretraining stage: some self-supervision learning tasks are designed in super-large corpora to pretrain the model. (2) fine-tuning stage: the parameters of the pretrained model are fine-tuned in specific downstream tasks (such as text classification). The principal structure of ELMO [18] is a multilayered LSTM network, which adopts autoregression tasks in the pretraining stage to predict the next word based on a group of given words. BERT [19] is a pretraining language model proposed by Google AI Language in 2018 based on the Transformer network. It mainly takes on two tasks in the pretraining stage: Masked Language Model (MLM) and Next Sentence Prediction (NSP). The advent of BERT marks a milestone progress in the natural language processing field. Since it was launched, it has considerably outperformed previous models in several natural language processing tasks [10]. Currently, BERT is applied to text summary, machine translation, text similarity calculation, question answering system, text classification, and so on [20].

In recent years, text mining concerning policies and politics have been the new research direction in the natural language processing realm. D'Orazio et al. [21] judged whether a policy document involves military-related information through the Support Vector Machine model. Krebs [22] extracted information from a document to identify whether it may carry a potential nationalist intention. Chang and Masterson [23] proposed a deep network model based on LSTM to classify and process different categories of policy texts. Pujari and Goldwasser [24] proposed a BERT-based neural network model and integrated the author's information to encode the policy text information from social media more accurately. Mukherjee et al. [25] employed Bart, an optimized version of BERT, to divide the text on social media, such as Twitter, into three categories: public health, policy, and others. Thus, it can be seen that the theoretical circle has not studied the text mining of policy texts extensively. Moreover, the application of natural language processing to policy instrument classification is more limited in the Chinese realm. Therefore, based on predecessors' research, the paper proposed a deep learning model based on the pretraining language model to classify entrepreneurial policy texts into policy instruments.

3. Research Methodology

3.1. Model Settings

3.1.1. Model Structure. The BERT model structure is displayed in Figure 1, which mainly consists of N (a preset model hyperparameter, generally taken as 12) Transformer coding units. The core idea of BERT is the bidirectional attention mechanism introduced by Transformer encoder. BERT piles multiple Transformer encoders together, and

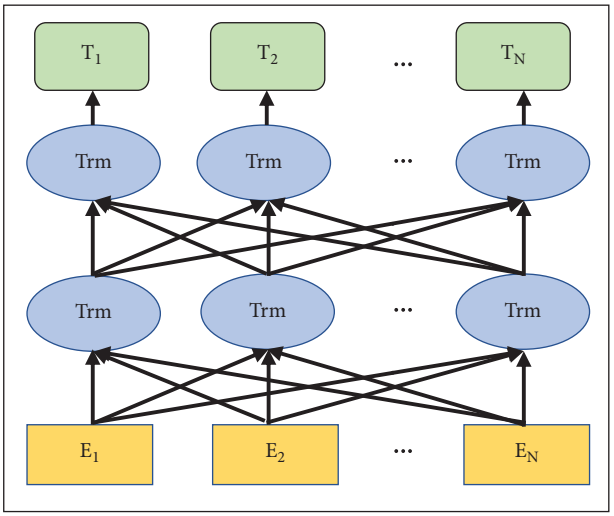


Figure 1: BERT model structure chart.

each encoder contains multihead attention mechanism and splices the coding of each multihead attention mechanism as the input of the next layer. Therefore, text features can be extracted better.

3.1.2. Pretraining Task. Two pretraining tasks are mainly proposed by BERT, namely, masked language model (MLM) and next sentence prediction (NSP). The core idea of MLM lies in randomly masking the tokens in a sentence at a certain probability so that they can be predicted by this model according to the context of the masked tokens. As for NSP, two sentences A and B are given, enabling the model to judge whether the sentence B is the next sentence of the sentence A in a concrete context. Positive and negative samples can be constructed by randomly sampling in large-scale corpora, to form a training set of NSP tasks.

3.1.3. Text Embedding. BERT embedding is mainly composed of three parts: token embedding, segment embedding, and position embedding, where token embedding resembles the word embedding in natural language processing. The tokens after text segmentation are mapped by BERT tokenizer to a vector one by one. Since the input of BERT may be two sentences, segment embedding means embedding different sentences. If the input is just one sentence, the segment embedding corresponding to each input token is E_A. If the input is two sentences A and B, the segment embedding corresponding to each token in the sentence A is E_A and that in the sentence B is E_B. E_A and E_B represent the segment embedding of sentences A and B, respectively. Given the lack of the position information of tokens in the sentences of transformer structure, the position of each word should be embedded, namely, each position is mapped to a vector that can be learned.

3.1.4. Transformer Encoder and Attention Mechanism. The core idea of transformer encoder lies in the introduction of the attention mechanism. For instance, when reading entrepreneurship policy texts, people tend to pay more attention to words related to concrete policy instruments like "tax and rate reduction" and "guaranteed loan" while neglecting some auxiliary words or those without practical significance, such as "different regions" and "different departments." Transformer encoder calculates the attention attracted by different words using the matrix multiplication method, to enable the parallel computing on GPU, which, to a great extent, accelerates the model training and computing speed. In addition, Transformer encoder is able to process the word dependence inside a random-length sequence, without needing to consider problems like gradient missing and explosion in RNN.

Multiheaded attention mechanism inputs the three following vectors: query vector $Q \in \mathbb{R}^{l\times d_q}$, key vector $K \in \mathbb{R}^{l\times d_k}$, and value vector $V \in \mathbb{R}^{l\times d_k}$, where l is the length of input sequence, d_q stands for the dimension of query vector, and d_k denotes the dimension of key vector and value vector. In practical applications, query vector is obtained by linearly transforming query statements (or its implicit expression), while key vector and value vector are acquired by linearly transforming key statement and value statements (or their implicit expressions).

In the multiheaded attention mechanism, each "head" corresponds to a scaled dot-product attention. Assume that there are totally h "heads" in the multiheaded attention mechanism, query, key, and value vectors are, respectively, input into h scaled dot-product attentions, and the h outputs are finally spliced as the final output of the multiheaded attention mechanism.

Scaled dot-product attention is specifically calculated through the following formula:

$$\begin{aligned} \text{Attention}(Q,K,V) &= \text{softmax}\left(\frac{\text{QK}^T}{\sqrt{d_k}}\right)V, \\ \text{softmax}(X) &= \frac{e^{X_i}}{\sum_{j=1}^{N} e^{X_j}}, \end{aligned} \tag{1}$$

where softmax(X) is the activation function to realize the logistic regression of data; that is, the numerical vector is normalized to the probability distribution vector, and the sum of each probability is 1.

Therefore, the final output of multiheaded attention mechanism is $A = [A_1, A_2, \ldots, A_h]$, where A_i is the output of the i (th) scaled dot-product attention.

3.2. Research Model and Process

3.2.1. Modeling. In this research, a PLM-multilayer perceptron (MLP) combined text classification model was proposed to classify the policy instruments in entrepreneurship policy texts. The open-source Chinese BERT model was firstly acquired, which was already pretrained in large-scale Chinese corpora, and a good deal of knowledge was learned. On this basis, the manually annotated entrepreneurship policy instrument samples were used to fine-adjust this BERT model.

The structure of the proposed model is exhibited in Figure 2, which mainly consists of three parts: PLM, max-pooling layer, and MLP, where PLM aims to extract a matrix representation fusing contextual information from policy instruments, max-pooling layer to perform dimension transformation, i.e., dimension reduction, of the characteristic matrix extracted from the PLM, and MLP to classify the textual characteristics extracted from the aforementioned network. In this research, entrepreneurship policy instruments were finally classified into 12 classes.

Since Chinese BERT model implements word segmentation by taking Chinese characters as units, the model input is a group of character sequences. In this research, the input of the BERT model was a character sequence with the length of 512, e.g., the analytical unit length of one policy instrument was 100 characters. As required by the BERT model, a special character "[CLS]" was added at the forefront of the sequence, and the length of this character sequence was 101 after word segmentation, being less than 512, so 512–101 = 411 [pad]s were supplemented after this sequence until the final sentence length was 512. The vector corresponding to [pad] was 768-dimensional (768 is the dimension of the hidden layer), and the value of it was kept at 0. If there were 600 characters in the analytical units of one policy instrument, the first 511 characters in this sentence were extracted and [CLS] was added at the forefront to form a 512-character sequence as the input of the BERT model. After this group of character sequence after the word segment was acquired, each character was mapped to a 768-dimensional vector according to the mapping table in BERT tokenizer, namely, the glossary of token embedding, and this vector was integrated into the segment embedding and position embedding vectors corresponding to this character to form a final vector of this character, which was finally input into the BERT model.

The input sequence of PLM is set as X. The above process is expressed by the following formula:

$$H = \mathrm{PLM}(X), \tag{2}$$

where $\mathrm{PLM}(*)$ stands for PLM; $H \in \mathbb{R}^{l \times d_p}$ denotes the output of PLM; l is the sequence length of the policy instrument, which was 512 in this model, and the part less than 512 was complemented by [pad]; and d_p represents the state dimension at the hidden layer of PLM, which was set to $d_p = 768$ in this model.

After the output H of PLM was acquired, it was input into the max-pooling layer, to transform the matrix output by PLM into a vector as an eigenvector and finally input into MLP. The schematic diagram of max-pooling layer is displayed in Figure 3, i.e., the maximum value was taken from each row of the $768 * 512$ matrix output by PLM to obtain a 768-dimensional vector, which was, namely, the output of max-pooling layer (see the following formula):

$$M = \mathrm{MaxPool}(H), \tag{3}$$

where $\mathrm{MaxPool}(*)$ represents the max-pooling layer and $\in \mathbb{R}^{d_p}$ stands for its output. In this model, $d_p = 768$, so M was a 768-dimensional vector.

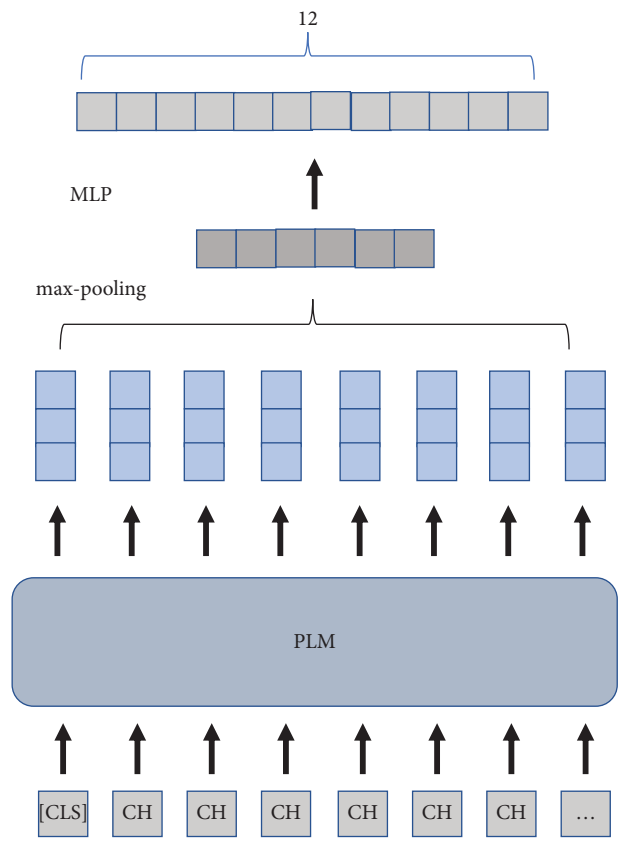


Figure 2: Structure chart of policy instrument classification model.

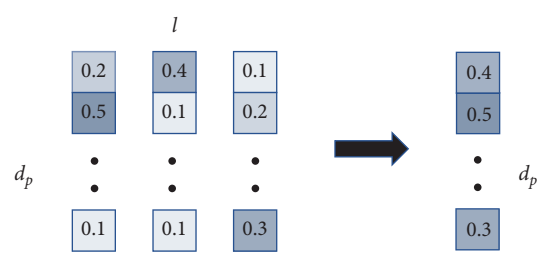


Figure 3: Schematic diagram of max-pooling layer.

In the end, the output M of max-pooling layer was input into MLP for classification, to obtain the final model output L, as follows:

$$L = W_2(\sigma(W_1 M + b_1)) + b_2, \tag{4}$$

where W_* and b_* represent model parameters, $\sigma(*)$ is an activation function, $\sigma(x) = 1/1 + e^{-x}$, L is the output vector of MLP, and the dimension of L is the number of policy instrument classes (12 in this research). Next, softmax processing was performed for L to facilitate its normalization. Therefore, the numerical value at the position i of the processed vector $\mathrm{softmax}(L)$ was the probability for the input policy instrument analytical unit to belong to the class i, and the final classification result of this input policy instrument analytical unit obtained by the model was the class corresponding to the maximum probability in the vector.

3.2.2. Samples and Data Processing. In this research, a total of 178 entrepreneurship policy texts were chosen from 470 national-level entrepreneurship policies and then manually encoded. The 178 entrepreneurship policy texts included 7 documents issued by the State Council, 15 ones issued by the General Office of the State Council and 156 ones issued by other national ministries and commissions, covering representative entrepreneurship documents at each level of each department, with a time span of 2001–2020, so the whole research period was covered. Finally, 1,682 manually annotated analytical units, namely, policy documents, were acquired.

Whether the coding and classification of analysis units in sample policies are reasonable and reliable is directly related to the accuracy of the classification of policy instruments in subsequent studies. Therefore, it is necessary to conduct reliability analysis on the results of manual classification. In order to ensure the accuracy of coding, avoid researchers from making wrong judgments on policy texts due to subjective awareness and value preferences, and ensure a high reliability level, this study adopts the reliability formula of content analysis [26] to test the reliability of coding. The formula is as follows:

$$R = \frac{n \times k}{1 + (n-1) \times k}, \tag{5}$$

where R is the reliability; n is the number of judges, $n = 2$ in this study, k is the average degree of mutual agreement (that is, the degree of mutual agreement between two judges), and its formula is

$$k = \frac{2M}{N_1 + N_2}, \tag{6}$$

where M is the number of policy instruments that the two judges agree on, N_1 is the number of policy instruments that the first judge judges, and N_2 is the number of policy instruments that the second judge judges.

In this study, the two judges classified 1682 texts with policy instruments at the same time and compared and analyzed the classification results. Among them, 1510 were consistent and 172 were inconsistent, so the average agreement degree $k = 0.8977$, and the reliability degree $R = 94.61\%$. It is generally believed that when the reliability is above 0.7, the previous research can be considered credible enough [27]. Therefore, the categories of entrepreneurship policy instruments classified in this study for the policy content analysis unit are credible. In order to further improve the accuracy of the classification of policy instruments, a secondary analysis was conducted for the 172 analysis units with inconsistent classification. The two judges discussed and negotiated, and expert consultation was adopted for the analysis units with large differences, and the classification of policy instruments was finally determined, as shown in Table 1.

3.2.3. Experimental Environment and Parameter Settings. In this research, the model was established using *Python*3 programming language under the deep learning framework of PyTorch to complete the classification task of entrepreneurship policy instruments. The experimental environment is depicted in Table 2.

The different values of hyperparameters were acquired through grid search within reasonable ranges, with partial results as shown in Figure 4, where the horizontal axis stands for the value of each hyperparameter and the longitudinal axis denotes the model effect under this value. Among the different values of each hyperparameter, the value corresponding to the best model effect was regarded as the value of this hyperparameter. Therefore, the model harvested the best effect under the batch size of 8 and learning rate of 2e-5. The final hyperparameter values and the related training details of this model are as seen in Table 3.

3.2.4. Evaluation Indices. To facilitate the evaluation of the model effect, universal evaluation criteria were used, namely, accuracy, precision, recall, and F1 as evaluation indices. The concrete formulas for such evaluation indices of the samples belonging to class i are as follows:

$$\begin{aligned} \text{accuracy} &= \frac{\sum_{i=1}^{N} (\text{TP}_i + \text{TN}_i)}{\sum_{i=1}^{N} (\text{TP}_i + \text{TN}_i + \text{FP}_i + \text{FN}_i)}, \\ \text{precision}_i &= \frac{\text{TP}_i}{\text{TP}_i + \text{FP}_i}, \\ \text{recall}_i &= \frac{\text{TP}_i}{\text{TP}_i + \text{FN}_i}, \\ F1_i &= \frac{2 \times \text{precision}_i \times \text{recall}_i}{\text{precision}_i + \text{recall}_i}, \end{aligned} \tag{7}$$

where TP_i is the number of true values, TN_i is the number of true negative values, FP_i is the number of false positive values, and FN_i is the number of false negative values.

The above formulas represent the evaluation indices for the samples of class i. The evaluation indices of each class should be integrated to evaluate the comprehensive model performance through integration methods like macro, micro, and weighted average. In this research, Weighted Average was chosen to integrate the evaluation indices of each class, specifically as follows:

$$\begin{aligned} \text{precision} &= \sum_{i=1}^{N} (\text{precision}_i \times w_i), \\ \text{recall} &= \sum_{i=1}^{N} (\text{recall}_i \times w_i), \\ F1 &= \sum_{i=1}^{N} (F1_i \times w_i), \end{aligned} \tag{8}$$

where w_i is the proportion of samples belonging to class i in all the samples.

3.2.5. Experimental Process. To better evaluate the model effect in the training process, the sampled dataset was randomly segmented according to the proportion of 8 : 2,

Table 1: Manual annotation frequencies of policy instruments.

Class	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Quantity	183	318	54	120	19	22	29	44	171	199	187	336

Table 2: Experimental environment.

Name	Configuration
CPU	Intel (R) Xeon (R) Silver 4114 CPU @ 2.20 GHz
Memory	32 GB
GPU	Tesla V100 16 GB
System	Ubuntu 20.04

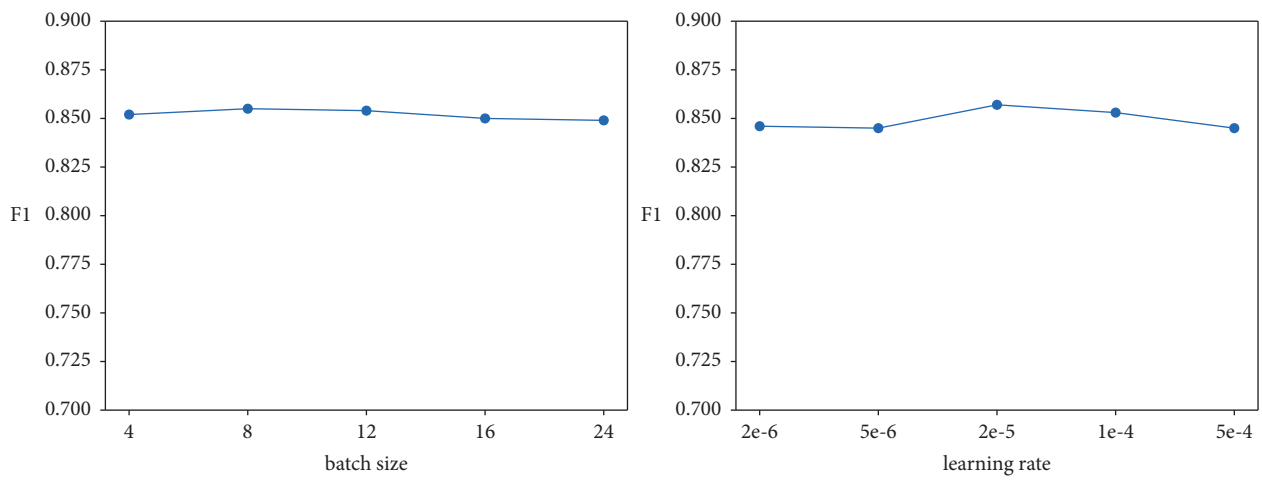


Figure 4: Analysis of different hyperparameter values.

Table 3: Hyperparameter settings.

Name	Value	Meaning
Optimizer name	Adam	Category of the optimizer used in model training
Batch size	8	Size of data trained by the model in each step
Epochs	10	Number of iterations on the training set during model training
Learning rate	2e-5	Learning rate in the optimizer
Dropout rate	0.2	Probability of shielding partial networks

and finally a training set (1346 units) and a test set (336 units) were acquired. The training set aimed to train the model and optimize the model parameters, and the test set aimed to evaluate the model effect.

It was not difficult to find by observing the manually annotated policy instrument samples that serious class unbalance existed among the samples, namely, the proportion of samples belonging to each class in all samples was unbalanced. Figure 5 shows the proportion of different categories in the sample. The class C4 with the largest number of samples accounted for 19.98% of all samples, while the class B1 with the least number of samples only accounted for 1.13%. On the whole, the proportion of class B policy instrument samples was evidently lower than that of the other classes.

Specific to this problem, Focal Loss was experimentally used to optimize the conventional Cross Entropy Loss of the model. This loss function could improve the loss weight of the class with the least number of samples and reduce that of the class with the largest number of samples, to balance the losses of different classes. The concrete calculation formula for Focal Loss is as follows:

$$\mathrm{FL}(p_t) = -(1 - p_t)^{\gamma} p_t, \tag{9}$$

where p_t is the model output of class t, i.e., the probability for a policy instrument to belong to the class t; γ represents a hyperparameter preset by Focal Loss, and the results of grid search for γ are shown in Figure 6. Finally, it appeared that the model effect was the best under γ value of 2.

In the experiment, BERT-base-Chinese was firstly used as a pretrained model, and the final F1 value on the test set was 0.82. Next, the conventional Cross Entropy Loss of the model was optimized using Focal Loss to tackle the class unbalance of policy instrument samples, followed by a further experiment. Finally, the F1 value on the test set was

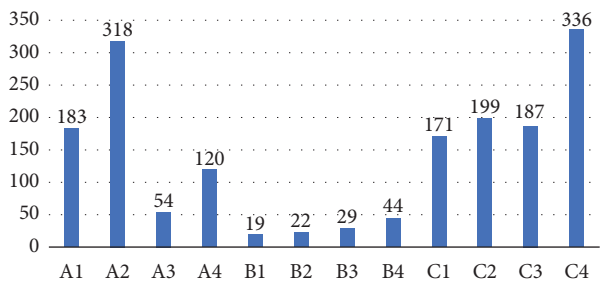


Figure 5: Schematic diagram of the proportion of training data.

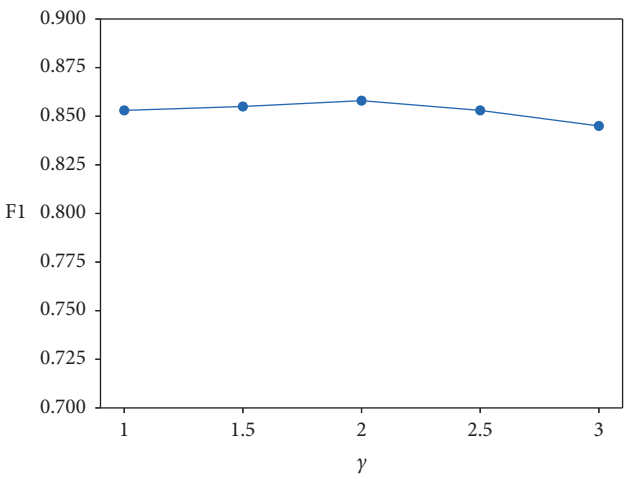


Figure 6: Value analysis of γ.

0.84, increasing by 2 percentages compared with that in the previous experiment.

Subsequently, different BERT modes were comparatively analyzed. Since the parameters in BERT pretraining process were further optimized by roberta model [28], a better effect than the original BERT model was achieved in multiple downstream tasks. Therefore, efforts were also made in this research to replace BERT-base-Chinese model with Chinese-RoBERTa-wwm-ext model to perform a similar experiment. Finally, the F1 value of Chinese-RoBERTa-wwm-ext model on the test set was 0.86, which was 2 percentages higher than the previous prediction effect.

Given this, Chinese-RoBERTa-wwm-ext was finally used as the PLM. The trend of the loss value during the training process of the proposed model is displayed in Figure 7, where the horizontal axis represents the training step and the longitudinal axis denotes the loss value under the current step number. Clearly, the model parameters tended to be converged after 2,000 steps, and the loss value was kept below 0.1 and no longer fluctuated.

The model effect on the test set upon the completion of each iterative step during the training process is exhibited in Figure 8, where the horizontal axis represents the number of iterations already completed in the training process and the longitudinal axis stands for the value of each evaluation index. Therefore, it could be seen that the proposed model gained the best effect after 10 iterations, under which all evaluation indices reached the highest values.

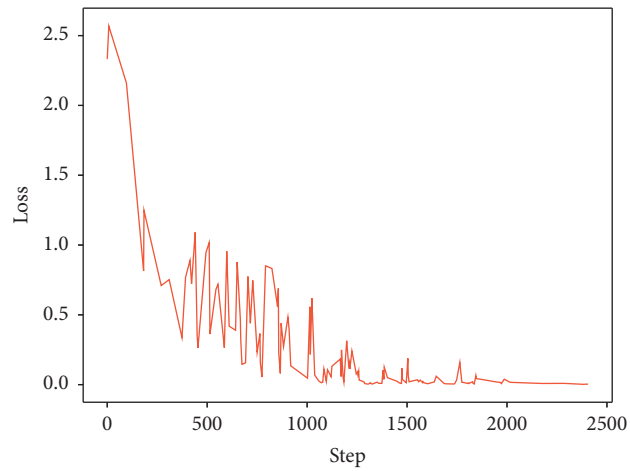


Figure 7: The trend of the loss value.

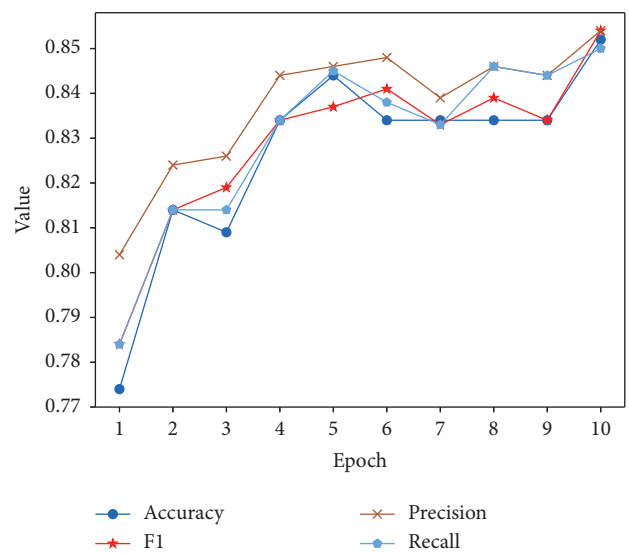


Figure 8: Test effect of the model.

4. Results and Discussion

To further verify the model effectiveness and feasibility, the experimental results obtained by the proposed policy instrument classification model (PLM + MLP) were compared with those achieved by three models (TF-IDF + SVM, TextCNN, and LSTM) performing well in previous studies. The names of the comparison models and their corresponding concrete values are listed in Table 4.

The classification effects achieved by different text classification models are listed in Table 5, among which the last three belong to the proposed classification model (PLM + MLP). The column of pretrained models lists the concrete name of each PLM. Since PLM was not involved in TF-IDF + SVM, TextCNN, or LSTM, these items were left blank.

It could be seen from Table 5 that no matter based on which pretrained model, the PLM + MLP model reached a much better effect than the first three models mainly because the PLM could learn more universal knowledge from large-scale corpora, thus greatly enhancing the text representation

Table 4: Comparative experimental models.

Model name	Meaning
TF-IDF + SVM	Texts are quantified using TF-IDF and text vectors are input into SVM for classification
TextCNN	Word vectors are randomly initialized and input into TextCNN for classification
LSTM	Word vectors are randomly initialized and input into LSTM for classification
PLM + MLP	The PLM-based classification model proposed in this research

Table 5: Comparative experimental results.

Model	Pretrained model	Loss function	Accuracy	F1	Precision	Recall
TF-IDF + SVM	—	CE	0.75	0.74	0.75	0.75
TextCNN	—	CE	0.67	0.66	0.68	0.67
LSTM	—	CE	0.67	0.67	0.71	0.67
PLM + MLP	BERT-base-Chinese	CE	0.82	0.82	0.83	0.83
PLM + MLP	BERT-base-Chinese	Focal	0.83	0.84	0.85	0.83
PLM + MLP	**Chinese-RoBERTa-wwm-ext**	**CE**	**0.85**	**0.86**	**0.86**	**0.85**

ability. This model could achieve a good effect even in the case of a small downstream training data size. Meanwhile, the experimental results revealed that the Chinese-RoBERTa-wwm-ext-based model reached a better effect than the BERT-base-Chinese-based model. This was mainly because the parameters of this model were optimized better in the pretraining stage, and thus this model could learn the representation better than the original BERT model did and harvest a better effect in the downstream tasks of policy instrument classification.

In addition, it was found from Table 5 that the effect of TF-IDF + SVM model was better than that of LSTM and TextCNN mainly for the following reasons: the language is normative in policy texts, and the texts belonging to each class of policy instruments usually include some fixed terms. For example, terms like "talent" and "education" are contained in policy instruments belonging to class A1 (talent cultivation), and these text features can be extracted by TF-IDF very well. Because just a few training corpora were used in this research, TextCNN and LSTM models could hardly train a good word eigenvector on the contrary, which degraded their classification effect to a great extent.

5. Conclusion

In this research, an entrepreneurship policy instrument classification model (PLM + MLP) was established through the PLM-based text analysis technology to realize the automatic classification of entrepreneurship policy instruments. Finally, the F1 value on the test set reached 0.86, manifesting a satisfactory classification effect. Hence, this model is applicable to the research on national-level entrepreneurship policies and to the classification of local entrepreneurship policy instruments in China. If used, this type of automatic classification algorithm can greatly improve the classification efficiency and objectivity for policy instruments, thus rendering a new idea for studying entrepreneurship policies and more generalized policy instruments.

However, the accuracy of the classification model of policy instruments has not been further discussed in this study. On the one hand, the policy text is divided into the units of analysis of policy instruments according to paragraphs, which is rather crude. Since the structure of policy texts issued by different publishing agencies is quite different, it is difficult to achieve accurate segmentation of policy instruments through a common rule for all policy texts. In this study, policy instruments are segmented according to newline characters, and this simple segmentation method will have a certain impact on the prediction results. On the other hand, in view of the category imbalance problem in entrepreneurial policy tools, this study does not further discuss the optimization of loss function. Therefore, the follow-up study will try to continue in large-scale policy text corpus BERT model training and optimization, to increase the BERT model related knowledge in the field of policy. In order to further improve the efficiency of policy text classifier, the division of policy instruments analysis unit and the imbalance of policy tool categories are optimized.

Data Availability

The data for this study are obtained upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Social Science Fund of China (18BJL39) and Key Course Project of Shanghai Education Commission (s202108002).

References

[1] N. D. William, *An Introduction to the Analysis of Public Policies*, China Remin University Press, Beijing, China, 2002.

[2] J. Zhang, *A Study on Building Public Services in the New Countryside from the Domain of Market-Based Policy Instruments*, Guangxi Normal University, Guilin, China, 2011.

[3] M. Howlett, "Government communication as a policy tool: a framework for analysis," *Canadian Political Science Review*, vol. 3, no. 2, pp. 23–37, 2009.

[4] Y. A. Zhang, Z. Geng, and Y. N. Wang, "Regional scientific and technological innovation policy classification and policy instrument mining: a research based on the data of Zhongguancun," *Science & Technology Progress and Policy*, vol. 32, no. 11, pp. 116–122, 2015.

[5] M. Huang, G. L. Zhu, and J. Y. Hu, "On classification, selection and evaluation of innovation policy instruments," *Forum on Science and Technology in China*, vol. 1, pp. 26–30, 2016.

[6] C. X. Zhou, M. J. Li, and H. Lin, "Research of regional strategic emerging industry policy analysis framework," *Studies in Science of Science*, vol. 35, no. 3, pp. 346–353, 2017.

[7] K. S. Kalyan, A. Rajasekharan, and S. Sangeetha, "Ammus: A Survey of Transformer-Based Pretrained Models in Natural Language Processing," 2021, https://arxiv.org/abs/2108.05542.

[8] Y. S. Kim, H. J. Song, and J. Han, "A deepfake-based deep learning algorithm for medical data manipulation detection," *Journal of System and Management Sciences*, vol. 12, no. 1, pp. 13–24, 2022.

[9] C. M. Dumitrescu and I. Dumitrache, "Combining deep learning technologies with multi-level gabor features for facial recognition in biometric automated systems," *Studies in Informatics and Control*, vol. 28, no. 2, pp. 221–230, 2019.

[10] X. Qiu, T. Sun, Y. Xu, Y. Shao, N. Dai, and X. Huang, "Pretrained models for natural language processing: a survey," *Science China Technological Sciences*, vol. 63, no. 10, pp. 1872–1897, 2020.

[11] K. Kowsari, K. Jafari Meimandi, and M. Heidarysafa, "Mendu , Barnes , Brown Text classification algorithms: a survey," *Information*, vol. 10, no. 4, p. 150, 2019.

[12] A. I. Kadhim, "Survey on supervised machine learning techniques for automatic text classification," *Artificial Intelligence Review*, vol. 52, no. 1, pp. 273–292, 2019.

[13] M. Iyyer, V. Manjunatha, J. Boyd-Graber, and H. Daumé, "Deep unordered composition rivals syntactic methods for text classification," in *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing*, pp. 1681–1691, Beijing, China, July 2015.

[14] T. Song, J. Sun, Y. Zhang, W. Peng, and J. Song, "An RNN model for generating sentences with a desired word at a desired position," *Tehnicki vjesnik-Technical Gazette*, vol. 27, no. 1, pp. 81–88, 2020.

[15] J. W. Choi and E. R. Jeong, "Genicular artery embolization: beyond the placebo effect, and planning for the long road ahead," *Journal of Vascular and Interventional Radiology: Journal of Vascular and Interventional Radiology*, vol. 33, no. 1, pp. 11–13, 2022.

[16] M. A. Kilvisharam, S. Poruran, and M. Y. Caffiyar, "A novel deep convolutional neural network architecture based on transfer learning for handwritten Urdu character recognition," *Tehnicki vjesnik-Technical Gazette*, vol. 27, no. 4, pp. 1160–1165, 2020.

[17] A. Vaswani, N. Shazeer, N. Parmar et al., "Attention is all you need," 2017, https://arxiv.org/abs/1706.03762.

[18] M. E. Peters, M. Neumann, M. Iyyer et al., "Deep contextualized word representations," 2018, https://arxiv.org/abs/1802.05365.

[19] J. Devlin, M.-W. Chang, K. Lee, and K. Toutanova, "Bert: pretraining of deep bidirectional transformers for language understanding," 2018, https://arxiv.org/abs/1810.04805.

[20] S. Y. Lin, Y. C. Kung, and F. Y. Leu, "Predictive intelligence in harmful news identification by BERT-based ensemble learning model with text sentiment analysis, Information Processing & Management: Libraries and Information Retrieval Systems and Communication Networks:," *An International Journal*, vol. 2, no. 59, 2022.

[21] V. D'Orazio, S. T. Landis, G. Palmer, and P. Schrodt, "Separating the wheat from the chaff: applications of automated document classification using support vector machines," *Political Analysis*, vol. 22, no. 2, pp. 224–242, 2014.

[22] R. R. Krebs, "How dominant narratives rise and fall: military conflict, politics, and the cold war consensus," *International Organization*, vol. 69, no. 4, pp. 809–845, 2015.

[23] C. Chang and M. Masterson, "Using word order in political text classification with long short-term memory models," *Political Analysis*, vol. 28, no. 3, pp. 395–411, 2020.

[24] R. Pujari and D. Goldwasser, "Understanding politics via contextualized discourse processing," 2020, https://arxiv.org/abs/2012.15784.

[25] A. Mukherjee, S. Bhattacharyya, K. Ray, B. Gupta, and A. K. Das, "A study of public sentiment and influence of politics in COVID-19 related tweets," *Computational Intelligence in Pattern Recognition*, pp. 655–665, Springer, Singapore, 2022.

[26] X. Wang, B. Guo, and L. Su, "Analysis on the evolution of Shanghai's science and technology policy based on content analysis," *Science and technology progress and countermeasures*, vol. 29, no. 23, pp. 104–107, 2012.

[27] Y. Li, S. Wu, and F. Gao, "Changes, evaluation and trend of research funds management policy in China since the reform and opening up -- based on the content analysis of policy text," *Studies in science of science*, vol. 27, no. 10, pp. 1441–1447, 2009.

[28] Y. Liu, M. Ott, N. Goyal et al., "Roberta: a robustly optimized bert pretraining approach," 2019, https://arxiv.org/abs/1907.11692.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9128819, 8 pages
https://doi.org/10.1155/2022/9128819

Research Article

The Evolution of Ecological and Environmental Governance Attention Allocation in J City Based on Big Data Analysis

Jing Gao [1] **and Yuhan Sun** [2]

[1] *Jilin Institute of Chemical Technology, Jilin, China*
[2] *Harbin Institute of Technology (Shenzhen), Shenzhen, China*

Correspondence should be addressed to Jing Gao; a15804320278@163.com

Received 2 June 2022; Accepted 6 October 2022; Published 12 October 2022

Academic Editor: Emilio Jiménez Macías

Analysing the evolution process of attention allocation in city governance is an effective way to understand modern governance. Among the city types, heavy industry cities are special cities. It relies too much on heavy industry and is difficult to achieve ecological and environmental governance. This study takes J City in Northeast China as an example. Based on big data analysis, this study analyses the evolution process of governance attention allocation in J City. It can be found that the realization of ecological and environmental governance requires people's participation. City development needs multiple synergies and an ecosystem-led governance model. However, this process is not a subjective product but needs to be promoted by history. Fundamentally, people need to change the logic of economic development.

1. Introduction

Attention allocation is an important theory to understand modern governance. In the governance agenda, there will be competition between different affairs, distracting leaders' attention. The preconditions of this theory are limited rationality, incomplete information, and social participation. In governance, whether a public affair can occupy the agenda fundamentally depends on people's conceptual understanding of the affair [1]. The cognitive change of this concept leads to a change in attention allocation. For the governance system itself, attention allocation should keep pace with the times. In the era of increasingly widespread ecological and environmental crises, the government needs to get rid of traditional administrative and economic thinking. Thus, this change can promote more sustainable governance. The transition to sustainability remains an important direction in the future [2]. This change in attention allocation is a meso-theory. It is not a visual meaning, but a historical concept. As long as a few people make decisions, attention is limited. For the government, they must find effective information in a large amount of information. This represents the problem domain and response domain of governance.

To understand this complex scope problem, we should not rely on a traditional questionnaire survey and statistical technology but should use big data collection and analysis methods [3]. In this way, people can better understand how the governance subject completes knowledge matching [4]. At the same time, people can also understand the production process of government decision-making to reasonably control their actions. Of course, the use of big data itself needs to be managed. It is not only a tool to understand governance but also the object of governance. In terms of method application, big data analysis has rich data sources. For example, under the framework of legal norms, the government can manage cities by collecting data traffic from mobile phones, sensors, and applications [5]. But this must be strictly authorized. The government must guarantee people's privacy. At the same time, the government should enhance the openness of information. People and governments should adapt to the changes in the era of big data [6]. Big data is also abused by some enterprises [7]. This is an

irregular action. Through information disclosure, people can understand the government and supervise the government. Ultimately, people will choose to participate in governance. The governance cost of the government will be reduced. In addition, big data is a fuzzy dataset. But big data is also a potential research material. It brings opportunities and challenges to today's governance actions. And it has promoted the process of urbanization and changed the distribution mode of materials [8]. For individuals, big data has also changed their understanding of health [9]. This is inseparable from ecological and environmental governance. Humans must be a part of the ecosystem. For researchers, big data is not entirely a quantitative analysis method. The black box problem of big data needs to be solved by qualitative analysis. This makes mixed research possible. This possibility has been explored and improved. For example, in some research on companies [10], this study will also provide a qualitative understanding of attention allocation based on big data.

In general, the contributions of this study mainly include three aspects. First, this study provides quantitative and qualitative evidence for understanding China's ecological and environmental governance. These materials and analysis results are helpful for people to understand how China realizes the transformation of its economic development mode. Second, this study can help people understand the rules of action of the Chinese government, including the advantages and limitations of the Chinese administrative model. It will help people to further improve the government's working mode and work efficiency. Third, this study provides a reference for researchers on how to deal with big data. This article attempts to interpret big data from the perspective of attention allocation. This approach gives full play to the characteristics of big data while incorporating the limited rationality of human beings into the information transmitted by data. In this way, people can better feel the relationship between nature and society and understand the discrete power of natural and social development.

Focusing on the research objectives and questions, the researchers organized the research work into four parts. First, researchers need to extensively study and discuss the general theory of big data and government attention distribution, and propose the basic norms for big data collection and analysis. Second, according to the research plan, the researchers will take the big data published by the government as the scope of material collection. This can avoid ethical disputes and establish a bottom-up perspective. Third, researchers choose to use an intuitive and low-level hybrid research method to analyse big data (including text and numbers), which can avoid the omission and distortion of materials by researchers and special research methods to the greatest extent. Fourth, the researcher reintroduces the analysis results into the history of China's city development to explore the development process of the Chinese government's model of ecological and environmental governance. In this way, this research can ensure the unity of logic and history.

2. Materials and Methods

2.1. Materials. This study selects J City in Northeast China as a case for in-depth research. There are some reasons for choosing J City as the research object. First of all, J City is a famous city in Northeast China, with a rich history, culture, and natural resources. In terms of city size, J City is the second-largest city in the J Province of China. By the end of 2020, the resident population of J City was about 3.5 million. In recent years, J City has insisted on the city construction and development orientation of an Ecological Liveable City. Moreover, the development of J City has integrated more ecological and environmental governance content. However, J City is a heavily industrial city. At the same time, after entering the 21st century, the relative development speed of Northeast China is low. In Northeast China, the development strategies and public policies of many cities have fallen behind the times. This is similar to the situation in many parts of the world. One of their common features is the limitation of the governance model. J City has an important chemical industry in China. On the one hand, this has caused economic dependence; on the other hand, it has also caused environmental pollution. Heavy industry breaks the relationship between nature and society. In history, the ecological and environmental governance model of J City can be summarized into three periods. The first is the period of pollution control and environmental restoration. The second is the period of coordinated development of the ecological environment and industrial economy. The third is the modern era led by the construction of tourism culture and the transformation and upgrading of heavy industry. Therefore, J City is fully typical. Through an in-depth study of the evolution process of ecological and environmental governance in J City, this study can put forward a new and scientific governance model.

2.2. Methods. In terms of research methods, this study integrates two theories.

The first is big data analysis. The validity of data represents the science of research. Through big data collection and statistics, this study can provide visual results. At the same time, the big data analysis method has the unique advantage of integrating multiple factors. It can directly and effectively evaluate the complex ecological environment. In this regard, there have been some research results. For example, people can integrate big data to scientifically evaluate the ecological quality of their environment [11, 12]. Even so, people can use big data to realize real-time management of cities [13]. It can be predicted that big data will improve human cognitive ability in another dimension. It allows human attention to enter the interior from the exterior of various events. It can be said that the big data method is not only the telescope of human society but also the microscope of human society.

The second is the attention allocation theory. The theory of attention distribution based on limited rationality is often used to study governance problems [14–16]. Understanding

the evolution of J City's governance model also needs to be based on the limited rationality of the government, the complexity of information, and the scarcity of attention. Because the government's attention allocation strategy and attention to certain matters can reflect the government's strategic thought and action line, and ultimately affect the development direction of the city. In fact, under the complex effects of multiple factors, such as domination, interaction, and concurrency, the attention allocation of local government governance activities is a dynamic change process, and the degree of attention allocation change and action change made by different local governments to the situation change is also very different. Therefore, from the perspective of attention allocation, exploring city development can better reflect the behavioural logic of government governance and enhance the reliability of the analysis.

In general, according to the characteristics of big data and the theory of attention allocation, researchers hope to adopt alow-level strategy to expand a hybrid research method. In the process of gaining a preliminary understanding of J City, because the focus of the discussion is to find the problems in J City and explain the particularity (including history and present) and representativeness of J City as a heavy industrial city, descriptive analysis is adopted. Based on the preliminary understanding of J City, the researchers found that J City is still in the transition stage from management to governance. It is at this transitional stage that people can fully understand why ecological and environmental governance can represent the modern governance model and why governance is superior to management. In such a complex situation, the government cannot take all matters into account, so there will be a problem of attention scarcity and attention allocation. To solve this problem, the researchers used priority perspective and quantitative methods to trace the historical development of J City. Finally, a general development process is given by integrating logic and history. The following picture is a visual research design (see Figure 1).

3. Results and Discussion

3.1. Basic Characteristics of Governance Problems in J City

3.1.1. The Citation of Governance According to Law Lacks Local Characteristics. In terms of governance by law, according to the information of China's authoritative legal website (https://www.pkulaw.net/), it can query the legal content of a certain aspect. This study finds that, in addition to national laws and provincial regulations, the governance characteristics of J City also come from local regulations and normative documents related to environmental protection by 2021 (see Table 1).

This study collects the text data of 376 environmental punishment decisions published on the website of the ecological environment department of J City from April 7, 2015 to February 5, 2021 (see Figure 2).

The difference in the proportion of governance citations shows that the degree of localization of governance in J City is not high. This result is reflected in that although J City can independently formulate some new local regulations and normative documents, they cannot be widely used in governance actions. At the same time, it also reflects that J City, as a heavy industrial city, is still in the stage of environmental restoration rather than construction. Therefore, local regulations and normative documents in J City are difficult to use directly to control pollution. J City still needs heavy industry, especially the state-owned industrial sector, to promote economic growth.

3.1.2. Unfairness Reflected in Punishment Results. The ecological environment department of J City released a document on February 25, 2021. This document is about the list of 70 key pollutant discharge enterprises in J City in 2021. The study compared 70 enterprises with 376 environmental punishment decisions. The results show that the matching rate is less than 5%. Therefore, most of the objects of environmental punishment are not key pollutant discharge enterprises, but individuals or other not key pollutant discharge enterprises.

Since 2019, the world economy has suffered from the impact of COVID-19. In order to prevent data distortion caused by this impact, the study added some new evidence.

The ecological environment department of J City publishes the list of sampling inspections in each quarter in the "pollution source supervision" column on the website. The study compared sample inspection lists from 2017 to 2021. The results show that the inspection times of key pollutant discharge enterprises account for only 7% to 22% of the total inspection times. This is an unfair result of punishment. In general, J City ignores heavy industrial enterprises in terms of ecological and environmental protection. However, J City needs heavy industrial enterprises in terms of the economy. In particular, J City is difficult to deal with state-owned heavy industrial enterprises. And it reflects a mechanism loophole in the governance of J City.

3.1.3. People's Willingness to Participate in Governance Is Not High. In China, conceptual innovation is abundant. In order to promote people's participation in governance and strengthen the degree of democratization, J City has established some organizations. For example, J City has built a platform of people talking (PPA). The function of this platform is to collect people's livelihood information and resolve contradictions. And this platform includes five specific contents (see Figure 3).

This study collected 953 data points from the message board of the J City website from January 2020 to March 2021 (see Figure 4). This time frame is the maximum that can be obtained by this study. Because China's local government information disclosure system is not perfect. This study found that people in J City are most concerned about construction. However, there are a lot of complaint messages. This proportion is about 50%. Second, people pay attention to the traffic problems in J City. In the total number of messages, the number of environmental protection information ranks third. People can directly see that among the subdivided types of environmental protection messages,

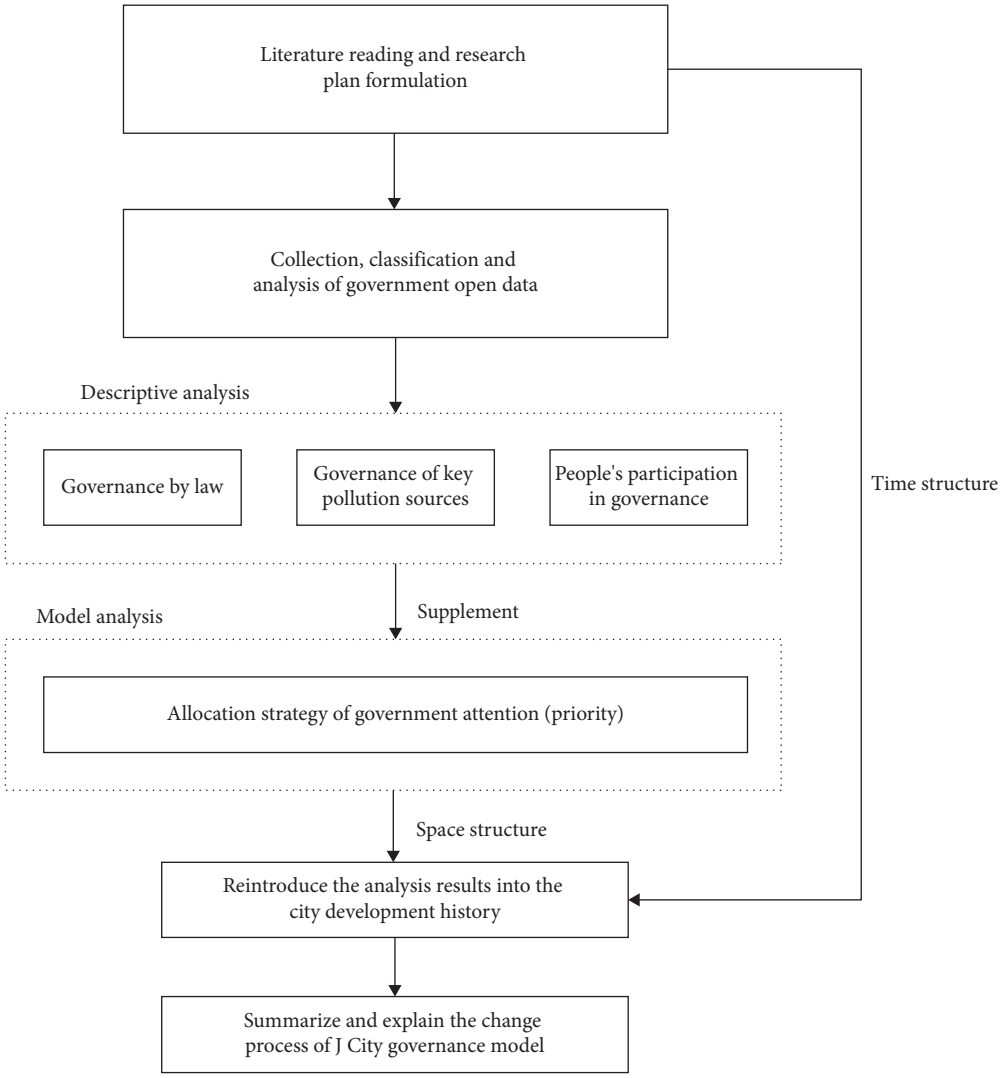


Figure 1: Research design.

Table 1: Themes of ecological and environmental governance in J City.

Number	Local regulations	Normative documents
1	River management	No-waste city
2	Greening problem	No straw burning
3	Protection of water and land resources	No fuel vehicles
4	City garden management	Air pollution control
5	Protection of forest	Water pollution control
.....	.....	.....

the number of complaint messages is the largest. This proportion is about 68%. In contrast to this phenomenon, people put forward a lot of suggestions in the messages of traffic themes. This proportion is about 44%. The results show that people in J City have some dissatisfaction with construction and environmental protection. In addition, people's willingness to participate in construction and environmental protection is not high. The problem is that the governance tools of J City, like the PPA, do not give people enough rights. However, they have prematurely emphasized the responsibility of people to participate in governance. When the economic development model is bound by state-owned heavy industry, people cannot put forward suggestions.

3.2. The Evolution of Governance Attention Allocation. J City is a typical heavy industrial city in Northeast China. Before China's economic reform and opening up, J City had an important position. However, with the reform and opening-

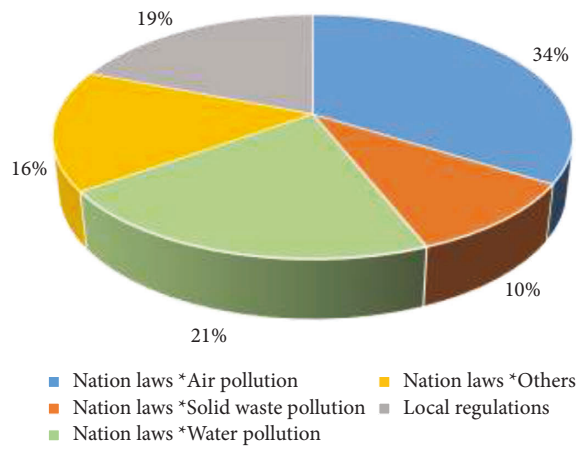


Figure 2: Localization degree of punishment citation.

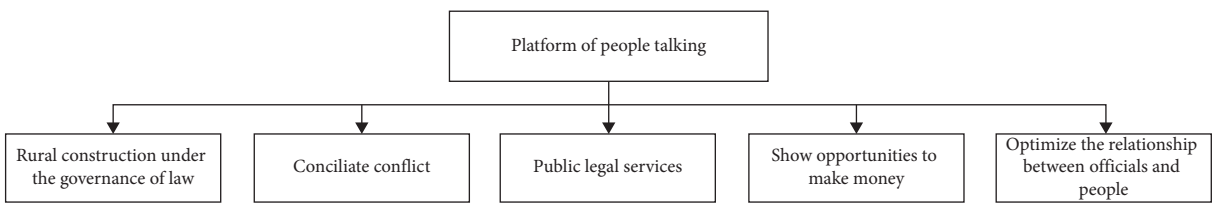


Figure 3: Platform of people talking in J City.

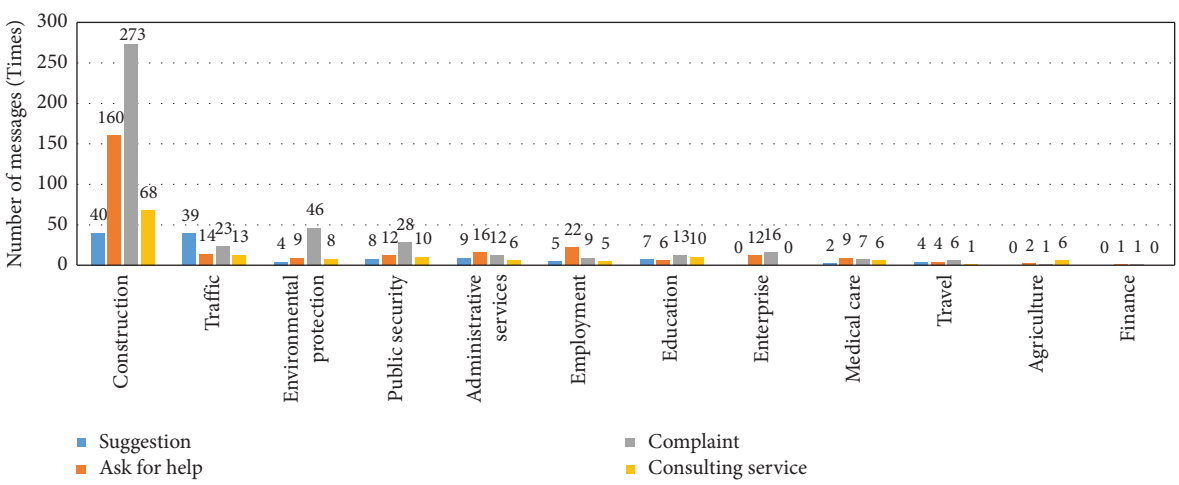


Figure 4: Statistics of people's messages to government departments in J City.

up, the relative development speed of J City in Chinese cities is becoming slower and slower. There is an important law in China's administration. It refers that in the official government report, the order of contents represents the importance of contents. Therefore, this study collected the statistical yearbook of J City from 1998 to 2017. This study constructs a simple mathematical model. It is referred in the following equation. This model can make the government's attention allocation visible.

$$\text{Degree of importance} = 1 - \frac{\text{Location of content}}{\text{Total number of content categories}}. \quad (1)$$

After calculation, this study gives a linear simulation of the attention allocation of J City government (see Figure 5). The lack of data represents the disappearance of the column, which proves that the J City government did not report this work in a certain year. Isolated points represent the sudden emergence of a work. For the sake of picture clarity, the degree of importance of the last content is set to 0.05 in this study. In addition, some special cases are found in the calculation process of this study. There are some discrete works, just like welfare and charity, legal aid, and ethnic minorities, etc.

In the recent report, food safety, consumer rights and interests' protection, resources, and the environment and basic organization construction have been shown. Among

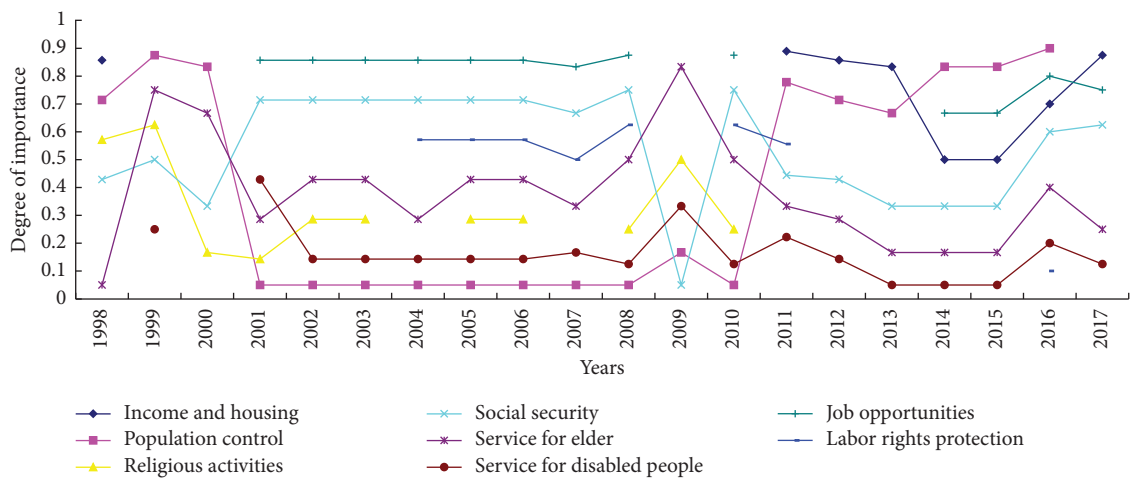


Figure 5: Evolution process of governance attention in J City.

them, because food safety and consumer rights protection are not continuous, it cannot affect the allocation of government attention. This is an important shortcoming of the report of the J municipal government. This study analyses three governance models in J City in different periods. Before 2000, J City implemented the traditional administrative leading governance with population control as the theme. During this period (1997–1998), large-scale layoffs occurred in China's state-owned enterprises. From 2001 to 2008, J City used job opportunities as the theme of the governance model. After 2011, the governance model of J City entered the stage of multiple synergies. The main governance contents of this stage include family wealth, population control, increasing job opportunities, and ecological and environmental governance. In the last five years, J City has gradually taken ecological and environmental governance as its model. However, due to the impact of COVID-19, this data has not been given. It emerged as a part of the multiple synergy governance models. From the perspective of the historical process, this evolution process from economy to ecology is enough as evidence.

3.2.1. Population Control: The Administrative-Led Governance Model. Before 2000, reducing the population growth rate was one of the most important national policies. In J City, population control has become the top priority of the government. This work involves a lot of political factors rather than economic factors. Therefore, under the special performance guidance, local governments are subject to strict assessment. Moreover, population control has also become a reward for local governments. So, local governments often express it in the report in the form of reaching the standard, exceeding the quota, and so on. Population control was the theme of J City in this period. But with the advent of the 21st century, this work has becomes less and less important. For example, there is a statement in the 1999 report of J city. The result of J City government statistics is that the natural population growth rate is 4.28‰ lower than the plan. In addition, the report emphasizes that the population control department of J city has won honours. However, in the 2001 report of J City, this expression has changed. According to the statistics of J City government, the natural population growth rate is 4‰ lower than the plan required by the superior department. In the 2003 report of J City, this kind of expression has changed again. In this report, J City only proposed that they had completed the requirements of the superior department. In addition, J City has no more expressions. To sum up, the above process shows that population control has been completed. J City governance no longer needs to create political performance through population control. This represents the end of the administrative-led governance model. J City must turn its attention to economic work in order to deal with the high unemployment rate.

3.2.2. Job Opportunities: The Economic-Led Governance Model. From 2001 to 2008, the governance of J City emphasized the provision of more job opportunities. In this way, they can ensure the social stability of J City. During this period, the governance of J City reflected its economic characteristics. First, J City pays more attention to people's basic demands for a better life, emphasizing that people's lives are the fundamental goal of city development. Second, the governance of J City is integrated into China's reform and opening-up strategy to a greater extent. Officials in J City can pay attention to emancipating the mind. Moreover, they began to use some new methods to solve social problems. At this time, J City implemented some new public policies. Third, J City pays more attention to the role of the market mechanisms. J City began to use market tools to promote city construction and adjust city development with market methods. Fourth, J City has effectively promoted the progress of labour security supervision, vocational skills training, and other work. Fifth, J City has activated the long-term mechanism of the social security system in the process of city development. Therefore, the governance of J City has reduced the level of social risk. It is worth noting that during this period, "labour rights protection" appeared in the governance of J City. This proves that the market itself has the problem of "market failure". Due to the lack of social

forces, J City returns to the administrative-led governance model for a short time. This brief retrogression shows the lack of resilience in the governance of J City. Moreover, it indirectly leads to some city problems. For example, getting old before getting rich, having fewer children, and population loss, etc.

3.2.3. Multiple Synergy: The Ecosystem-Led Governance Model. After 2011, the governance model of J City changed from economic dominance to ecosystem dominance. Moreover, this governance model reflects the characteristics of multiple synergies. During this period, the problems of income and housing, population, and employment became the key areas of the development of J City. At the same time, ecological and environmental governance have become new leading factors. This ecosystem is embodied as a logically closed loop. In the first place, income and housing levels affect family fertility strategies and training strategies in terms of population. Second, fertility strategies and training strategies affect the distribution of family investment in all aspects of children, which affects the employment quality of future generations. Third, the level of employment quality affects the level of income and housing. Importantly, under this logical framework, the concept of fewer and better children in the family planning era is deeply rooted in the hearts of the people. Not only does "fewer children" weaken the effect of population on economic growth, but also it merges with the triple trend of high-quality population outflow and population aging under "better children," which poses a challenge to city development.

4. Conclusions

The rational allocation of governance attention comes from people's participation. After people's participation, management will become governance. Costs will fall. The political performance will improve. However, this participation is not a subjective product. It is limited by the time. Under the administrative-led governance model, it is difficult for people to participate in governance. Under the economic-led governance model, people began to participate in governance. But people are hampered by tradition. Only in the governance mode led by the ecosystem can people be liberated. This is a harmonious relationship between humans and nature. For ecological and environmental governance, it cannot appear independently. In fact, it is a special economic logic. And it serves the coexistence of humans and nature. It can be found that the economy and nature do not conflict. In J City, city development relies too much on heavy industry. However, this approach will be changed. It has experienced a process from singleness to multiple synergies. This is in line with the law of history. Overall, the government needs to be more open and inclusive. The governance system should guarantee people's rights. People's opinion can be produced, especially under the condition of information disclosure. The government's attention can be shifted to people's real needs.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the research topic of higher education teaching reform of Jilin Institute of Chemical Technology in 2022 "Research on the influencing factors of university students' green entrepreneurship orientation" (Project Principal: Jing Gao).

References

[1] P. Alexandrova, "Explaining political attention allocation with the help of issue character: evidence from the European council," *European Political Science Review*, vol. 8, no. 3, pp. 405–425, 2016.

[2] N. Frantzeskaki, D. Loorbach, and J. Meadowcroft, "Governing societal transitions to sustainability," *International Journal of Sustainable Development*, vol. 15, no. 1/2, pp. 19–36, 2012.

[3] G. George, E. C. Osinga, D. Lavie, and B. A. Scott, "Big data and data science methods for management research," *Academy of Management Journal*, vol. 59, no. 5, pp. 1493–1507, 2016.

[4] M. R. Haas, P. Criscuolo, and G. George, "Which problems to solve? Online knowledge sharing and attention allocation in organizations," *Academy of Management Journal*, vol. 58, no. 3, pp. 680–711, 2015.

[5] A. Manzoor, C. Patsakis, A. Morris et al., "CityWatch: exploiting sensor data to manage cities better," *Transactions on Emerging Telecommunications Technologies*, vol. 25, no. 1, pp. 64–80, 2014.

[6] R. W. Lake, "Big Data, urban governance, and the ontological politics of hyperindividualism," *Big Data & Society*, vol. 4, no. 1, Article ID 205395171668253, 10 pages, 2017.

[7] W. Fang, X. Z. Wen, Y. Zheng, and M. Zhou, "A survey of big data security and privacy preserving," *IETE Technical Review*, vol. 34, no. 5, pp. 544–560, 2017.

[8] J. Grayson, "Big data analytics and sustainable urbanism in Internet of Things-enabled smart governance," *Geopolitics, History, and International Relations*, vol. 12, no. 2, pp. 23–29, 2020.

[9] S. Holm and T. Ploug, "Big data and Health Research-the governance challenges in a mixed data economy," *Journal of bioethical inquiry*, vol. 14, no. 4, pp. 515–525, 2017.

[10] K. N. A. Arthur and R. Owen, "A Micro-ethnographic study of big Data-Based Innovation in the financial services sector: governance, ethics and organisational practices," *Journal of Business Ethics*, vol. 160, no. 2, pp. 363–375, 2019.

[11] F. He, L. Gu, T. Wang, and Z. Zhang, "The synthetic geo-ecological environmental evaluation of a coastal coal-mining city using spatiotemporal big data: a case study in Longkou, China," *Journal of Cleaner Production*, vol. 142, no. 142, pp. 854–866, 2017.

[12] X. Li, H. Zhang, J. Yu, Y. Gong, X. Guan, and S. Li, "Spatial-temporal analysis of urban ecological comfort index derived

from remote sensing data: a case study of Hefei, China," *Journal of Applied Remote Sensing*, vol. 15, no. 04, Article ID 042403, 2021.

[13] R. Kitchin, "The real-time city? Big data and smart urbanism," *Geojournal*, vol. 79, no. 1, pp. 1–14, 2014.

[14] Q. Meng and Z. Fan, "Punctuations and diversity: exploring dynamics of attention allocation in China's E-government agenda," *Policy Studies*, vol. 43, no. 3, pp. 502–521, 2022.

[15] L. He, L. Huang, and G. Yang, "Invest in innovation or not? How managerial cognition and attention allocation shape corporate responses to performance shortfalls," *Management and Organization Review*, vol. 17, no. 4, pp. 815–850, 2021.

[16] Z. Liao, J. Lu, Y. Yu, and Z. J. Zhang, "Can attention allocation affect firm's environmental innovation: the moderating role of past performance," *Technology Analysis & Strategic Management*, vol. 34, no. 9, pp. 1081–1094, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7981885, 10 pages
https://doi.org/10.1155/2022/7981885

Research Article

Development of Comprehensive Evaluation Model of Free Trade Port Investment under Macroeconomic Support

Haitian Zhang and Wang Benxue

Quzhou University, Quzhou, China

Correspondence should be addressed to Wang Benxue; 11012@qzc.edu.cn

Received 14 July 2022; Revised 1 September 2022; Accepted 20 September 2022; Published 11 October 2022

Academic Editor: Lele Qin

The financial benchmark rate of return is gradually declining, and the free trade port policy is not enough to improve the investment financial benchmark rate of return. Therefore, a comprehensive evaluation model for free trade port investment under the support of macroeconomics is proposed. A theoretical model of free trade port investment price fluctuations and monetary policy response is constructed under the support of macroeconomics, and the model is used to observe the impact of changes in free trade port investment prices on the economic effects of monetary control policies; thus, free trade port investment price fluctuations are constructed and as a result, a theoretical model of investment price fluctuations and interest rate policy responses in the free trade port is constructed to observe the impact of changes in investment prices in the free trade port on the economic effects of interest rate regulation policies; a theoretical model of investment and fiscal and taxation policy responses in the free trade port is constructed to observe the impact of changes in investment in the free trade port on the economic effects of fiscal and taxation policies. Explore the path of optimizing the comprehensive investment evaluation environment in the pilot free trade zone, and realize the development of a comprehensive evaluation model for investment in the free trade port. The experimental results show that the model can realize the comprehensive evaluation of free trade port investment under the support of the macroeconomy and has a good evaluation effect.

1. Introduction

Building a free trade port is the basic requirement for the country to participate in international economic integration at a high level and in a deep range. Hainan has the first free trade port to be completed in China. Without the reference of other mature trade reference and management systems, there are still many drawbacks that need to be improved in the development process of the free trade port policy, especially, with the support of the macroeconomy, the free trade port policy plays a major role in the institutional framework [1, 2]. Further analysis of the free trade port policy of the free trade port has a very important theoretical value and practical significance and has played a great role in establishing a complete set of comprehensive investment evaluations and financial management mechanisms for the Hainan free trade port [3, 4]. However, the construction history of the free trade port is relatively short compared with the international community, and there is a lack of experience accumulation. The existing investment comprehensive evaluation model cannot fully meet the development needs of the free trade port policy [5, 6]. We must learn from the experience of the developed countries in the world and combine the actual situation of the free trade port policy to study its impact on the financial benchmark rate of return. It plays a positive role in improving the financial benchmark rate of return of the free trade port.

Tang et al. [7] put forward a comparative analysis of locational factors and their external influence on free trade port zones in China. This study analyzes the locational factors of the Shanghai and Ningbo-Zhoushan free trade ports using an econometric model. The corresponding external influences of locational factors are examined as well. Based on our analysis and comparison of the location characteristics and locational value of the Shanghai and Ningbo-Zhoushan free trade ports, three constructive

suggestions are made to enhance the locational value of free trade ports based on the actual situation of the Ningbo-Zhoushan free trade port. These suggestions can also maximize the value of free trade ports' locations and promote high-quality regional economic growth. The results show that the regional economic development level, industrial structure, institutional policies, market scale, market consumption potential, and market openness are important factors affecting the location value of the free trade zone. Tang et al. [8] put forward the value element system and development path of free trade port location, gave the element system of the location value of Ningbo-Zhoushan Port Bonded Port, analyzed the elements and influencing factors that affect the location value of the bonded port, and constructed the location value evaluation system of the bonded port. Using the factor analysis method, this paper makes an empirical analysis of the location value of Ningbo-Zhoushan port and nine major ports in China. Finally, the specific development path of Ningbo-Zhoushan port is given. The research shows that analyzing the factor system and development path of the free trade zone will help to improve the value-added capacity of the free trade port and promote the development of the regional economy [9, 10]. Although the above research has made some progress, in order to consider the policies supported by the macroeconomy, it is still necessary to clarify the construction objectives, specific positioning, key tasks, opinions, and practical measures of the free trade port. With the impact of the free trade port policy on the financial benchmark rate of return as the theme, further study the influencing factors of the financial benchmark rate of return, to improve the comprehensive benchmark yield of free trade port investment.

2. Research Method

2.1. Theoretical Model of Investment Price Fluctuation and Monetary Policy Response in Free Trade Port. Monetary policy is a combination of macrodemand and management, which plays an important role in the financial management system of the investment industry. The ultimate goal of monetary policy is the purpose of direction and the core of the function of the banking system. The ultimate goal of monetary policy will change with the country's economic situation. With the support of macroeconomy, build a theoretical model of investment price fluctuation and monetary policy response of free trade port, regard the model as a small macroeconomic system, and observe the impact of changes in investment price of free trade port on the economic effect of monetary control policy [11, 12].

When constructing the theoretical model of investment price fluctuation and monetary policy response of free trade ports, we need to comprehensively consider commodity prices, macromonetary control policies, and their actual influencing factors [13–15]. The model is an economic system including an inflation equation, currency equation, investment equation, and consumption equation.

First, based on the absolute income theory, the consumption equation is constructed by considering the wealth factor, as shown in the following formula:

$$A_{SD} = \alpha_1 \times V_Z + \alpha_2 \times V_X + \alpha_3 \times V_Y. \quad (1)$$

In formula (1), V_Z represents the total consumption in Z period, V_X represents the investment commodity price in X period, V_Y represents the basic investment raw material commodity price in Y period, α_1 represents the corresponding action delay of the wealth effect of the basic investment commodity price in the first period, α_2 represents the corresponding action delay of the wealth effect of the basic investment raw material commodity price in the first period, and α_3 represents the corresponding action delay of the wealth effect of the investment commodity price in the third period.

Consider the interest rate variable to build the following investment equation:

$$H_{ZXY} = \lambda_1 \times W_A + \lambda_2 \times W_B + \lambda_3 \times W_C. \quad (2)$$

In formula (2), W_A represents the total income of investment commodities in A period, W_B represents the total income of basic investment raw material commodities in B period, W_C represents the total income of investment commodity prices in C period, λ_1 represents the interest rate coefficient of investment commodities in the first period, λ_2 represents the interest rate coefficient of basic investment raw material commodities in the second period, and λ_3 represents the price interest rate coefficient of investment commodities in the third period.

Simplify the monetary policy into a single target inflation equation, as shown in the following formula:

$$P_O = K_L + \theta_1 \times E_{ab}. \quad (3)$$

In formula (3), P_O represents the inflation rate, K_L represents the response function of monetary policy, θ_1 represents the stability coefficient of currency value, and E_{ab} represents the fluctuation coefficient of commodity price in i period [16, 17].

The monetary equation constructed is as follows:

$$H_B = \beta_0 + \beta_1 \times \theta_i + \beta_2 \times E_{ab}. \quad (4)$$

In formula (4), H_B represents the growth rate of money supply, β_0 represents the money supply coefficient, β_1 represents the growth coefficient of interest rate [18, 19], and β_2 represents the reduction coefficient of interest rate [20, 21]. Therefore, the development of an economic system including an inflation equation, money equation, investment equation, and consumption equation is completed.

2.2. Theoretical Model of Investment Price Fluctuation and Interest Rate Policy Response in Free Trade Port. Build a theoretical model of investment price fluctuation and interest rate policy response in free trade port and observe the impact of changes in commodity prices on the economic effect of interest rate regulation policy [22, 23]. The theoretical model of commodity price fluctuation and interest rate policy response includes total supply equation, total demand equation, and asset price composition equation.

The total supply equation is as follows:

$$Q_{AS} = \chi_i \times v_i - \chi_i \times \Delta q_i \times H_B. \quad (5)$$

In formula (5), χ_i represents the total supply of goods in i period, v_i represents the influence coefficient of the change of real output in the short term on inflation, χ_i represents the gap of real output, and Δq_i represents the corresponding effective exchange rate of the indirect pricing method [19, 24].

The design of the total demand equation is as follows:

$$D_i = w_1 \times d_i - w_2 \times n + \sum_{i=1}^{n} w_3 f_i + w_4 a_i + Q_{AS}. \quad (6)$$

In formula (6), D_i represents the total demand for commodities in i period, d_i represents the total demand for commodities in i period, w_1 represents the nominal interest rate coefficient, w_2 represents the short-term fluctuation coefficient of commodities, n represents the number of commodity types, w_3 represents the elasticity coefficient of commodity price fluctuation, f_i represents the corresponding exogenous impact of the effective exchange rate in i period [25], w_4 represents the elasticity coefficient of inflation, and a_i represents the corresponding exogenous impact of the commodity asset price.

The design of the asset price composition equation is as follows:

$$Z_i = Z_{i-1} \times A_{i+1} + L_i \times D_i. \quad (7)$$

In formula (7), Z_i represents the commodity asset price in i period, Z_{i-1} represents the commodity asset price in $i-1$ period, L_i represents the exogenous shock of commodity asset price in i period, and A_{i-1} represents the corresponding exogenous shock of the commodity asset price in $i-1$ period [26]. Therefore, the model development including the total supply equation, total demand equation, and asset price composition equation is completed.

2.3. Theoretical Model of Investment and Fiscal and Tax Policy Response in Free Trade Port. Build a theoretical model of commodity price fluctuations and fiscal and tax policy responses and observe the impact of changes in commodity prices on the economic effects of fiscal and tax policies.

The constructed theoretical model of commodity price fluctuation and fiscal and tax policy response is as follows:

$$F_{i+1} = \frac{F_i z_0 + A_1 C_1 + A_2 C_2 + A_3 C_3 + \vartheta_i}{Z_i}. \quad (8)$$

In formula (8), F_{i+1} represents the fiscal tax amount in $i+1$ period, F_i represents the fiscal tax amount in i period, z_0 represents the economic growth rate, A_1 represents the intercepted item of energy commodities, A_2 represents the intercepted item of basic raw materials commodities, A_3 represents the intercept item of agricultural and sideline commodities, C_1 represents the year-on-year growth rate of the consumption index of energy commodities, C_2 represents the year-on-year growth rate of the consumption index of basic raw materials commodities, C_3 represents the year-on-year growth rate of the consumption index of agricultural and sideline commodities, and ϑ_i represents the year-on-year growth rate of fiscal taxes.

In the influence of the price-based policy in the free trade port policy on the financial benchmark rate of return of the investment industry, on the one hand, according to the internal value determination theory of the investment industry and the financial benchmark income discount model [27, 28], the internal value of the investment industry is the present value of the future financial benchmark income. When the loose price-based policy is adopted, the decline of the financial benchmark rate of return leads to the decline of the discount rate. As a result, the discount value of the financial benchmark rate of return of the investment industry will become larger in the future, and the intrinsic value of the investment industry will rise. As the actual financial benchmark rate of return of the investment industry cannot deviate too far from it, the financial benchmark rate of return of the investment industry will rise accordingly [29]. The impact of price-based policies on the financial benchmark rate of return of the investment industry in the past five years is shown in Figure 1.

On the other hand, from the perspective of the investment industry, when the financial benchmark return rate decreases, the financing cost of the investment industry will be reduced, which is conducive to the growth and profitability of the investment industry, and finally the financial benchmark return of the investment industry rise is made. If the price-based policy is in a tight state, the rise of the financial benchmark rate of return will increase the discount rate, the discount value of the financial benchmark rate of return will become smaller in the future, and the intrinsic value of the investment industry will decline. When the financial benchmark yield rises, the financing cost of the investment industry will increase [30, 31]. At this time, it is unfavorable to the growth and profitability of the investment industry, and eventually the financial benchmark yield of the investment industry will decline.

3. Results and Analysis

3.1. Optimizing the Environmental Path of Investment Comprehensive Evaluation with Macroeconomic Support. In the market economy, with the support of macroeconomy, one of the important conditions for development is to optimize the investment comprehensive evaluation environment and improve the investment comprehensive evaluation environment by establishing a new development path, which is also the development trend of the investment comprehensive evaluation environment under the development of the current market economy. The current comprehensive evaluation environment of free trade port investment is shown in Table 1.

According to the overview of the investment comprehensive evaluation environment of the free trade port in Table 1, explore the path to optimize the investment comprehensive evaluation environment under macroeconomic support. Only by forming a good investment comprehensive evaluation environment, we can attract market players, concentrate on production factors, summarize development ideas, and promote an economic development.

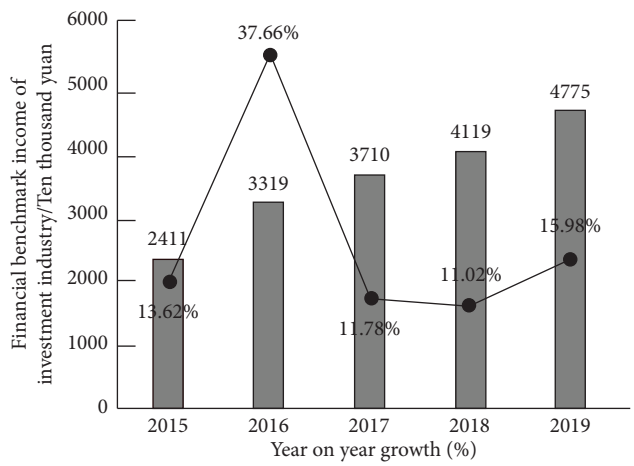


Figure 1: The impact of price-based policies on the financial benchmark rate of return of the investment industry in the past five years.

Table 1: Overview of investment comprehensive evaluation environment of the free trade port.

Index	2021	2020	2019	2018	2017
Comprehensive indicators	44	57	73	81	82
Build license	120	172	178	181	128
Grade permission	27	41	42	42	45
Tax revenue	112	135	137	135	136
Cross-border trade	66	87	110	117	118
Execution of contract	6	5	5	4	4
Access to credit	73	65	60	41	35

3.2. Building a Comprehensive Evaluation Model of Free-Trade Port Investment. In order to analyze the impact of macroeconomic effects, a comprehensive evaluation model of free trade port investment involving multiple industries and departments is established. Each industry produces only one type of goods. The investment policy of the free trade port is usually funded by financial allocation, and the funds raised for society are very few. At present, in the venture capital structure of the free trade port policy, the capital sources are mainly large state-owned enterprises and governments, some are listed companies and foreign-funded enterprises, and only a small part is from private capital. The capital source of venture capital is shown in Figure 2.

The venture capital policy has a certain impact on the development of free trade ports, mainly as follows:

First, it can solve the financial capital problem of free trade port investment. Due to the lack of tangible assets in the free trade port and the lack of guarantee strength of the industry itself, the management risks, market risks, and technical risks faced in the development process are relatively prominent, which has made the free trade port difficult in financing and reduced the financial benchmark rate of return. The funds brought by the venture capital policy to the free trade port can not only meet the multiround capital needs of the free trade port at different stages of development but also help to cultivate the follow-up financing capacity of the free trade port.

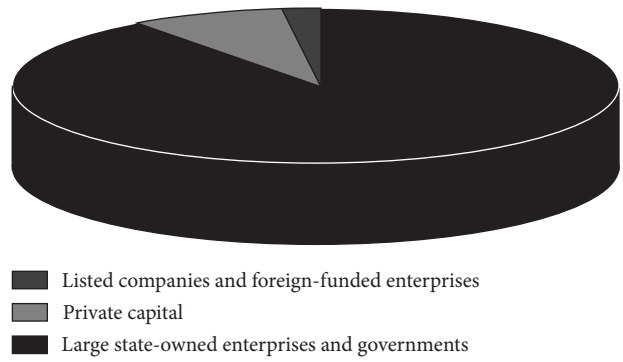


Figure 2: Capital sources of venture capital.

The second is to provide human resources for the free trade port. The venture capital policy can not only provide funds for the free trade port but also provide a large number of management talents. The venture capital policy can provide a free aid mechanism for the free trade port. For the partners of the free trade port, they can supplement the free trade port through social networks, which not only solves the problems in the management and development of the free trade port but also improves the financial benchmark rate of return of the free trade port.

Third, it is conducive to improving the management level of the free trade port. The purpose of venture investors' participation in the management of free trade ports is not to operate their own enterprises but to promote the rapid growth of free trade ports from the aspects of financial management and development strategy, so as to improve the management level of a free trade port.

The impact of monetary policy on the financial benchmark yield of free trade port is mainly reflected in the impact of the monetary policy transmission mechanism, which can be divided into two ways: monetary channel and credit channel, as shown in Figure 3.

The influence of the monetary policy transmission mechanism on the financial benchmark yield of free trade ports is manifested in the demand of free trade ports for the holding and allocation structure of monetary assets, which changes the financial benchmark yield of free trade ports and affects the real economy of a free trade port.

In the development of the comprehensive evaluation model of free trade port investment, the production process of labor, enterprise capital, and intermediate products input to various industries is described. According to this process, the model is obtained, and the expression is

$$U_i = \frac{X_i}{A_P} \times \frac{C_X}{P_U}. \tag{9}$$

In formula (9), X_i represents the initial input, A_P represents the factor input coefficient of intermediate products, C_X represents the cost, and P_U represents the input price of

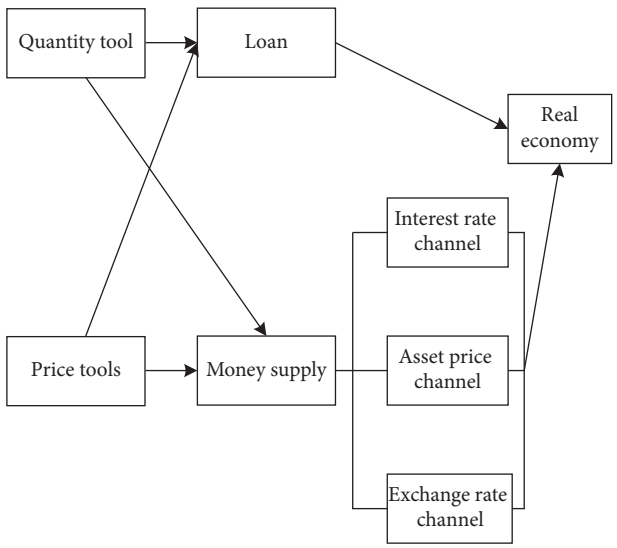


Figure 3: Transmission mechanism of monetary policy.

synthetic products in the intermediate stage. Thus, the comprehensive evaluation model of free trade port investment with macroeconomic support is completed.

4. Experiment and Analysis

In order to analyze the impact of free trade port investment on enterprise debt structure from the perspective of the macroeconomy, firstly the changing trend of debt structure from some free trade ports in a city in the five years from 2017 to 2021 is studied by statistical analysis method, and the effectiveness of the constructed comprehensive evaluation model of free trade port investment supported by macroeconomy is judged.

4.1. Data Sources and Research Samples. The data used for empirical research in this paper are still based on the investment panel data of 3844 effective free trade ports in the five years from 2017 to 2021.

4.2. Design of Variables. At present, for most enterprises in China, including free trade port investment, long-term loan financing is still one of the most important financing methods. In the asset-liability structure, the long-term loan ratio L_{BR} is also the most critical indicator. Therefore, taking the long-term loan ratio as the alternative indicator of the explained variable enterprise debt structure, at this time, the explained variable indicator L_{BR} can be expressed as follows:

$$L_{BR} = \frac{L_{BR_1} + L_{BR_2}}{L_C} \times 100\%. \tag{10}$$

In formula (10), L_{BR_1} and L_{BR_2} represent the sum of long-term borrowings of enterprises, including long-term borrowings due within one year and bank borrowings due within one year, and L_C represents the sum of enterprise liabilities. There are two explanatory variables involved, namely, monetary policy variables and political correlation variables. In this paper, D_{MT} index is used to replace monetary policy as one of the explanatory variables in the design model.

$$D_{MT} = \frac{\Delta c}{c} - \left(\frac{\Delta \eta}{\eta} + \frac{\Delta \varsigma}{\varsigma}\right). \tag{11}$$

In formula (11), Δc and c, respectively, represent the net increase of money and the total amount of money supply, $\Delta\eta$ and η, respectively, represent the net increase and total increment of GDP within the study area, and $\Delta\varsigma$ and ς, respectively, represent the increment and the present value of China's domestic consumption index. According to the definition of D_{MT} index, the higher the index value, the looser the country's monetary policy at this stage, the lower the financing difficulty of the free trade port, and can improve the structural proportion of long-term loan financing and optimize the debt structure; the smaller the D_{MT} index value, the tighter the monetary policy adopted by the country, and the financing difficulty of the free trade port increases.

For the variables of political relevance, this paper replaces them with indicators S_1 and S_2, respectively, where indicator S_1 indicates whether the core managers in the investment and loan enterprises of the free trade port have experience in performing their duties in government departments. When the indicator S_1 is 1, it is proved that they have work experience, and when indicator S_1,S_1 is 0, it is proved that they have no work experience. Indicator S_2 indicates whether there are any core managers in the investment and loan enterprises of the free trade port who have served in banks or financial institutions or have performed their duties. When the indicator S_2 is 1, it indicates that they have served or performed their duties, and when S_2 is 0, it indicates that they have not served or performed their duties. Other control variables related to the explained variables in the empirical study are shown in Table 2.

Financial listed companies are excluded from the selected samples. The sample observations from 2017 to 2021 are shown in Table 3.

Analysis Table 3 shows the changes in the overall debt structure long-term debt structure, short-term debt structure of the 3844 valid study sample over the five-year period from 2017 to 2021. In the analysis of the overall debt structure of the sample data, three indicators, asset liability ratio, long-term debt ratio, and short-term debt ratio, are selected for analysis and research. The calculation formulas of the selected three indicators are as follows:

$$E_V = \frac{A_1}{Z_C} \times 100\%, \tag{12}$$

$$H_V = \frac{F_i}{A_1} \times 100\%, \tag{13}$$

$$K_V = \frac{F_j}{A_1} \times 100\%. \tag{14}$$

In the above formulas, E_V represents the average asset-liability ratio, H_V represents the average long-term debt

Table 2: Design of model control variables.

Symbol	Variable	Explain
Size	Enterprise size	Value is the natural logarithm of total assets
Top5	Shareholding ratio of top 5 shareholders	Calculated according to the proportion of the actual total holdings
F_{AR}	Shareholding ratio of fixed assets	Proportion of fixed assets in total assets
E_{PA}	Profitability of enterprises	Calculated using the return on total assets indicator
G_{RO}	Development capacity of enterprises	Calculated by using the operating revenue growth rate indicator

Table 3: Sample observations of empirical research.

Particular year	2017	2018	2019	2020	2021
Number of observations	767	782	759	791	745

ratio, K_V represents the average short-term debt ratio, A_1 represents the total liabilities, Z_C represents the total assets, F_i represents the total noncurrent liabilities, and F_j represents the total current liabilities. According to the above formula, the overall average debt structure of the collected samples is shown in Table 4.

According to Table 4, considering the data of the overall debt structure level of the sample enterprises, the highest value of the average asset-liability ratio index is 53.24%, and the lowest value is 49.85, maintained at about 50%, which is a relatively ideal equity and debt structure ratio; from the perspective of the average short-term debt ratio, it is still at a relatively high level, with the lowest value of more than 73%, indicating that most free trade port investments still have difficulties in financing, and banks and other financial institutions have taken a more cautious attitude towards long-term loans for their free trade port investments. However, considering the trend of debt structure change, the average long-term debt ratio of free trade port investment has shown an increasing trend due to the gradual easing of the country's overall monetary policy in recent years. The reason for the high proportion of average short-term debt is also related to the business category of free trade port investment. Compared with long-term debt, the interest of short-term debt is lower. In addition to continuing to hold a large number of funds at the initial stage of development, enterprises prefer to hold short-term debt to replace long-term debt, so as to reduce interest expenses. However, holding a large number of short-term liabilities will also have certain risks for free trade port investment; that is, it is easy to fall into the dilemma of liquidity debt financing.

The debt structure change trend of free trade port investment is further analyzed from two aspects: long-term debt structure and short-term debt structure. The indicators selected for the long-term debt structure mainly include long-term loans, long-term accounts payable, bonds payable, and special accounts payable; the analysis indicators of short-term debt structure mainly include short-term loans, commercial credit, other payables, and taxes payable. After statistical analysis, the proportion of indicators in the long-term debt structure and short-term debt structure is shown in Figures 4 and 5.

From the changes in the structural proportions of the constituent elements of long-term liabilities in the 3,844 effective research samples from 2017 to 2021 shown in Figure 4, it can be seen that long-term loans occupy an absolutely dominant position, which shows that the free trade port still relies mainly on banks and other financial institutions in the choice of financing methods. In addition to relying on market risk factors, bank strategic decisions and loan standards largely depend on national macrocontrol policies and credit rationing systems. Therefore, the political relationship between the free trade port and the government and financial institutions cannot be avoided. However, from the development and change trend of the long-term debt structure, it can be seen that the proportion of long-term loans still shows a slight downward trend, while the proportion of long-term accounts payable, bonds payable, and special accounts payable continues to increase, indicating that the financing channels of long-term funds invested in the free trade port are expanding, alleviating some external factors to a certain extent. The negative impact of human factors on the optimization of the FTA investment debt structure. From the proportion relationship of short-term debt structure in the sample data shown in Figure 5, the two main short-term debt financing methods, short-term borrowing and commercial credit, are in a relationship of ebbing and flow. From the analysis of the long-term evolution trend, the proportion of short-term borrowing has decreased slightly, while the proportion of commercial credit and other payables has shown an increasing trend.

Through comparative analysis, we can see that the current debt structure of China's free trade port is obviously unreasonable. Although this changing trend has improved in recent five years, the short-term average debt of more than 70% will bring a huge capital gap to the investment of the free trade port, which is not conducive to the development and growth of the free trade port. In the long-term debt financing structure, the free trade port investment also has the problem of too single a financing channel. In addition, considering the fairness of the market and the competitive relationship between enterprises, some enterprises that have close relations with the government or have long-term stable cooperation with financial institutions are often more able to get the financial support of the bank, so as to adjust the debt structure of the company to the best.

Through the experimental data to estimate parameters, set different commodity price fluctuations of free trade port investment and explore the impact mechanism of commodity price fluctuations on the economic effect of macroeconomic regulation. The data of money supply growth rate, commodity interest rate, commodity tax point, and economic growth rate in 2021 and 2022 are shown in Table 5.

When the annual growth rate of commodity prices exceeds 5%, the model is used to predict the growth rate of

Table 4: Analysis of the overall average debt structure of the collected samples.

Particular year	Average asset-liability ratio (%)	Average short-term debt ratio (%)	Average long-term debt ratio (%)
2017	51.30	81.95	20.65
2018	53.24	81.22	20.90
2019	52.48	80.08	22.61
2020	50.45	77.92	24.24
2021	49.85	73.25	28.97

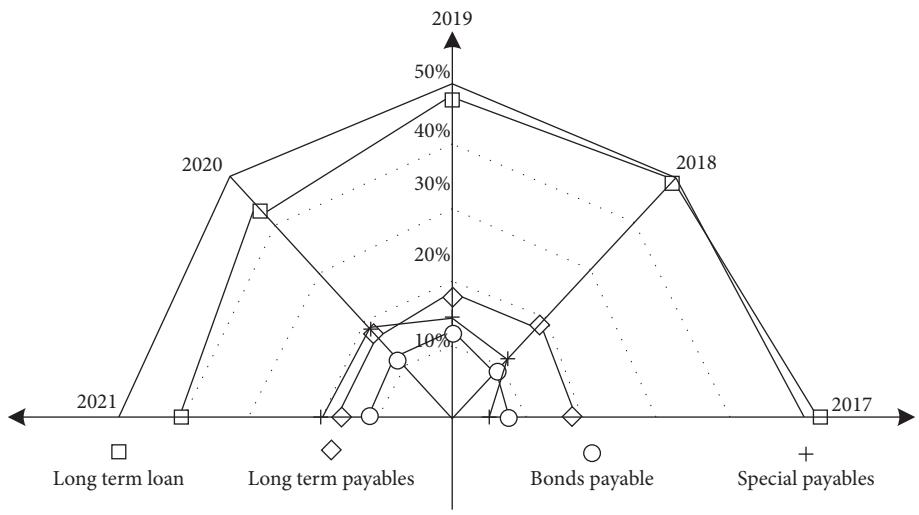


Figure 4: Structural proportion relationship of indicators in a long-term debt structure.

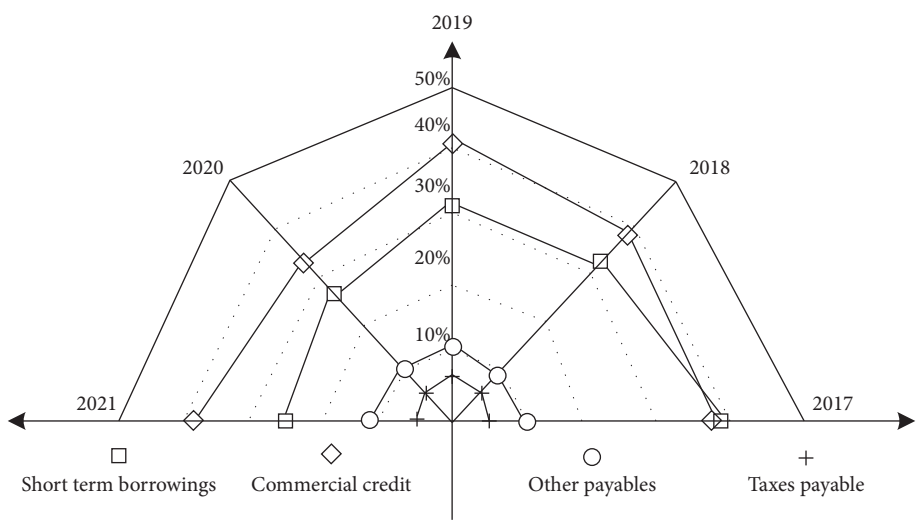


Figure 5: Structural proportion relationship of various indicators in a short-term debt structure.

money supply, commodity interest rates, commodity tax points, and economic growth rate in the next five years, and the prediction results are verified. The forecast results of the money supply growth rate, commodity interest rate, commodity tax point, and economic growth rate are shown in Table 6.

According to the prediction results in Table 6, the growth rate of money supply, commodity interest rate, commodity tax point, and economic growth rate can be predicted through the theoretical models of commodity price fluctuation and monetary policy response. The forecast results show that when the annual growth rate of commodity prices exceeds 5%, the growth rate of money supply, commodity interest rates, commodity tax points, and economic growth rate will increase accordingly. It shows that the comprehensive evaluation of free trade port investment under macroeconomic support can be achieved through the theoretical model of commodity price fluctuation and monetary

Table 5: Money supply growth rate and economic growth rate in the past two years.

Particular year	Money supply growth (%)	Commodity interest rate (%)	Commodity tax point	Economic growth rate (%)
2021	58.63	0.52	0.35	10.36
2022	58.35	0.54	0.36	10.39

Table 6: Prediction results.

Particular year	Forecast growth rate of money supply (%)	Commodity interest rate (%)	Commodity tax point	Forecast rate of economic growth (%)
2023	58.39	0.54	0.368	10.40
2024	58.42	0.54	0.369	10.40
2025	58.45	0.55	0.371	10.41
2026	58.49	0.55	0.374	10.41
2027	58.52	0.55	0.375	10.41

Table 7: Test results of time series stationarity.

Inspection items	Forecast data of money supply growth	Forecast data of commodity interest rate	Forecast data of commodity tax points	Forecast data on economic growth rate
ADF statistics	−6.34	−5.23	−3.32	−3.32
5% critical value	−3.21	−3.25	−3.20	−3.25
Stationarity	Stable	Stable	Stable	Stable

policy response, the theoretical model of commodity price fluctuation and interest rate policy response, and the theoretical model of commodity price fluctuation and fiscal and tax policy response.

In order to verify the accuracy of the evaluation results, the test method is used to test the stability of the time series. The specific test results are shown in Table 7.

According to the time series stability test results in Table 7, the time series of money supply growth rate, commodity interest rate, commodity tax point, and economic growth rate prediction data is stable, indicating that the prediction results are relatively accurate as a whole, and the model has a good evaluation effect.

To sum up, the average asset-liability ratio index under the model of this paper is maintained at about 50%, which is ideal equity and debt structure ratio; the free trade port still mainly relies on banks and other financial institutions in the choice of financing methods. Considering the overall debt structure level data of the sample enterprises, it is an ideal ratio of equity and debt structure; the time series of the growth rate of money supply, commodity interest rate, commodity tax point, and economic growth rate forecast data is stable, indicating that the forecast data is stable. The results are generally more accurate.

5. Discussion

5.1. The Influence of Monetary Policy on the Investment Debt Structure of Free Trade Ports. As a rational market entity, the free trade port will inevitably consider the structure of debt financing in the process of fundraising. The debt structure will not only be affected by internal factors such as the size and nature of the free trade port and the risk appetite of the management but also by the influence of some external institutional factors and noninstitutional factors. The country's monetary policy at different stages is one of the important noninstitutional factors that affect the investment and financing methods and debt structure of the free trade port. Especially in the period of social and economic transformation or the period of severe fluctuations in the international financial market, the government will adjust the monetary policy relatively frequently, in order to achieve the aim of stabilising China's domestic economic order. This adjustment will inevitably affect the total money supply in the market and the level of market interest rates and promote the diversification and complication of the national macro-adjustment effect. The level of risk control will indirectly affect the financing method and debt structure system of enterprises, especially free trade ports.

5.2. The Influence of Political Connections on the Structure of Investment Debt in Free Trade Ports. The government plays an important role as a coordinator and referee in the operation of the market economy. A large number of research results show that in the historical process of China's reform and opening up, the social and economic system has been transformed from a planned economy to a market economy, and political connections have played a role. An important and crucial role, especially at a stage when the market economy is not yet perfect and political relations are a necessary macroregulatory tool. At present, China's social economy has entered a historical stage of a new normal. In the national macrocontrol, economic and legal means should be used as much as possible to reduce the interference of administrative means in the market. However, it is undeniable that various backgrounds and forms of enterprise organization coexist in China at the present stage. Compared

with ordinary private enterprises, enterprises with state-owned assets holding background, or enterprises with other political connections. Whether enterprise, there are obvious advantages in terms of scale, profitability, market competitiveness, financing ability, and financing difficulty. These free trade ports with political connections have a more reasonable debt structure and lower financing costs and interest costs. In view of the importance of political connections in the existing economic environment, free trade ports often try to establish a relationship with the government through various means, in order to achieve the purpose of improving and optimizing the debt structure.

6. Conclusion

(1) Considering the data of the overall debt structure of the sample enterprises, the average asset-liability ratio index is maintained at about 50%, which is a relatively ideal equity and debt structure ratio.

(2) The change in the structural proportion of each constituent element of long-term liabilities shows that long-term loans occupy an absolute dominant position, which indicates that the free trade port still mainly relies on banks and other financial institutions in the choice of financing methods. Considering from the data of the overall debt structure of the sample enterprises, it is an ideal ratio of equity and debt structure; the change of the structural proportion of each constituent element of long-term liabilities shows that long-term loans occupy an absolutely dominant position, which indicates that the free trade port still mainly relies on banks and other financial institutions in the choice of financing methods. From the perspective of the proportion of short-term debt structure in the sample data, the two main short-term debt financing methods, short-term borrowing and commercial credit, are in a trade-off relationship.

(3) Through the theoretical model of commodity price fluctuation and monetary policy response, the theoretical model of commodity price fluctuation and interest rate policy response, and the theoretical model of commodity price fluctuation and fiscal and tax policy response, the comprehensive evaluation of free trade port investment under macroeconomic support can be realized. The time series of money supply growth rate, commodity interest rate, commodity tax point, and economic growth rate prediction data is stable, indicating that the prediction results are relatively accurate as a whole.

Although the above research has made some progress, there are still shortcomings. The next research work needs to be further studied. The specific contents are as follows:

(1) We will promote the development of the logistics system and supporting facilities and actively play the pivotal role of an international shipping center. Build a transportation network between the free trade port and its hinterland, and improve the logistics service function of the free trade port.

(2) The next step needs to create a good policy environment and vigorously promote the development of free trade port ecological zone, logistics park, and other industries.

(3) Under the background of the steady rise of economic conditions and the gradual strengthening of opening up, the development of free trade ports is the driving force of economic construction, which makes the comprehensive evaluation of an investment in free trade port develop better and better.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] T. A. Bakven`E and O. V. Ponomareva, "African continental free trade area as a new step in African integration," *Russian Foreign Economic Journal*, vol. 11, no. 11, pp. 58–71, 2021.

[2] S. Ansari and B. R. Rajesh, "5 north American free trade agreement (nafta) disputes," *Yearbook of International Environmental Law*, vol. 19, no. 7, pp. 483–488, 2021.

[3] P. Wanke, Z. Chen, Q. Dong, and J. Antunes, "Transportation sustainability, macroeconomics, and endogeneity in China: a hybrid neural-markowitz-variable reduction approach," *Technological Forecasting and Social Change*, vol. 170, no. 5, pp. 120860–120922, 2021.

[4] J. M. Cardebat, "Guest editor's introduction to the special issue: wine, macroeconomics, and finance," *Journal of Wine Economics*, vol. 15, no. 2, pp. 131–133, 2020.

[5] J. L. Meng, "Demand prediction and allocation optimization of manufacturing resources," *International Journal of Simulation Modelling*, vol. 20, no. 4, pp. 790–801, 2021.

[6] J. M. Lee, I. H. Jung, and K. Hwang, "Classification of beef by using artificial intelligence," *Journal of Logistics, Informatics and Service Science*, vol. 9, no. 1, pp. 1–10, 2022.

[7] L. S. Tang, X. Tan, P. Guo, T. T. Huang, and T. L. Liu, "Comparative analysis of locational factors and their external influence on free-trade port zones in China," *Sustainability*, vol. 14, no. 4, pp. 2232–2319, 2022.

[8] L. Tang, J. Gu, and X. Yu, "Value element system and development path of free trade port location," *American Journal of Industrial and Business Management*, vol. 12, no. 5, pp. 782–795, 2022.

[9] J. Y. Liu, S. F. Liu, and D.-Q. Gong, "Electric vehicle charging station layout based on particle swarm simulation," *International Journal of Simulation Modelling*, vol. 20, no. 4, pp. 754–765, 2021.

[10] N. Chaukura, M. Maya, and W. Gwenzi, "A biochar-based point-of-use water treatment system for the removal of fluoride, chromium and brilliant blue dye in ternary systems," *Environmental Engineering and Management Journal*, vol. 19, no. 1, pp. 143–156, 2020.

[11] M. G. Merayo and Y. Zhang, "MACRO-SYS: an interactive macroeconomics simulator for advanced learning," *International Conference on Intelligent Information & Database Systems*, vol. 3, no. 3, pp. 47–56, 2020.

[12] A. Sbarile, "Book review: "the behavioral economics of inflation expectations: macroeconomics meets psychology," *Economia Internazionale/International Economics*, vol. 75, no. 1, pp. 131–134, 2022.

[13] T. Ray, J. Kaljun, and B. Dolsak, "Numerical model application to predict the sound quality of an instrument," *International Journal of Simulation Modelling*, vol. 20, no. 4, pp. 696–706, 2021.

[14] V. F. Filaretov, A. Y. Konoplin, A. V. Zuev, and N. A. Krasavin, "A method to synthesize high precision motion control systems for underwater manipulator," *International Journal of Simulation Modelling*, vol. 20, no. 4, pp. 625–636, 2021.

[15] G. Vita, "Mexico's 20 years of north american free trade agreement: socio-environmental trends and unequal exchange," *SocArXiv*, vol. 5, no. 5, pp. 1–10, 2021.

[16] J. D. Quartey, "Addressing the missing link for sustainable african continental free trade: lessons from Ghana€s manufacturing industry," *Asian Development Policy Review*, vol. 9, no. 1, pp. 1–23, 2021.

[17] N. A. Arreyndip, "African continental free trade area (afcfta): projected economic impact assessment under future warming in cmip6," *Environmental Research Letters*, vol. 16, no. 9, pp. 094046–94120, 2021.

[18] S. W. Ju and Y. S. Park, "Public design method based on smart service system technology: centered on the cases of bus stops in Korea and China," *Journal of Logistics, Informatics and Service Science*, vol. 9, no. 1, pp. 177–194, 2022.

[19] I. D'Adamo, F. Cucchiella, M. Gastaldi, L. Koh, and E. D. Santibanez-Gonzalez, "Assessment of GHG emissions in Europe: future estimates and policy implications," *Environmental Engineering and Management Journal*, vol. 19, no. 1, pp. 131–142, 2020.

[20] Ferdi, "International environmental law enforcement using iso 14001 in the wto free trade system and its implementation in Indonesian law," *Ecology Environment and Conservation*, vol. 27, no. 1, pp. 240–246, 2021.

[21] M. Krivelevich and E. Berezhnova, "Evaluation of strategies of key categories of actors in the functioning of the free port of vladivostok and other development programs of the far east based on the determination of the value of expected future losses and acquisitions," *IOP Conference Series: Earth and Environmental Science*, vol. 666, no. 6, 73 pages, Article ID 062086, 2021.

[22] M. Harrison, W. Hong, S. Lam, and G. Xiao, "The promise of China's free trade zones – the case of hainan," *Asian Education and Development Studies*, vol. 9, no. 3, pp. 297–308, 2019.

[23] R. G. Kleiser, "An empire of free ports: british commercial imperialism in the 1766 free port act," *Journal of British Studies*, vol. 60, no. 2, pp. 334–361, 2021.

[24] K. Hwang, J. M. Lee, and I. H. Jung, "Performance monitoring of MQTT-based messaging server and system," *Journal of Logistics, Informatics and Service Science*, vol. 9, no. 1, pp. 85–96, 2022.

[25] A. Khan, F. Dobbie, K. Siddiqi et al., "Illicit cigarette trade in the cities of Pakistan: comparing findings between the consumer and waste recycle store surveys," *Tobacco Control*, vol. 31, no. 5, pp. 635–641, 2021.

[26] J. E. Scanlon Ao, "Wildlife must be protected from crime and trade for the sake of public and planetary health," *PLoS Biology*, vol. 19, no. 10, Article ID e3001422, 11 pages, 2021.

[27] N. S. Kollmann, "English trade and adventure to Russia in the early modern era: the muscovy company, 1603–1649, by maria salomon arel," *English Historical Review*, vol. 136, no. 583, pp. 1638–1640, 2021.

[28] M. Liukkonen, I. Kronholm, and T. Ketola, "Evolutionary rescue at different rates of environmental change is affected by trade-offs between short-term performance and long-term survival," *Journal of Evolutionary Biology*, vol. 34, no. 7, pp. 1177–1184, 2021.

[29] B. Nawel, "The importance of developing foreign trade to achieve economic growth in Algeria during the period (1991–2017) using the ARDL model," *Post-Print*, vol. 7, no. 7, pp. 1–10, 2021.

[30] K. L. Lin, K. W. Lo, Ta-W. Cheng, and W.-H. Lee, "Study on solid/liquid ratio and microstructure properties of alkali-activated metakaolin-based geopolymer contained in LCD waste glass," *Environmental Engineering and Management Journal*, vol. 19, no. 1, pp. 157–173, 2020.

[31] J. Xu and H. K. Kim, "A service system study on the effects of the influencers' characteristics on purchase intention," *Journal of Logistics, Informatics and Service Science*, vol. 9, no. 1, pp. 136–155, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8245983, 10 pages
https://doi.org/10.1155/2022/8245983

Research Article

Redesigning and Implementing the Public Game Information and Rating System in South Korea

HoSeong Kang [1] **and JungYoon Kim** [2]

[1] *Department of Game Engineering, Graduate School, Gachon University, Seongnam-si 13120, Gyeonggi-do, Republic of Korea*
[2] *Department of Game Media, College of Future Industry, Gachon University, Seongnam-si 13120, Gyeonggi-do, Republic of Korea*

Correspondence should be addressed to JungYoon Kim; kjyoon@gachon.ac.kr

Received 26 July 2022; Revised 2 September 2022; Accepted 22 September 2022; Published 10 October 2022

Academic Editor: Lele Qin

Rating reviews in the game industry aim to enhance the protection of young users, promote game ethics, and prevent negative use of it as a gambling but recent studies and public opinions have reported that the current rating system in South Korea is excessively regulative. To address this issue, this study was conducted to redesign the public game rating system on the Game Ratings and Administration Committee (GRAC) for the public data usage based on the comparison with other better structured media rating systems. The redesigned system utilized a parsing technique to easily access specific data or items, and a Jsoup library was utilized in the Java environment. The system consists of a URL collection module, connection module, detailed collection module, and storage module. If a user requests information from a game rating database through the proposed system, the requested information is arranged sequentially and provided to the user in XML and JSON forms. The designed and implemented collection data were comparatively inclusive and structural to satisfy the public for the better and easier public data usage. This study is expected to help build an environment where game users can obtain information both easily and correctly, and it will eventually lead to a better understanding of the current game industry in South Korea and its clear way to go.

1. Introduction

The statistical data on a white paper published by the Korea Creative Content Agency in 2019 indicated that the South Korean digital game industry has shown a gradual growth since 2009 as depicted in Figure 1 [1]. Just when people's interest in games has increased and the game industry accomplishes good results at home and abroad, the regulatory review procedures, however, impeding the growth of the game industry in South Korea. According to Article 21 of the Game Industry Promotion Act, those who intends to create or distribute a new digital game shall go through the game classification system and receive a rating from the Committee [2]. Rating reviews aim to enhance the protection of young users, promote game ethics, and prevent negative use of it as gambling but recent studies and public opinions have reported that rating reviews are excessively regulative [3–5].

The Game Ratings and Administration Committee (GRAC) was launched in response to the controversy over whether the game "The Sea Story" was a gamble or not in 2006 as gambling is an illegal act in South Korea [6]. Since then, the GRAC builds the rating system to inform the users of the nature of the game. However, it is a complicated process to go through the rating system and it is more difficult to receive a pass. In addition, the GRAC suddenly charges high fees for the review process.

In 2019, the GRAC forced more regulations for indie games, test version games, and flash games that were published through the Internet. They have forced legal orders, thus, game developers have to go through the rating system before they publish the new game title to the game platforms including the zuzunza.com [7]. In addition, voluntary ratings were implemented to relieve regulation of the reviews. However, as shown in Table 1, the monitoring group for voluntary rating is composed of persons who have

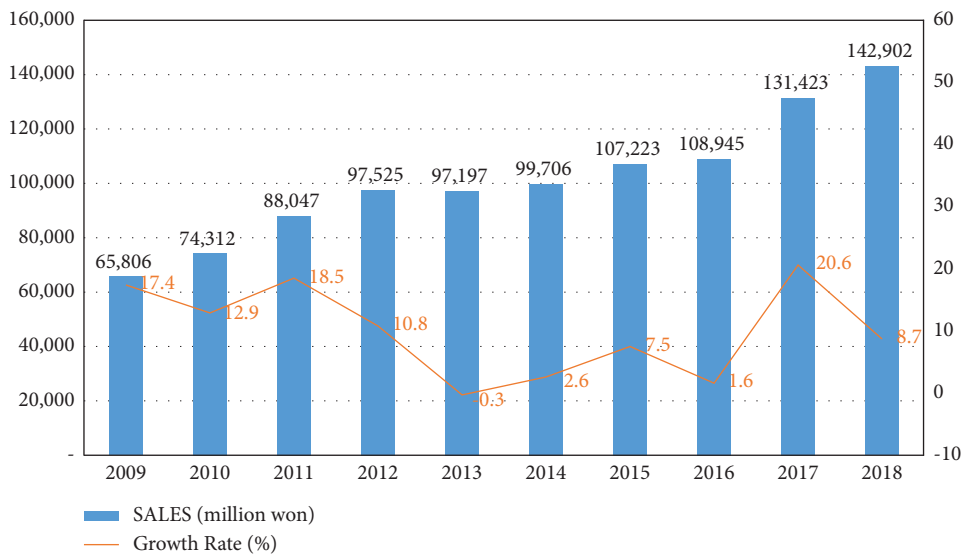


Figure 1: Overall size and growth rate of the Korean game market (2009~2018).

Table 1: Controversy over South Korea's game monitoring group and qualification requirements in 2019.

Conditions of qualification requirement
(i) Disabled person/career discontinued women
(ii) Smartphone owners available in mobile open market
(iii) People who can participate in monthly offline meetings (required)
(iv) Document authoring person
(v) The four major uninsured persons

a poor understanding of digital games including job-discontinued women and disabled people which led to controversy on the lack of fairness and professionalism on the rating system [8–10]. This can result in the stoppage of a game service caused by wrong judgments from the non-professional groups and it makes a critical issue for the growing game industry [11]. Also, public data aims at "improving the quality of life and national economy by promoting people's use of data owned and managed by a public institution" [12] and the GRAC belongs to a public institution and its game rating service is included in the public data.

Amid this controversy, this study was conducted to analyse and redesign the game rating system and its public data provided by the GRAC. This study is expected to help build an environment where game users can obtain information on the digital games both easily and correctly, which will eventually lead to a better understanding of the current game industry in South Korea and its clear way to go.

2. Literature Review

In other countries, research on the validity of game rating from a user's perspective has been continuously conducted as well as on the role of parents in rating their children's right to the use of games [13–16]. In South Korea, most studies related to rating classifications are conducted from sociological and legal perspectives but the studies from an engineering perspective are insufficient to verify the validity of the rating review system [17–20]. Thus, this study was conducted to analyse both types and contents of game classification and the ways in which the data is delivered to the public through the GRAC website from an engineering perspective.

First, the GRAC provides information on games in a form of open API (application programming interface) based on the public data policy as shown in Table 2. The list of contents is the variables and description of information that can be received through the GRAC API [21].

The game review data are very limited because they simply enumerate the results of game ratings as shown in Figure 2 and Table 3. The information regarding the game content and the reasons for which the game has received the given rating is insufficient. On the other hand, an open API shown in Table 4 depicts a movie rating provided by the Korea Media Rating Board (KMRB) that includes the results of ratings as well as additional information on the movie such as synopsis and lead role\ and provides reasons for the ratings [22]. Public data that allow people to check information in more detail can be used to satisfy the people's rights to know and can be used for application service aiming at providing information on movies.

This comparison clearly indicates that the GRAC rating system needs to provide more information just like an open API that provides a movie rating system. People can check information and reviews on games by browsing through their titles and rating number on the rating decision check page found on the GRAC website.

3. Research Methodology

The entire process in which this study designed and implemented a system is shown in Figure 3. In order to improve the game and rating system on the GRAC's website, firstly this study drew the wider range of items that users can

Table 2: GRAC open API—list of game API output variables.

Request variables	Contents
Result	No special meaning as root element of search results
Tcount	Number of search results
res_date	Date and time of search results generation
Pageno	Search page number
Item	Game individual search results root element
Gametitle	Game name
Orgname	Rating organization
Entname	Applicant (company) name
Hoperate	Application rating (all, 12+, 15+, 18+)
Givenrate	Decision rating (all, 12+, 15+, 18+, reject(scheduled), reject, cancellation (scheduled), cancellation)
Rateno	Rating classification number
Rateddate	Rating classification date


```
▼<result>
  <tcount>4</tcount>
  <pageno>1</pageno>
  <res_date>2021-02-24 오후 3:36:46</res_date>
 ▼<item>
    <gametitle>V4 [PC]</gametitle>
    <orgname>GRAC</orgname>
    <entname>Nexon Korea</entname>
    <hoperate>18+</hoperate>
    <givenrate>18+</givenrate>
    <rateno>CC-NP-191204-009</rateno>
    <rateddate>2019-12-04</rateddate>
  </item>
 ▼<item>
    <gametitle>V4</gametitle>
    <orgname>GRAC</orgname>
    <entname>Nexon Korea</entname>
    <hoperate>18+</hoperate>
    <givenrate>18+</givenrate>
    <rateno>CC-OM-190918-002</rateno>
    <rateddate>2019-09-18</rateddate>
  </item>
```


Figure 2: GRAC Open API—game API output result.

Table 3: GRAC contents of providing public data (game API).

Items	Sample data
Game name	V4 (PC)
Rating organization	GRAC
Applicant name	Nexon Korea
Application rating	18+
Decision rating	18+
Rating classification number	CC-NP-191204-00
Rating classification date	2019-12-04

tap on the website for their search. For this, this study made a comparison with the well-designed website from the Korea Media Rating Board (KMRB). A database where the data collection and classification are performed is built to provide users with extended public data for game rating.

4. Analysis of the Rating System and Interface by the Game Ratings and Administration Committee

The GRAC provides game rating data which are distributed through its website. People can check the information on games on the page of "a decision on rating" that allows users to understand the reason why the decision on rating of games was made as shown in Figure 4 [23]. The website also provides the links that moves to pages related to games and rating reviews that include "detailed information on games," "a written decision," "rating history," and "present condition of the acquisition of overseas grade."

The "detailed information on games" page allows users to check the detailed information on games that have requested a rating review as shown in Figure 5. Users can move to the relevant pages through the hyperlink on the game titles displayed on the "check for a decision on rating." Users can check each item that includes the basic information on games such as "genre" and "nationality." Users can also check for the basic information on ratings, for example, the "date of rating" and the "rating number." According to the items on the relevant pages, the summary of the description and sample data can be obtained as shown in Table 5.

The "a written decision on game rating" page allows users to check a decision on rating of games that have requested rating reviews as shown in Figure 6. The content of a decision on games that requested rating includes the reason for the rating, a description of the game in one sentence, and the information on game contents. In the item of "indication of content information," sensationality, violence, fear, unsuitability of languages, drugs, crime, and speculation are indicated based on the standard for consideration of ratings in the relevant studies.

Users can collect data on the page of "a written decision on games." The summary of descriptions and sample data according to the items on the relevant pages can be obtained as shown in Table 6.

In order to improve the GRAC's rating and information system, the game information items were derived based on "detailed information on games" page and the "a written decision on game rating" page that the GRAC website provides to the public as shown in Table 7.

5. Results

5.1. Extending on Game and Rating Information Items. After making a comparison with KMRB, this study drew the items that are needed to be improved from the page of

Table 4: Korean media rating board open API—media rating list API output result.

Items	Sample data
Director	Jang Joon Hwan
Director nationality	Korea
Decision rating	15+
Leading role	Kim Yoon-Seok, Ha Jung-Woo, Yoo Hae-jin, Kim Tae-Ri, Park Hee-Soon, and Lee Hee-Jun
Movie species	A film drama
Original title	1987
Production year	2017
Producer	Friendship film Co., Ltd.
Country of production	Korea
Screening time	130 minutes 0 seconds
Standard	DCP
Title	1987
Reasons for core harm	Violence
Topic	15+
Sexuality	All
Violence	15+
Fear	15+
Drugs	15+
Lang	12+
Imitative risk	15+
Plot	A film about the 1987 torture death of the late Park Jong-Chul and the death of Lee Han-Yeol's tear gas
Rating classification number	2017-MF02149
Rating classification date	20171211

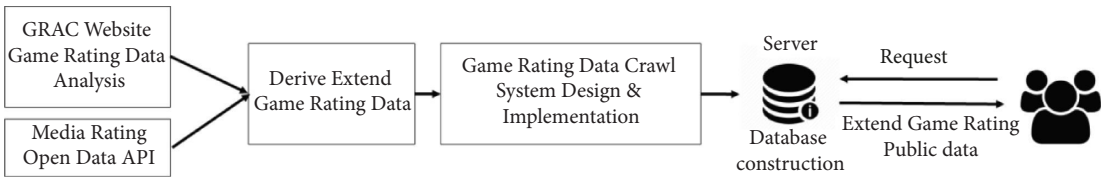
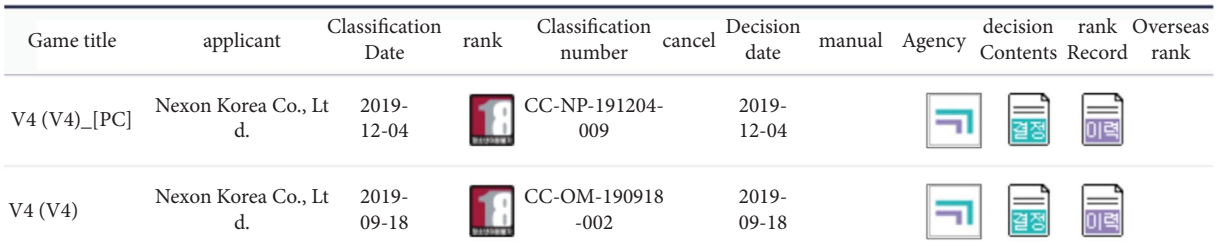


Figure 3: An entire process to build the Public Data Expansion Model.



Game title	applicant	Classification Date	rank	Classification number	cancel	Decision date	manual	Agency	decision Contents	rank Record	Overseas rank
V4 (V4)_[PC]	Nexon Korea Co., Ltd.	2019-12-04		CC-NP-191204-009		2019-12-04					
V4 (V4)	Nexon Korea Co., Ltd.	2019-09-18		CC-OM-190918-002		2019-09-18					

Figure 4: Checking for a decision on the rating page (Google Translate Web).

"detailed information on games" and "a written decision on game rating" as shown in Table 8. The relevant items can be extracted from the GRAC database that contains the information on games and can be collected from the GRAC's website. This redesigned and extended data base can allow users to check the information on game rating reviews more clearly and prepare a foundation that can be used in analysing and visualizing big data as shown in Table 8.

5.2. Designing and Implementing the Public Data Collection System. Then, this study designed and implemented a system that collects game rating data to provide users. The collection system was built based on the working environment as shown in Table 9. A parsing technique was used to easily access specific data or items and a Jsoup library was utilized in the Java environment. Jsoup is a library that enables users to easily find or extract data that they go by using a DOM search or a CSS selector. It can also implement the collection process by accessing a web page with a simple code. Jsoup allows users to make the analysis and access both effective and ineffective tags provided in a tree structure approach [24].

The system was designed to collect rating data from GRAC's homepage as shown in Figure 7. The system consists of a URL collection module, connection module, detailed

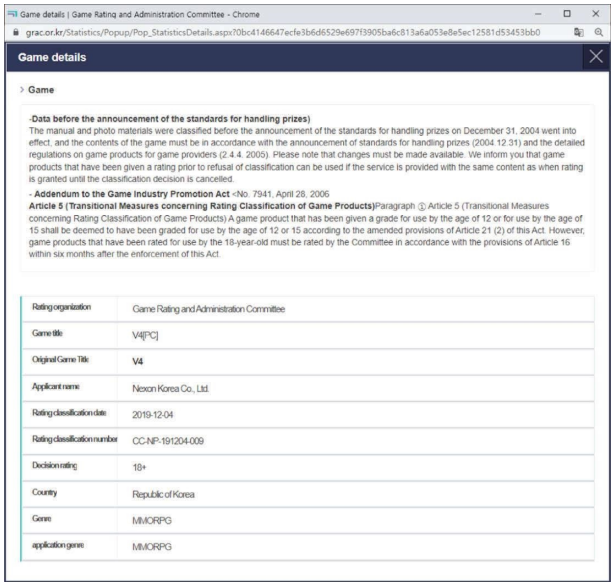


Figure 5: Game details (Google Translate Web).

Table 5: Game details item description.

Items	Sample data
Rating organization	GRAC
Game title	V4 (PC)
Original game title	V4
Applicant name	Nexon Korea
Rating classification date	2019-12-04
Rating classification number	CC-NP-191204-009
Decision rating	18+
Country	Korea
Genre	MMORPG
Application genre	MMORPG

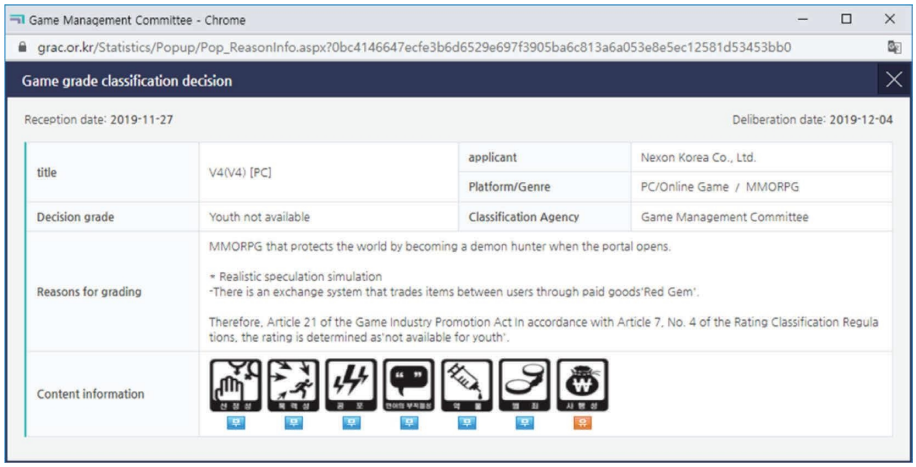


Figure 6: Game rating on page of a written decision on games page (Google Translate Web).

collection module, and storage module. The scheduler controlled the requests and modules.

The system collected detailed page URLs of each game and then verified whether the data exists in the relevant URLs. Then, the detailed page URL of each game was accessed to collect the rating data and store them in the database to build the data for game rating. Then, the system determined the state on whether data were stored normally by a scheduler, the time when the collection was done, and the time when storage was completed. Table 10 shows the

Table 6: Game rating on page of a written decision on games item description.

Items	Sample data
Game title	V4 (PC)
Applicant name	Nexon Korea
Platform/genre	PC/OnlineGame/MMORPG
Decision rating	18+
Rating organization	GRAC
Reasons for rating	When the portal opened, MMORPG became a demon hunter and protected the world. *Copying realistic gambling practices (i) Exchange system exists to trade items between users through paid goods 'Red Gem' (skip)
Content descriptors (sexuality, violence, fear, language, drugs, crime, and gambling)	YES: gambling NO: sexuality, violence, fear, language, drugs, and crime

Table 7: Derived items based on the pages provided the GRAC website.

Related pages	Page items	Derived items	Classification
Detailed information on games page	Game title	Game title	Game information
	Country	Country	
	Applicant name	Applicant name	
	Genre	Genre	
	Original title	Original title	
	Decision rating	Decision rating	Rating decision information
	Rating organization	Rating organization	
	Rating classification date	Rating classification date	
	Rating number	Rating number	
A written decision on the game rating	Platform/genre	Platform/genre	Game information
	Reasons for rating	Reasons for rating Key reasons for harm rating	
	Content descriptors	Sexuality, violence, fear, drugs, language, and gambling	

Table 8: Game rating classification information, public data extension item description, and sample data.

Items	Sample data
Game title	V4 (PC)
Country	Korea
Decision rating	18+
Hoperate	18+
Rating organization	GRAC
Applicant name	Nexon Korea
Genre	MMORPG
Platform	PC/OnlineGame
Reasons for rating	*Copying realistic gambling practices (Exchange system exists to trade items between users through paid goods 'Red Gem')
Sexuality	NO
Violence	NO
Fear	NO
Drug	NO
Language	NO
Crime	NO
Gambling	YES
Game content description	When the portal opened, MMORPG became a demon hunter, and protected the world.
Rating classification number	CC-NP-191204-009
Rating classification date	2019-12-04

Table 9: Data collection system environment.

Items	Contents
Base language	JAVA
Development environment (program)	Eclipse
Development environment (OS)	Windows 10 64bit
Development equipment	I7–7700K 4.20 GHz, RAM 16GB
Using library	Jsoup

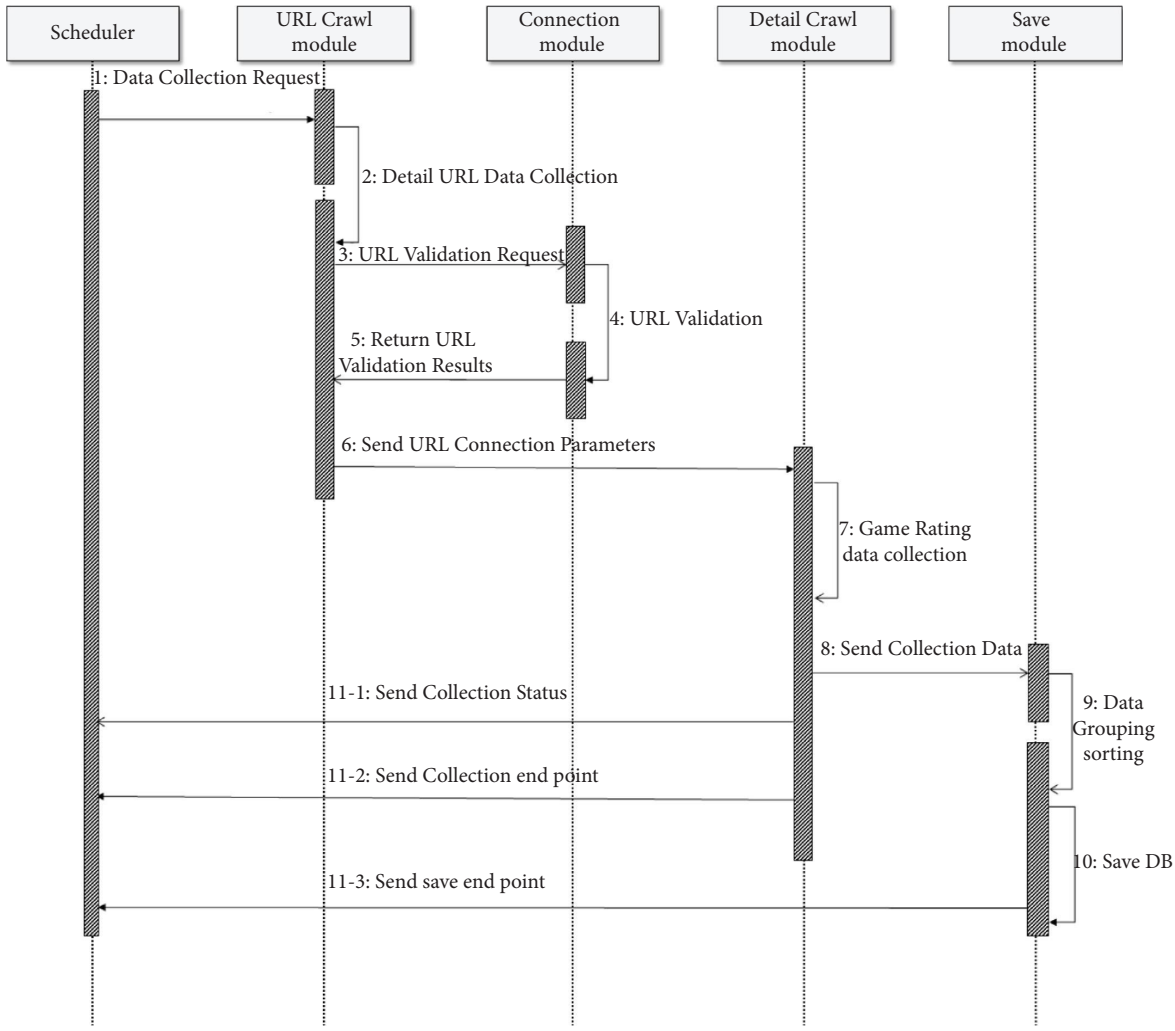


Figure 7: Classification data acquisition system sequence diagram.

Table 10: Data collection history.

Items	Volumes
Data range collected	1988.01.01 ~ 2020.05.10
Registered games	80,180
Game details page	80,180 (contains pages where only URLs exist)
Classification decision page	29,963

results of data collection through the system. The collected data for game rating amounted to a total of 80,180 from May 12, 2020 to May 15, 2020 as shown in Table 10.

If a user requests information from a game rating database built through the proposed collection system, a preindexed dataset delivers the user's requested data. The

```
▼<result>
  <tcount>1</tcount>
  <res_date>17:19 2021-2-26</res_date>
 ▼<item>
   <gametitle>V4 [PC]</gametitle>
   <national>Korea</national>
   <givenrate>18+</givenrate>
   <hoperate>18+</hoperate>
   <orgname>GRAC</orgname>
   <entname>Nexon Korea</entname>
   <genre>MMORPG</genre>
   <platform>PC/OnlineGame</platform>
   <coreHarmRsn>* Copying realistic gambling practices - Exchange system exists to trade items between
   users through paid goods 'Red Gem')</coreHarmRsn>
  ▼<Harm_list>
     <sexuality>NO</sexuality>
     <violence>NO</violence>
     <fear>NO</fear>
     <drugs>NO</drugs>
     <lang>NO</lang>
     <gambling>YES</gambling>
   </Harm_list>
   <game_Continfo>When the portal opened, MMORPG became a demon hunter and protected the world.
   </game_Continfo>
   <rateno>CC-NP-191204-009</rateno>
   <rateddate>2019-12-04</rateddate>
  </item>
 </result>
```


(a)


```
{} result
  tcount : "1"
  res_date : "17:19 2021-2-26"
  {} item
    gametitle : "V4 [PC]"
    national : "Korea"
    givenrate : "18+"
    hoperate : "18+"
    orgname : "GRAC"
    entname : "Nexon Korea"
    genre : "MMORPG"
    platform : "PC/OnlineGame"
    coreHarmRsn : "Copying realistic gambling practices- Exchange system exists to trade items between users through paid goods 'Red Gem')"
    {} Harm_list
      sexuality : "NO"
      violence : "NO"
      fear : "NO"
      drugs : "NO"
      lang : "NO"
      gambling : "YES"
    game_Continfo : "When the portal opened, MMORPG became a demon hunter and protected the world."
    rateno : "CC-NP-191204-009"
    rateddate : "2019-12-04"
```


(b)

Figure 8: Classification extended public data output results (ENG): (a) XML; (b) JSON.

requested data are arranged sequentially based on their IDs and provided to the users in XML and JSON forms as shown in Figure 8.

In order to prove the utilization of the extended result data through the redesigned system in this paper, a comparison was made with other rating systems of movies. First, the preexisting GRAC rating system presents fragmentary items such as the game name, the decided rate, and the rating institution. On the other hand, the proposed extended data shows detailed information on the game's genre, platform, descriptions, and the reasons for the review, sensationality, and violence as shown in Table 11. Thus, the extended data can be used as the basis for analysing the ratings. Second, it can be seen that the proposed game rating system is comparatively inclusive and structural enough to satisfy the public for the better and easier public data usage as shown in Table 12.

6. Discussion

After analysing the current system of the GRAC, the information provided to the public are very limited compared to other media rating system such as movies. Thus, this study first drew the items to be added for better understanding and fair rating system, and secondly designed a data collection system tailoring to the extended public classification data. The designed and implemented collection system successfully built the expanded public data provision foundation and was comparatively inclusive and structural to satisfy the public for the better and easier public data usage.

Table 11: Data collection history.

Variable names	Existing API result data	Extended result data
Gametitle	V4 (PC)	V4 (PC)
National	-	Korea
Givenrate	18+	18+
Hoperate	18+	18+
Orgname	GRAC	GRAC
Entname	Nexon Korea	Nexon Korea
Platform		PC/OnlineGame
Genre	—	MMORPG
coreHarmRsn	—	*Copying realistic gambling practices - Exchange system exists to trade items between users through paid goods 'Red Gem')
Sexuality	—	NO
Violence	—	NO
Fear	—	NO
Drugs	—	NO
Lang	—	NO
Crime	—	NO
Gambling	—	YES
game_Continfo	—	When the portal opened, MMORPG became a demon hunter and protected the world.
Rateno	CC-NP-191204-009	CC-NP-191204-009
Rateddate	2019-12-04	2019-12-04

Table 12: Comparisons among the rating system of movies, video, and (proposed) digital games.

Categories	Movies	Videos	Digital games
Information	Director	Director	—
	Director's nationality	Director's nationality	Country
	Main actor/actress	Main actor/actress	Applicant name
	Genre	Medium	Genre
	Original title	Original title	Original title
	Production year	Production year	—
	Producer	Producer	—
	Production country	Production country	Country
	Running time	Running time	—
	Size	Size	Platform
	Title(translated title)	Title(translated title)	Game title
	Plot	Plot	Game description
Rating information	Decision rating	Decision rating	Decision rating
	—	Desired rating	Desired rating
	—	-	Rating organization
	Rating number	Rating number	Rating number
	Rating classification date	Rating classification date	Rating classification date
	Key reasons for harm rating	Key reasons for harm rating	Key reasons for harm rating
	Topic	Topic	—
	Sexuality	Sexuality	Sexuality
	Violence	Violence	Violence
	Fear	Fear	Fear
	Drugs	Drugs	Drugs
	Language	Language	Language
	Copycat risk	Copycat risk	Gambling

7. Conclusion

As the game industry and its users are rapidly expanding in South Korea, the public needs to check and gain the information about the games are also increasing. Unlike rating agencies in other countries that are comprised of private institutions, the GRAC in South Korea serves as a public institution [25]. Korean public institutions have a legal obligation to disclose the data that they held so the rating system needs to be thoroughly examined to strengthen fairness and the public's right to know [26]. To properly perform this obligation, the entity must provide specific classification information including the research results, rather than just formal disclosure [27]. Thus, this paper was

conducted to redesign the game rating system that the GRAC currently provides to make it a proper and fair rating system.

Further studies on expanding to big data analysis methods such as clustering and factor analysis will be conducted to predict the time of deliberation of games. Recently, research such as performance analysis of ML models for game grade prediction has been conducted [28]. This study will be the basis for expanding research to artificial intelligence or machine learning for game grade classification. In addition, the advanced big data analysis will be considered by utilizing ICT technologies such as machine learning and artificial intelligence.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Conceptualization was done by K.-H.S.; data analysis was done by K.-H.S.; data curation was done by K.-H.S.; original draft preparation was done by K.-H.S. and K.-J.Y.; review and editing was done by K.-J.Y. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

This research was supported by Ministry of Culture, Sports and Tourism and Korea Creative Content Agency (project number: R2020040243). This work was also supported by the Gachon University Research Fund of 2020 (GCU-202008460010), excerpt submitted thesis by HoSeong Kang for Master's degree, University of Gachon, Republic of Korea, in 2020.

References

[1] "White paper on Korean games (KOCCA)," 2019, https://www.kocca.kr/cop/bbs/view/B0000146/1841389.do.

[2] "Act on the promotion of the game industry promotion act(korea) ," 2021.

[3] J. I. Kim, "Problems of game rating policy in Korea and proposal for improvement," *HUFS Law Review*, vol. 41, no. 4, pp. 89–117, 2017.

[4] S. G. Hwang, "The present state and improvement direction of the major regulations on internet game," *Journal of Media Law, Ethics and Policy Research*, vol. 17, no. 3, pp. 1–35, 2018.

[5] S. H. Lee, "Case study on rating practice of GRAC that restrict freedom of expression," *KSCG*, vol. 28, pp. 75–82, 2015.

[6] C. S. Kim and T. S. Park, "Consideration on role and functions of game rating board," *The Journal of the Korea Contents Association*, vol. 7, no. 4, pp. 114–122, 2007.

[7] S. W. Kim, H. S. Jung, and H. S. Lee, "A study on improvement way of game rating system," *JKGS*, vol. 19, no. 5, pp. 15–37, 2019.

[8] "About career interrupted women, disabled people, and professionalism of the monitoring team of the Game Committee," 2021, https://www.gamemeca.com/view.php?gid=1459016.

[9] "The eyes on the game are 'housewives'... Monitoring bias severe," 2021, http://www.topdaily.kr/news/articleView.html?idxno=51284.

[10] "GRAC 'game monitoring team'.. "Professionalism" concerns still remain," 2021, http://biz.newdaily.co.kr/site/data/html/2019/04/09/2019040900155.html.

[11] D. W. Kim, "Problems and problems and improvement of game rating system - focused on IARC member countries," *JCCT*, vol. 5, pp. 321–327, 2019.

[12] "The act on the promotion of public data provision and utilization(korea) ," 2021.

[13] D. A. Walsh and D. A. Gentile, "A validity test of movie, television, and video-game ratings," *Pediatrics*, vol. 107, no. 6, pp. 1302–1308, 2001.

[14] P. Nikken, J. Jansz, and S. Schouwstra, "Parents' interest in videogame ratings and content descriptors in relation to game mediation," *European Journal of Communication*, vol. 22, no. 3, pp. 315–336, 2007.

[15] D. Felini, "Beyond today's video game rating systems: a critical approach to PEGI and ESRB, and proposed improvements," *Games and Culture*, vol. 10, no. 1, pp. 106–122, 2015.

[16] K. L. Becker-Olsen and P. A. Norberg, "Caution, animated violence: assessing the efficacy of violent video game ratings," *Journal of Advertising*, vol. 39, no. 4, pp. 83–94, 2010.

[17] M. K. Tak, "A Study on the legal issues of classification of game contents," *Cohnbuk Law Review*, vol. 54, pp. 133–153, 2017.

[18] C. H. Shin, "A study on the harmonization and development of the game rating system-with respect to the international age rating coalition (IARC)," *The Journal of Cultural Policy*, vol. 34, no. 1, pp. 187–215, 2020.

[19] Y. M. Kim, "A study on the administrative law for the improvement of the online game regulatory system in korea-focusing on the grading and self-regulatory system," *CAUJLS*, vol. 44, no. 1, pp. 305–338, 2020.

[20] H. S. Lim and J. W. Shin, "Analysis of insufficiency about self-classification system for mobile games," *A Treatise on The Plastic Media*, vol. 21, no. 2, pp. 150–157, 2018.

[21] "Game ratings and administration committee - game API," 2021, https://www.grac.or.kr/Game3.0/OpenAPIGuide.aspx.

[22] "Video rating board movie classification list," 2021, https://www.data.go.kr/data/3043382/openapi.do.

[23] "Game ratings and administration committee - check for decision on rating," 2021, https://www.grac.or.kr/Statistics/GameStatistics.aspx.

[24] "Jsoup: Java HTML parser," 2021, https://jsoup.org/.

[25] S. W. Kim, H. S. Lee, and H. S. Jung, "A global comparative study on the game rating system," *JDC*, vol. 17, pp. 91–108, 2019.

[26] H. Kang and J. Kim, "A study on ways to extend public data for game ratings from Korea," 2021.

[27] B. Haberer and D. Schnurr, "Open government data for digital services: effects on innovation, competition and societal benefits," in *Proceedings of the TPRC48: The 48th Research Conference on Communication, Information and Internet Policy*, September 2020.

[28] F. Zhipeng and H. Gani, "Interpretable models for the potentially harmful content in video games based on game rating predictions," *Applied Artificial Intelligence*, vol. 36, no. 1, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9501415, 16 pages
https://doi.org/10.1155/2022/9501415

Research Article

An Empirical Study on the Digital Display Design of Intangible Cultural Heritages Based on Audience Satisfaction

Lei Zhang,[1] **Di Fu**,[1] **and Jinlong Zhao**[2]

[1]*College of Art and Design, Wuhan Textile University, Wuhan 430079, China*
[2]*The Hubei Research Centre for Intangible Cultural Heritage, Wuhan Textile University, Wuhan 430073, China*

Correspondence should be addressed to Jinlong Zhao; fzgh@wtu.edu.cn

Received 18 August 2022; Revised 18 September 2022; Accepted 22 September 2022; Published 5 October 2022

Academic Editor: Lele Qin

How the audience perceive the display of intangible cultural heritages (ICHs) and what are their psychological needs of ICH display are of great value to the display design of ICHs. This article carries out a questionnaire survey on the audience of the "Splendid China" ICH costume show and empirically analyzes the survey results. After constructing the American Customer Satisfaction Index (ACSI), the authors classified the psychological needs of customers for the on-site display of ICHs through analytical hierarchy process (AHP) and factor analysis, conducted the theoretical discussion, and verified the results with actual data. The research explores how should the digital display of ICHs be designed to satisfy the audience and provides a reference for China's ICH display designers. The research shows that the construction of a public satisfaction evaluation model for the digital display of ICHs is the key to satisfaction evaluation, there is ample room to improve public satisfaction with the digital display of ICHs, the dissemination of ICH can be strengthened through model construction, and personalized service is an effective way to promote the digital development of ICHs.

1. Introduction

The display design of intangible cultural heritages (ICHs) fully reflects China's ICH protection principle of inheriting and representing vitality. It provides an important way to promote ICHs, making the public understand and love ICHs. However, the actual display effect of the "Splendid China" costume show and related textile and apparel ICH exhibitions was not desirable. Due to the lack of scientific management and effect feedback mechanism, some ICH exhibitions fail to attract the audience, albeit incurring a high cost. The audience are not very impressed, and some exhibitions are way to commercialized.

During ICH displays, the audience do not merely glance over the exhibits but go through a complex psychological process. The visit helps the audience form an overall cognition of ICHs through reasonable imagination, as their memories are invoked by the visual, auditory, and tactile perceptions of ICHs [1]. In essence, visiting an ICH display is about the mutual influence and interaction between ICH skills and the audience's psychological activities [2]. To inherit and disseminate ICH culture, it is crucial to explore the ICH display design based on the audience's perception and preference.

The significance of this research is to expand the research fields of ICH, design, and communication and to provide theoretical reference for promoting the creative transformation and innovative development of excellent traditional culture, at the same time promote the systematic protection of ICHS, provide consultation for the competent department of ICH exhibition and display, and provide a reference for the design practice of ICH display. As a combination of human knowledge and skills and aesthetic taste, the dissemination of ICH is facing the dilemma of "difficult to enter and difficult to exit." In order to greatly improve the dissemination effect of ICH, it is necessary to focus on audience satisfaction and actively use artificial intelligence technologies such as computer recognition, human-computer interaction, and simulation scene construction, in the digitization of dissemination subjects, the correlation of

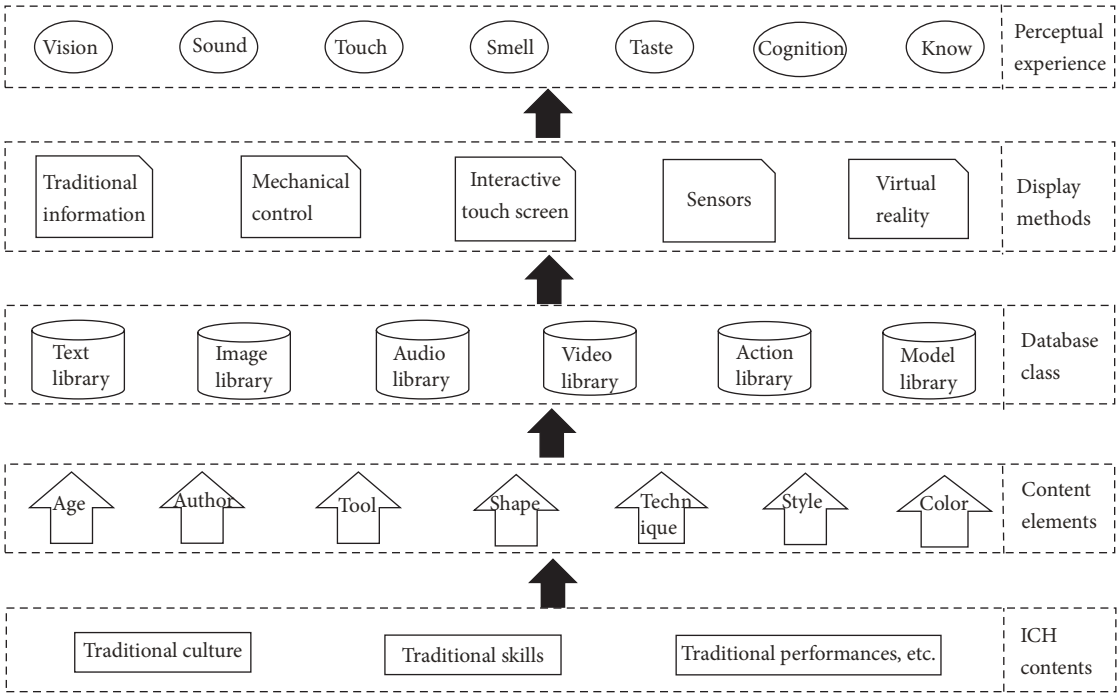


Figure 1: Flow of ICH digital display.

dissemination objects, and the liveliness of dissemination content. Innovate the ways of communication of ICHs from the expansion and diversification of dissemination channels.

2. Theoretical and Technological Overview

2.1. Overview of ICH Digital Display Technologies. Digital display compiles and reorganizes the contents of the exhibit in a way to form a complete work of digital display, using digital technology as the main technical means [3]. Currently, the traditional protection and inheritance methods of ICH can no longer meet the needs of development, which requires the continuous development of ICH display towards the digital display. The digital display of ICHs relies heavily on new media technologies, such as virtual reality, human-computer interaction, and augmented reality, to make the display authentic, complete, and interactive [4].

In the field of digital display, the ingenious application and combination of different technical means can stimulate the vitality of ICHs and improve the effectiveness of digital display, promoting innovation in the field [5]. However, advanced technology is not necessarily suitable. The digital display effect of ICHs can only be maximized by fully stimulating the audience's senses, which calls for mining the inherent elements of different kinds of ICHs, and utilizing scientific and reasonable digital technology [6].

Figure 1 shows the flow of ICH digital display [7]. Starting from the ICH contents, ICH digital display involves content elements, database classes, display methods, and the perception experience. Based on the dissemination features of ICHs and appropriate digital technology, this article analyzes the display methods of different types of ICHs, with the aim to extract differentiated features of each type, and leaves the audience an excellent impression [8].

The research on ICH digitization technology started early in Europe and North America and has achieved outstanding results in theory and application. For example, Rossella Cafib expounded the opportunities and challenges of digital cultural heritage protection in ethnic cultural areas and gave examples of its application in Italian libraries, cultural protection departments, and tourism departments [9]. Hong [10] studied the strategies and methods of digital recording of ICHs and enumerated the advantages and disadvantages of digital recording, providing a guide for digital acquisition. Idris et al. [11] clarified the relationship between cultural diversity and ICH digitization and discussed the strengths and weaknesses of the application of ICH digitization technology as well as related issues. Using the open data resources of social media, Kyriacos [12] carried out a three-dimensional (3D) visual reconstruction of cultural heritages. Suarez et al. [13] promoted the protection and inheritance of cultural contents, using computer modeling tools and virtual reality, combined with the sensory experience of archaeological acoustics.

The technology application in China is as follows: Focusing on the ICHs of ethnic minorities in western Hunan province, Dong [14] and Zhang and Zhao [15] proposed a digital protection strategy for digital museums and other entities. Song et al. [16] investigated the display of domestic digital websites and presented the construction strategy and model for creating a comprehensive network platform. Meanwhile, some progress has been achieved by ICH researchers in the digital protection of traditional handicrafts with regional features. The relevant researchers have constructed ICH digital collection standards, the reproduction

methods of ICH digital storage, the general architecture of ICH database construction, and other digital strategies [17–21].

With the advent of the era of digital communication, the characteristics of the Internet, such as interactivity, speed, convenience, openness, and comprehensiveness, have profoundly affected the way of digital display and dissemination of ICHs. Therefore, the dissemination characteristics of China's ICHs in the digital ecological environment have also occurred. Great changes and presents the following five new characteristics: plasticity, rheology, unboundedness, sharing, and interactivity. (1) Plasticity – showing the state of active display; (2) rheology – from invisible bearing to polymorphic rheology; (3) unbounded – from local cognition to wide-area communication; (4) sharing – across regional boundaries; and (5) interactivity – multidirectional interaction and "circle layering." Finally, based on the integration of digital technology and media, the advantages of digital display and dissemination will be brought into play, and intelligent and innovative digital display and dissemination methods of China's ICHs will be developed.

At present, the wide application and popularization of 5G technology in China is bound to bring about innovative changes in various industries. With the continuous development and large-scale application of AI technology, the digital communication of ICH has also been pushed into the era of application scenario experiential communication. This requires making full use of modern digital technology and AI technology to enhance the scene-based experience of ICH, which is embodied in two aspects: first, content experience, building an ICH virtual experience center, and comprehensively using VR and augmented reality, 3D dynamic, and other digital technologies, to show the audience the content of ICH culture, inheritance history, craftsmanship, and other contents from multiple dimensions and enhance the scene interaction and experience of ICHs.

2.2. Overview of Satisfaction Index Research. In 1965, American scholar Cardozo proposed customer satisfaction—the very first concept of satisfaction. Since then, the meaning of satisfaction, the evaluation method of satisfaction, and the analysis model of satisfaction have been widely studied and used. At present, business and academic circles commonly define satisfaction as a person's feeling of pleasure or disappointment, which resulted from comparing a product's perceived performance or outcome against his/her expectations, following the definition given by Philip Kotler, father of modern marketing. Satisfaction measures the level of his/her satisfaction.

Domestic and foreign scholars and institutions have established customer satisfaction evaluation models and utilized them to measure customer satisfaction, for example, Fornell and Larcker's [22] normal quality (NQ) standard model, Churchill and Supernant's [23] evaluated performance (EP) behavior evaluation model, and Parasuraman et al.'s [24] SERVQUAL model. In addition, Sweden established the Sweden Customer Satisfaction Barometer (SCSB) in 1989, based on which Europe constructed the European Customer Satisfaction Index (SCSI) [25]. Since 1999, China started to build China Customer Satisfaction Index (CCSI) and has achieved certain results.

The current research on satisfaction, especially customer satisfaction, is relatively systematic and mature in China. But the domestic research on ICH display satisfaction has just started. Chen Bin, a pioneer in this field [26], examined the quadrant graph model based on importance and satisfaction and discovered that professional visitors and exhibitors have obviously different evaluations of the exhibition objectives and indices. Ju et al. [27] used factor analysis to analyze the exhibition features valued by exhibitors and the exhibitors' perception of each characteristic index. But they did not directly measure or consider the core of audience satisfaction. He [28] adopted the structural equation model to construct a model of factors affecting the Chinese audience's satisfaction of international ICHs.

Later, domestic scholars have combined the quadrant graph model with factor analysis and structural equation model to study audience satisfaction. For instance, Xu et al. [29] first carried out an exploratory factor analysis on 21 original indices and then performed structural equation modeling. Later, scatterplots were drawn and analyzed according to the importance rated by the organizers and audience satisfaction. Wu and Zhang [30] successively analyzed 21 main factors affecting tourists' destination choice through factor analysis, structural analysis model, and quadrant graph model.

During the survey, satisfaction is actually a multivariate selection variable for ranking. The domestic research on ranking qualitative variables is relatively mature. For example, Lin and Ai [31] established an ordered probit regression model to examine the influence of main individual demographic features and social-economic status variables (e.g., age, income, gender, and education) over display demand. Zhao and Miao [32], Jin et al. [33], and Guo [34] also constructed and applied the probit model to systematically analyze the ranking qualitative variables in their research. Some domestic scholars have also used the probit model to analyze satisfaction.

On this basis, the United States constructed the American Customer Satisfaction Index (ACSI) evaluation model in 1994, which is a customer-based organizational performance evaluation system and a market- or customer-oriented performance evaluation method [35]. There are many researches on ACSI at home and abroad [36–39]. The ACSI model is a national-level global customer satisfaction evaluation model that takes the quality of products or services as the evaluation object and including four levels: department, enterprise, industry, and country. The US government takes the ACSI model as the foundation, refers to its own domestic government service status and characteristics of public services, and finally obtains the US government public satisfaction index evaluation model, which is an innovative application of the customer satisfaction model in the government public service level. Figure 2 presents the final improvement of the ACSI model [40], which covers public expectations, perceived quality, public satisfaction, public complaints, and public trust [41].

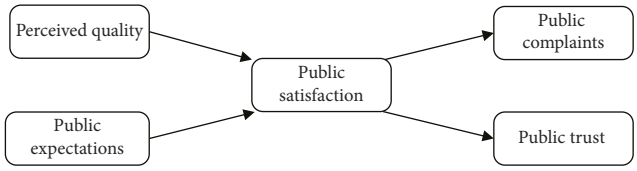


Figure 2: ACSI model.

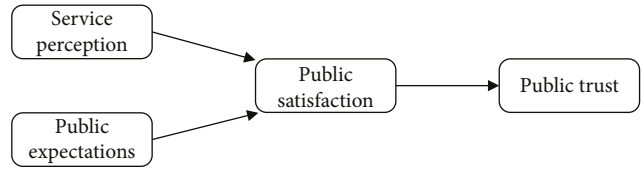


Figure 3: ACSI-based public satisfaction index model for ICH digital display.

ACSI is a macro-index to measure the quality of economic output. It is a comprehensive evaluation index of audience satisfaction level based on the process of product and service consumption. It is a national audience satisfaction theory with the most complete system and the best application effect model. The biggest feature of ACSI is that audience satisfaction can not only be compared between different products and industries but also between different customers of the same product, reflecting the differences between people. Compared with other models, the biggest advantage of the ACSI model is that it can carry out cross-industry comparisons, as well as vertical and cross-time comparisons, which has become a barometer of the US economy. At the same time, ACSI is a very effective management tool, which can help companies compare with competitors and evaluate their competitive position. It should be pointed out that ACSI is an accurate quantitative economic model established based on advanced consumer behavior theory. It is used to monitor the macroeconomic operation, and the main consideration is the comparison of audience satisfaction across cross-industry and cross-industry sectors, rather than firm-specific diagnostic guidance, so this model is rarely used in micro-level satisfaction surveys.

Based on the above discussion, this article takes the theory of ICH digital display service and satisfaction as the basis, and by sorting out and analyzing the related theories of public satisfaction in the digital display of ICH, it creates conditions for the subsequent theoretical integration. (1) The digital dissemination of ICH should not be bound by the boundaries of traditional communication methods and continue to lead the innovation of ICH dissemination through its own technological advantages so as to help the continuous advancement of ICH in terms of protection and inheritance. At the same time, it also provides a new model for the inheritance of the current ICHs. (2) The research on satisfaction (especially customer satisfaction) provides an important reference for the display of ICHs.

3. Model Construction

3.1. Evaluation Model. The original ACSI model contains five structural variables, while the optimized ACSI model has four structural variables (Figure 3). In order to further optimize the structure, the research is guided by the public satisfaction index structure model constructed by the US government and further improved. Positive sentiment is relative, so incorporating the structural variable of public complaints into public trust is more conducive to building a public satisfaction evaluation model for the digital display of ICHs:

(1) Public expectations: the public's pre-event expected service level for the digital display service provided by the ICH digitization service provider. As the object of ICH digital services, the public must have expectations for the services they enjoy. Its structural variables include the following three observation variables: the overall expectation of ICH digital display service, the ICH new media communication service expectation, and the ICH venue digital service expectation.

(2) Service perception: the public's actual perception of the digital display service provided by the ICH service provider. Due to the difference between each person's subjective ideology and the actual external environment, they will also have differentiated psychological perceptions of the same service they enjoy. The evaluation variables include the service perception of the digital dissemination of ICH and the digital service of ICH venues.

(3) Public satisfaction: the public's post-event satisfaction with the digital display service provided by the ICH digitization service provider. The observed variables include the public's overall satisfaction with ICH digital services and the public's satisfaction with new media dissemination of ICH digital services and venues.

(4) Public trust: the public's psychological response, emotional response, and complaints to/about the digital display service provided by the ICH digitization service provider [42, 43]. The high level of satisfaction brought by a good digital display service of ICH can convey more positive emotions; otherwise, it will bring the opposite result. The observed variables are divided into the following three aspects: the public's reuse of ICH services, the public's recommendation of ICH services, and the public's complaints about services.

3.2. Calculation Principle. Our discussion and empirical analysis mainly utilize analytic hierarchy process (AHP) and factor analysis method (FAM), aiming to provide a guide for future calculation of satisfaction indices. The research mainly refers to the calculation principle of Cheng [44]. The calculation principle of public satisfaction index for ICH digital display is as follows:

(1) Let ξ denote public satisfaction; $x_1, x_2, \ldots, x_m$ denote the observed variables of public satisfaction; $\lambda_1, \lambda_2, \ldots, \lambda_m$ denote the standardized path

Table 1: Measurement indices.

Structural variables	Observed variables
Public expectations (ξ)	Overall expectation of ICH digital display service (x_1) Expectation of ICH new media communication service (x_2) Expectation of ICH venue digital display service (x_3)
Service perception (η_1)	Perception of f ICH new media communication service (y_1) Perception of ICH venue multimedia service (y_2) Perception of ICH venue human-machine interaction service (y_3)
Public satisfaction (η_2)	Overall satisfaction with ICH digital display service (y_4) Overall satisfaction with ICH new media communication (y_5) Overall satisfaction with ICH venue digital display (y_6)
Public trust (η_3)	Complaints (y_7) Public reuse of ICH digitization service (y_8) Public recommendation of ICH digitization service (y_9)

coefficients of $x_1, x_2, \ldots, x_m$ relative to ξ, then public satisfaction can be calculated as

$$\text{publicsatisfaction} = \frac{E(\xi) - \text{Min}(\xi)}{\text{Max}(\xi) - \text{Min}(\xi)} * 100, \quad (1)$$

where $E(\xi) = \sum_{i=1}^{m} \lambda_i \overline{x}_i$; $\text{Max}(\xi) = \sum_{i=1}^{m} \lambda_i \ \text{Max} \ (x_i)$; and $\text{Min}(\xi) = \sum_{i=1}^{m} \lambda_i \ \text{Min} \ (x_i)$. $E(\xi)$, $\text{Max}(\xi)$, and $\text{Min}(\xi)$ are the mean, maximum, and minimum of public satisfaction, respectively; $\overline{x}_i$, Max (x_i), and Min (x_i) are the mean, maximum, and minimum of x_i, respectively, $i \in \Omega_m$.

(2) Formula (1) can be properly simplified as

$$\text{publicsatisfaction} = \sum_{i=1}^{m} \lambda_i \overline{x}_i, \quad (2)$$

where $\lambda_1, \lambda_2, \ldots, \lambda_m$ are the standardized path coefficients of $x_1, x_2, \ldots, x_m$ relative to ξ; and $\overline{x}_i$ is the mean of x_i, $i \in \Omega_m$. The relevant indices of the observed variables can be weighted by

$$y_i = \frac{1}{n} \sum_{j=1}^{n} w_i y_{ij}, \quad (3)$$

where y_i is the evaluation item; y_{ij} is the score of item y_i against an index; w_i is the weight (importance) of that index; and n is the number of indices for evaluating item y_i.

(3) The FAM measures the degree of influence of each variable on the structural model, in the light of the correlation between variables, and then describes the model generally with a few common factors.

In the null hypothesis model, there are k measurement indices and n statistical variables:

$$X_i = \alpha_{i1}\lambda_1 + \alpha_{i2}\lambda_2 + \cdots + \alpha_{ip}\lambda_m + \varepsilon_i, \quad (4)$$

where $\lambda_1, \lambda_2, \ldots, \lambda_m$ are the common factors of the model (these factors are related to all statistical variables; their correlation coefficients are 0, a sign of the independence between them); ε_i is the unique special correlation factor of each statistical variable X_i; and coefficient α_{i1} is the weight index of the jth common factor relative to the ith statistical variable, reflecting the explanatory power and effect of the common factor on that variable [43]. Because in factor analysis, only jth main factors are usually selected, that is, the first main factor is selected according to the correlation of variables, so that its contribution to the variance of the common factor variance of each variable is the largest, and then the variance of this factor is eliminated. Therefore, $\alpha_{i1} > 0.5$.

3.3. Evaluation Method. The public satisfaction evaluation model for ICH digital display consists of four structural variables, namely public expectations, service perception, public satisfaction, and public trust; each structure contains one or more observed variables. The variables interact with each other to form a whole. The author mainly refers to the evaluation methods and models of scholar Cheng [44] and recollects the data for calculation. The specific variables are defined in Table 1.

The public satisfaction evaluation model for ICH digital display assumes that there is a linear relationship between variables. The structural variable of public expectations is the only exogenous causal variable in the model, while the other structural variables are the endogenous structural variables. The relationship can be represented by three matrix equations, including one structural equation and two measurement equations:

Structural equation:

$$\eta = A\eta + B\xi + m. \quad (5)$$

Measurement equations:

$$\begin{aligned} Y &= \Lambda_1 \eta + n, \\ X &= \Lambda_2 \eta + p, \end{aligned} \quad (6)$$

where A and B are the coefficient matrices reflecting the structural variable relationship in the structural model (A can be regarded as the relationship matrix of the mutual influence between all endogenous structural variables, and B can be understood as the relationship matrix of the influence of the exogenous structural variable "public expectations" on all endogenous variables); $\Lambda_1 and \Lambda_2$ are the relationship matrices of the mutual influence between observed variables,

and that between structural variables; and m, n, and p are the error vectors of the three equation models, respectively.

The three matrix equations are as follows:

The structural model, that is, the relationship between structural variables can be calculated as

$$\begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta_{21} & 0 & 0 \\ 0 & \beta_{32} & 0 \end{bmatrix} * \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} + \begin{bmatrix} \gamma_{11} \\ \gamma_{12} \\ 0 \end{bmatrix} * \xi + \begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix}, \quad (7)$$

where $\eta_1, \eta_2, \text{and} \eta_3$ are service perception, public satisfaction, and public trust, respectively; β_{ij} is the degree of influence of endogenous structural variable j on endogenous structural variable i; γ_{ij} is the degree of influence of endogenous structural variable ξ on exogenous structural variable η_j; and m is the error vector of the model.

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \\ y_9 \end{bmatrix} = \begin{bmatrix} \varphi_{11} & 0 & 0 \\ \varphi_{21} & 0 & 0 \\ \varphi_{31} & 0 & 0 \\ 0 & \varphi_{42} & 0 \\ 0 & \varphi_{52} & 0 \\ 0 & \varphi_{62} & 0 \\ 0 & 0 & \varphi_{73} \\ 0 & 0 & \varphi_{83} \\ 0 & 0 & \varphi_{93} \end{bmatrix} * \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \\ n_8 \\ n_9 \end{bmatrix}, \quad (8)$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} * \xi + \begin{bmatrix} \rho_1 \\ \rho_2 \\ \rho_3 \end{bmatrix}, \quad (9)$$

where $x_1, x_2, \text{and} x_3$ are the observed variables of exogenous structural variable public expectations (ξ); $y_1, y_2, y_3 \cdots y_8, \text{and} y_9$ are the observed variables of service perception (η_1), public satisfaction (η_2), and public trust (η_3);φ_{ij} andω_i are the coefficients of the coefficient matrices Λ_1 *and*Λ_2 of the measurement models, respectively (the two coefficients reflect the degree of influence of each structural variable over its own observed variables); and n_i andρ_i are the error vectors of the two models, respectively.

This article will use the Amos Graphics tool in the statistical software SPSS to construct and analyze the structural model in order to derive the structural equations of the measurement model of public satisfaction of the digital display of ICH and to verify and optimize the path coefficients of the measurement equations in order to obtain the optimal fitting model. Common model validation fit indicators are P-value, confidence level, significance level, chi-square value, chi-square ratio, canonical fit index, etc. Among them, P-value is generally applied together with the significance level for true-false speculation of the hypothesized model. And it is generally considered that if $P < 0.10$, it can indicate that the model test variable is significant and the original hypothesis is not valid.

The specific index criteria are as follows [44].

3.3.1. Chi-Squared Test. To test the reasonableness of the model, or to verify the consistency of the theoretical model with the empirical data, some scientific indicators are needed. One of the most commonly used evaluation indicators is the chi-squared statistic. Its derived formula is as follows:

$$x^2 = (N-1)F_{\min}, \quad (10)$$

where x^2 represents the check value of the model fit and N is the number of samples, and $F_{\min}$ indicates the minimum value of the test equation derived by different parameter estimation methods (maximum likelihood estimation and generalized least squares method).

At the significance level, if $x^2 < x_\alpha^2$, it indicates that the original hypothesis is approved and the model fit meets the requirements. Otherwise, the original hypothesis is rejected and the alternative hypothesis is accepted. From the above, it can be seen that the chi-squared test statistic is smaller, and the data is the better. It can also be seen that when its value is 0, it indicates that the measured data fit the hypothesized model perfectly.

3.3.2. Goodness-of-Fit Index. GFI (goodness-of-fit index) is the division of the explanatory strength of the hypothetical model based on the theory of the overall variability of the measured data. The formula is as follows:

$$GFI = \frac{tr(\sigma w \sigma)}{tr(sws)}. \quad (11)$$

AGFI (adjusted goodness-of-fit index) will be combined with the number of parameters of the model itself for a comprehensive analysis. The greater the number of parameters, the greater the value of the AGFI, and the more favorable it is to obtain a model with a good fit. The formula is as follows:

$$AGFI = \frac{1 - GFI}{1 - \text{the number of estimated paramters/the number of observations}}. \quad (12)$$

Table 2: Key aspects of audience satisfaction with ICH display design.

Serial number	Name
1	Favorability and intelligibility of the subject
2	Representativeness of craftsmanship
3	Rationality of the visiting route
4	Creation of atmosphere (sound and light)
5	Instructions for texts and images
6	Communication between artisans and audience
7	Space design
8	Audience engagement
9	Construction of relevant cultural scenes
10	Purchase of souvenirs
11	Relevance to life
12	Combination of high technology such as Internet and virtual reality
13	Entertaining design
14	Rest facilities for audience
15	ICH video introduction
16	Quality of display service

When normalized values are taken, the value of AGFI is between 0 and 1. The difference between its value and 1 is inversely related to the degree of fit of the model. In general, when its value is not lower than 0.90, it indicates that the fitting model is acceptable.

PGFI (parsimony goodness-of-fit index) can reflect the number of parameters to be estimated in the fitting model from the side, and its formula is as follows:

$$PGFI = \left(1 - \frac{\text{the number of estimated paramters}}{\text{the number of observations}}\right) * GFI. \tag{13}$$

In general, according to (12), the PGFI is related to the number of estimated parameters and the number of observations, so it is not much less than, but there is a definite coefficient relationship between them.

NFI (normed fit indices) and NNFI (non-normed fit indices) can both be interpreted as the level of difference between the fitting model and the independent model [44].

$$\begin{aligned} NFI &= \frac{x^2_{\text{indep}} - x^2_{\text{test}}}{x^2_{\text{indep}}}, \\ NNFI &= \frac{x^2_{\text{indep}} - df_{\text{indep}} x^2_{\text{test}} / df_{\text{test}}}{x^2_{\text{indep}} - df_{\text{indep}}}, \end{aligned} \tag{14}$$

where x^2_{test} and df_{test} denote the chi-square value and degrees of freedom of the fitting model, and x^2_{indep} and df_{indep} denote the chi-square value and degrees of freedom of the independent model. Practice has proved that when the amount of data obtained is insufficient and there are many model parameters. The NFI can be misjudged in the evaluation of a well-fitted model, while the NNFI compensates for its deficiency to some extent. A value of not less than 0.90 for both marks an acceptable fitting model.

4. Empirical Analysis

4.1. Basic Data Analysis

4.1.1. Index Determination. The research team consulted 21 experts in relevant research directions. Among them, 11 are experts in planning cultural exhibitions, 5 are professors from cultural heritage research institutes of relevant universities, and 5 are ICH protection experts. These experts were invited to evaluate the correlation between indices. According to their opinions, the audience mainly focus on 16 aspects of ICH display design (Table 2).

4.1.2. Data Collection. From June 1, 2018 to July 1, 2022, four sessions of the "Splendid China" ICH costume show were hosted by Prince Kung's Palace Museum of the Ministry of Culture and Tourism. The subjects were extracted from all the audience interested in the show. A total of 400 questionnaires were distributed, and 395 were collected. Among them, 97% (390) responses were valid. The statistical results show that the respondents are largely aged between 18 and 60, including 51.2% males and 48.8% females. The audience are roughly made up of employees of enterprises and public institutions (44%), college students (25%), and the retired (31%). The random sampling of the subjects assures the representativeness and reliability of the questionnaire survey.

4.2. Model Calculation and Empirical Analysis

4.2.1. Model Calculation. Tables 3 and 4 show the parameter estimations based on the model structure in

Table 3: Statistical estimates of path coefficients.

	Nonstandardized path coefficients	S.E.	C.R.	*P*	Label	Standardized path coefficients
fwgz←gzqw	0.711	0.089	7.887	***	par_9	0.642
gzmy←fwgz	0.647	0.071	9.997	***	par_10	0.728
gzmy←gzqw	0.281	0.059	4.209	***	par_11	0.289
gzxr←gzmy	1.129	0.089	11.502	***	par_12	0.791
y1←fwgz	1.000					0.856
y2←fwgz	0.899	0.049	17.494	***	par_1	0.891
y3←fwgz	1.005	0.061	17.098	***	par_2	0.802
x3←gzqw	0.971	0.089	10.611	***	par_3	0.799
x2←gzqw	0.667	0.080	9.037	***	par_4	0.611
x1←gzqw	1.000					0.776
y4←gzmy	1.000					0.751
y5←gzmy	1.079	0.079	12.989	***	par_5	0.799
y6←gzmy	1.139	0.078	13.798	***	par_6	0.873
y7←gzxr	−0.108	0.040	−3.087	***	par_7	−0.198
y8←gzxr	1.000					0.947
y9←gzxr	0.941	0.061	17.571	***	par_8	0.895

Note: ***significance at the level of 0.01; S.E. and C.R. represent standard error and Cronbach's alpha, respectively.

Table 4: Variance estimates.

	Variance estimates	S.E.	C.R.	*P*	Label
gzqw	0.456	0.071	6.399	***	par_13
m1	0.368	0.051	6.876	***	par_14
m2	0.037	0.019	3.411	0.001	par_15
m3	0.341	0.052	6.897	***	par_16
n1	0.234	0.019	8.610	***	par_17
n2	0.130	0.021	7.576	***	par_18
n3	0.173	0.028	8.311	***	par_19
p3	0.268	0.042	7.209	***	par_20
p2	0.314	0.051	9.596	***	par_21
p1	0.327	0.049	7.410	***	par_22
n4	0.335	0.042	9.945	***	par_23
n5	0.264	0.037	9.311	***	par_24
n6	0.186	0.039	8.210	***	par_25
n7	0.246	0.019	11.219	***	par_26
n8	0.137	0.041	3.809	***	par_27
n9	0.240	0.038	6.298	***	par_28

Note: ***significance at the level of 0.01.

Figure 4, through the statistical analysis on Amos Graphics. In the two tables, x1, x2, x3, y1, y2, y3, . . ., y8, y9 represent the 12 observed variables; p1, p2, p3, n1, n2, n3, . . ., n8, n9 represent their error terms; m1, m2, and m3 are the disturbance terms of the three endogenous structural variables, namely service perception, public satisfaction, and public trust, respectively. A path coefficient can be considered significant, when its confidence is 96% and *P* value is smaller than 0.01.

As shown in Tables 3 and 4, every model parameter was significant at the level of 0.05, which is in line with reality. Table 5 displays the common fitness indices solved by the model.

The results in Table 5 reflect a good fitness of our model. However, the fitness indies have not reached the ideal values.

Next, the model was modified by the modification index (MI) obtained through Amos fitting. Tables 6 and 7 show the MI results for covariance and regression weight, respectively, which were fitted through the structural equation model. Note that the sign ⟷ indicates the measuring results on the relationship between the error term and disturbance term of the structural equation model, that is, how much the chi-squared of the model is improved by adding the bidirectional relationship between indicator variables. The sign ← indicates the measuring results on the relationship between observed variables in the structural equation model, that is, how much the chi-squared of the model is improved by adding the unidirectional relationship between indicator variables.

Before optimizing the model with the MI, it is important to consider the rationality and comprehensibility of each index. For each revision, the largest value should be selected from the obtained index values and analyzed first. The modification starts from the covariance part. It

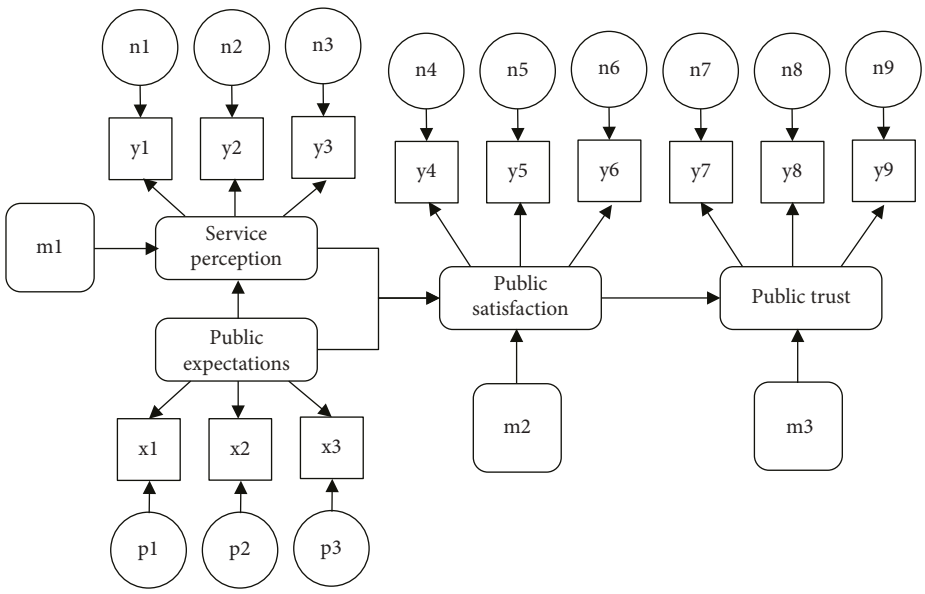


Figure 4: Structural equation model for public satisfaction with ICH digital display.

Table 5: Common fitness indices.

Fitting index	X^2 (chi-squared)/degree of freedom	X^2/df value	AGFI	RMR	RMSEA	IFI	CFI	AIC
Results	152.421/50	3.048	0.864	0.031	0.091	0.895	0.931	202.412

Note: X^2, df, AGFI, RMR, RMSEA, IFI, CFI, and AIC represent chi-squared, degree of freedom, adjusted goodness-of-fit index, root mean square residual, root mean square error of approximation, incremental fit index, comparative fit index, and Akaike's information criterion (AIC), respectively.

Table 6: MI values of covariance.

	M.I.	Par change
n9↔m1	4.198	0.036
n9↔m2	10.159	−0.043
n8↔m2	6.611	0.041
n7↔n8	5.129	0.034
n6↔m3	8.213	0.059
n5↔m3	4.412	−0.048
n5↔n9	17.798	−0.079
n4↔n5	4.712	0.051
p2↔n8	4.712	0.053
p2↔n6	5.312	−0.052
n3↔n9	9.513	0.063
n3↔n5	7.312	−0.039
n3↔n4	6.899	−0.038
n2↔n9	8.910	0.051
n2↔n5	9.812	−0.037
n1↔n9	4.212	−0.041
n1↔n5	35.421	0.122

can be seen from Table 6 that the path parameter between variables n1 and n5 led to the greatest decline of chi-squared (MI)—35.421. In other words, the chi-squared of the model declined the deepest, after the path related to the error between n1 and n5 was added. In addition, there must be a correlation between the perception of ICH new media communication and the overall satisfaction of ICH new media service. Therefore, the null hypothesis model could be optimized by adding the path between n1 and n5.

Table 7: MI values of regression weight.

	M.I.	Par change
y9←y5	6.511	−0.112
y9←y3	4.241	0.097
y8←y7	4.798	0.162
y6←x2	4.396	−0.087
y5←y9	7.298	−0.087
y5←y1	6.899	0.111
y4←x2	4.411	0.105
y3←y4	4.399	−0.087
y1←y5	13.019	0.147

After optimizing the null hypothesis model, the relevant parameters were recalculated, and the MI was selected in the same way. The largest chi-squared (MI) value (12.369) was found between n5 and n9. But no clear correlation was observed between the overall satisfaction of ICH new media service and the public recommendation of ICH digitization service. Moreover, the MI between other variables was small and fell short of fitting and optimization requirements. Thus, the model improved from the null hypothesis model is displayed in Figure 5.

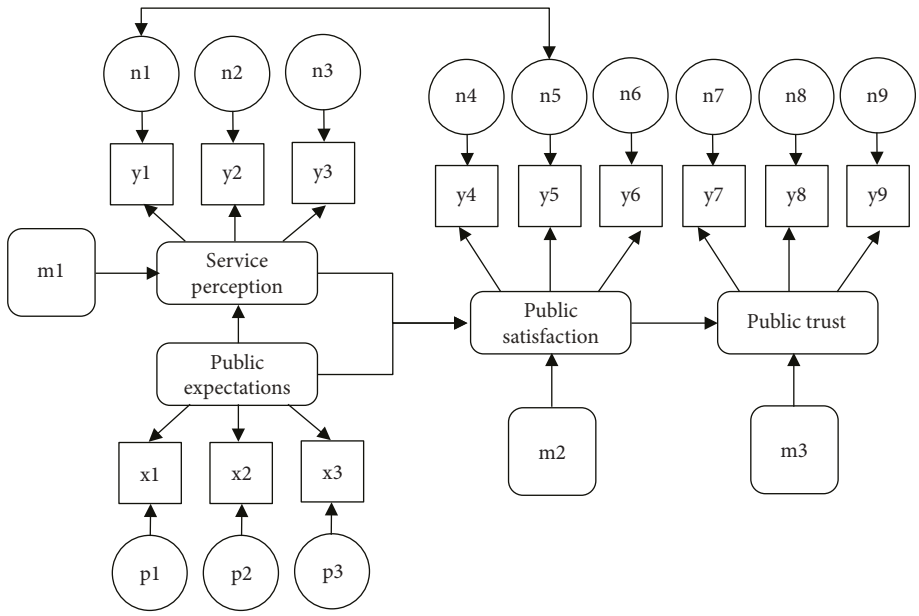


Figure 5: Optimized structural equation model for public satisfaction with ICH digital display.

Table 8: Common fitness indices.

Fitting index	X^2 (chi-squared)/degree of freedom	X^2/df value	AGFI	RMR	RMSEA	IFI	CFI	AIC
Results	108.126/49	2.207	0.916	0.018	0.072	0.971	0.971	167.421

Table 9: Final estimates of path coefficients.

	Nonstandardized path coefficients	S.E.	C.R.	P	Label	Standardized path coefficients
fwgz←gzqw	0.692	0.089	7.856	***	par_9	0.637
gzmy←fwgz	0.631	0.059	10.011	***	par_10	0.721
gzmy←gzqw	0.291	0.058	4.741	***	par_11	0.302
gzxr←gzmy	1.152	0.101	11.554	***	par_12	0.789
y1←fwgz	1.000					0.828
y2←fwgz	0.932	0.061	17.542	***	par_1	0.889
y3←fwgz	1.034	0.071	17.095	***	par_2	0.881
x3←gzqw	0.972	0.098	10.547	***	par_3	0.781
x2←gzqw	0.687	0.081	9.121	***	par_4	0.629
x1←gzqw	1.000					0.771
y4←gzmy	1.000					0.739
y5←gzmy	1.071	0.089	12.823	***	par_5	0.791
y6←gzmy	1.162	0.091	13.771	***	par_6	0.858
y7←gzxr	−0.119	0.042	−3.131	0.002	par_7	−0.211
y8←gzxr	1.000					0.931
y9←gzxr	0.941	0.061	17.590	***	par_8	0.882

Note: ***significance at the level of 0.01.

Table 8 shows the parameter estimations based on the model structure in Figure 5 through the statistical analysis on Amos Graphics.

Comparing Tables 5 and 8, it is clear that the fitness indices were optimized to different degrees, and the correlation paths all passed the significance test. The final optimal estimates of path coefficients and variances are shown in Tables 9 and 10, respectively.

Referring to formulas (8)–(10), the relationship between structural variables and observed variables can be described by the following three equations, where the coefficients are standardized coefficients:

Table 10: Final variance estimates.

	Estimate	S.E.	C.R.	P	Label
gzqw	0.451	0.070	6.447	***	par_14
m1	0.319	0.051	6.988	***	par_15
m2	0.056	0.017	3.982	***	par_16
m3	0.334	0.051	6.798	***	par_17
n1	0.241	0.029	8.977	***	par_18
n2	0.115	0.019	7.098	***	par_19
n3	0.181	0.023	7.969	***	par_20
p3	0.270	0.038	7.109	***	par_21
p2	0.324	0.034	9.622	***	par_22
p1	0.310	0.047	7.348	***	par_23
n4	0.331	0.034	9.792	***	par_24
n5	0.296	0.032	9.413	***	par_25
n6	0.189	0.031	7.781	***	par_26
n7	0.241	0.028	11.177	***	par_27
n8	0.149	0.041	3.932	***	par_28
n9	0.241	0.041	6.337	***	par_29

Note: ***significance at the level of 0.01.

$$\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix} = \begin{bmatrix}0 & 0 & 0\\ 0.721 & 0 & 0\\ 0 & 0.789 & 0\end{bmatrix} * \begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix} + \begin{bmatrix}0.637\\ 0.302\\ 0\end{bmatrix} * \xi + \begin{bmatrix}m_1\\ m_2\\ m_3\end{bmatrix},$$

$$\begin{bmatrix}y_1\\ y_2\\ y_3\\ y_4\\ y_5\\ y_6\\ y_7\\ y_8\\ y_9\end{bmatrix} = \begin{bmatrix}0.828 & 0 & 0\\ 0.889 & 0 & 0\\ 0.881 & 0 & 0\\ 0 & 0.739 & 0\\ 0 & 0.791 & 0\\ 0 & 0.858 & 0\\ 0 & 0 & -0.211\\ 0 & 0 & 0.931\\ 0 & 0 & 0.882\end{bmatrix} * \begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix} + \begin{bmatrix}n_1\\ n_2\\ n_3\\ n_4\\ n_5\\ n_6\\ n_7\\ n_8\\ n_9\end{bmatrix},$$

$$\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} = \begin{bmatrix}0.771\\ 0.629\\ 0.781\end{bmatrix} * \xi + \begin{bmatrix}\rho_1\\ \rho_2\\ \rho_3\end{bmatrix}. \tag{15}$$

4.2.2. Empirical Analysis. The main function of the structural equation model is to reveal the structural relationships between the structural variables. These relationships are reflected by path coefficients in the model. Combined with the empirical research of scholar Cheng [44], the optimal structural equation model for public satisfaction with ICH digital display was analyzed on Amos Graphics. Table 11 shows the estimated standardization effects between the structural variables.

The direct effect refers to the direct influence of the cause variable on the result variable in all paths of the structural equation model. Generally, the direct effect is measured by the standardized path coefficient from the cause variable to the result variable, as shown in the last column of Table 9. For example, the normalized path coefficient from public expectations (gzqw) to public satisfaction (gzmy) is 0.302, indicating that the direct effect of public expectations on public satisfaction through the path relationship is 0.302, that is, when other conditions remain unchanged in the structural equation model, the structural variable "public expectations" will increase by 1 standardized coefficient and the structural variable "public satisfaction" will correspondingly increase by 0.302 of a standardized coefficient.

The indirect effect means that in all paths of the structural equation model, the cause variable and the result variable are not directly connected, but are influenced by the mutual conduction of one or more intermediary variables between them. The value of the indirect effect is the product between the standardized path coefficients of connected paths. As shown in Table 9, the standardized path coefficient from public expectations (gzqw) to service perception (fwgz) was 0.637 and that from service perception (fwgz) to public satisfaction (gzmy) was 0.721. Then, the indirect effect from public expectations to public satisfaction was $0.637 * 0.721 = 0.459$. When the other conditions in the structural equation model remain unchanged, if the structural variable "public expectations" increases by 1 standardized coefficient, then the structural variable "public satisfaction" will indirectly increase by 0.459 of a standardized coefficient.

The total effect refers to the overall influence of the cause variable on the result variable in all paths of the structural equation model. It consists of direct effect and indirect effect. For example, the direct effect from public expectations (gzqw) to public satisfaction (gzmy) was 0.302 and the indirect effect was 0.451. Then, the total effect was $0.302 + 0.451 = 0.753$. When the other conditions in the structural equation model remain unchanged, if the structural variable "public expectations" increases by 1 standardized coefficient, then the structural variable "public satisfaction" will increase by 0.753 of a standardized coefficient.

Tables 11 and 12 show the structural relationship between each structural variable and each observed variable, indicating the total effect of each structural variable on the observed variable. It can be found that almost all structural variables have a positive effect or no effect on the observed variable. The only exception is the negative effect of the structural variable public trust (gzxr) on the observed variable public complaints (y7). Therefore, the increase of the structural coefficient by each standardized coefficient can enhance each observed variable. The factor weights are shown in Table 13.

Following the calculation principle, public satisfaction was solved by formulas (1) and (2) based on the data in Table 13.

For the structural variable public satisfaction (gzmy), the sum of factor weights was 0.856. Thus, the MI of the structural variable was $\psi = 1/0.856$.

By formula (1), we have

Table 11: Estimates of standardization effect.

	Public expectations	Service perception	Public satisfaction	Public trust
Service perception (total effect)	0.637	0.000	0.000	0.000
(Direct effect)	0.637	0.000	0.000	0.000
(Indirect effect)	0.000	0.000	0.000	0.000
Public satisfaction (total effect)	0.753	0.717	0.000	0.000
(Direct effect)	0.302	0.000	0.000	0.000
(Indirect effect)	0.451	0.000	0.000	0.000
Public trust (total effect)	0.589	0.565	0.790	0.000
(Direct effect)	0.000	0.000	0.790	0.000
(Indirect effect)	0.589	0.565	0.000	0.000

Table 12: Estimates of standardized total effect.

	Public expectations	Service perception	Public satisfaction	Public trust
y1	0.521	0.828	0.000	0.000
y2	0.560	0.889	0.000	0.000
y3	0.545	0.881	0.000	0.000
y4	0.556	0.533	0.739	0.000
y5	0.585	0.562	0.791	0.000
y6	0.648	0.622	0.869	0.000
y7	−0.121	−0.117	−0.163	−0.211
y8	0.545	0.523	0.732	0.931
y9	0.516	0.495	0.692	0.882
x1	0.771	0.000	0.000	0.000
x2	0.629	0.000	0.000	0.000
x3	0.781	0.000	0.000	0.000

Table 13: Final factor weights.

	x1	x2	x3	y1	y2	y3	y4	y5	y6	y7	y8	y9
Public expectations	0.25	0.16	0.28	−0.01	0.02	0.01	0.03	0.05	0.080	−0.00	0.02	0.01
Service perception	0.00	0.00	0.00	0.18	0.34	0.24	0.04	−0.01	0.1004	−0.00	0.02	0.01
Public satisfaction	0.04	0.02	0.04	0.00	0.13	0.09	0.10	0.12	0.226	−0.00	0.06	0.03
Public trust	0.01	0.00	0.01	0.00	0.03	0.02	0.02	0.03	0.057	−0.03	0.51	0.30

$$\begin{aligned}\text{publicsatisfaction}\,(cs)_1 &= \frac{E(\xi)-\text{Min}(\xi)}{\text{Max}(\xi)-\text{Min}(\xi)} * 100\\ &= \frac{1/12\left(\sum_{i=1}^{3} w_i\overline{x}_i + \sum_{j=1}^{9}\varphi_j\overline{y}_j\right) - 1/12\left(\sum_{i=1}^{3} w_i\text{Min}(x_i) + \sum_{j=1}^{9}\varphi_j\text{Min}(y_i)\right)}{1/12\left(\sum_{i=1}^{3} w_i\text{Man}(x_i) + \sum_{j=1}^{9}\varphi_j\text{Max}(y_i)\right) - 1/12\left(\sum_{i=1}^{3} w_i\text{Min}(x_i) + \sum_{j=1}^{9}\varphi_j\text{Min}(y_i)\right)} * 100,\\ \psi &= \frac{3.54-1.03}{4.47-1.03} * 100 * \psi = \frac{2.51}{3.44} * 100 * \psi = 85.24,\end{aligned} \tag{16}$$

where $E(\xi)$, $\text{Max}(\xi)$), and $\text{Min}(\xi)$ are the mean, maximum, and minimum of public satisfaction, respectively; $\overline{x}_i$, $\text{Max}(x_i)$, and $\text{Min}(x_i)$ are the mean, maximum, and minimum of x_i; $\overline{y}_j$, $\text{Max}(y_j)$, and $\text{Min}(y_j)$ are the mean, maximum, and minimum of y_j; w_i and φ_j are the weights of each factor; and ψ is the correction index, $i \in \Omega_3$, $j \in \Omega_9$.

By formula (2), we have

$$\text{publicsatisfaction}\,(cs)_2 = \left(\sum_{j=1}^{3} w_i\overline{x}_i + \sum_{j=1}^{9}\phi_j\overline{y}_j\right) * \psi = 3.54 * \psi = 4.14. \tag{17}$$

The above result can be expressed as a percentage:

Table 14: Digital forms of the ICH works visited by the public.

		Response		Case percentage
		N	Percentage	
Form of digital works	Image	477	25.9	77.3
	Audio	310	16.9	51.6
	Video	498	27.1	85.0
	Animation	266	14.5	41.6
	Interactive game	121	6.6	17.4
	Human-computer interaction	78	4.2	11.1
	Integrated display of sound and light	89	4.8	14.8
	In total	1839	100.0	298.8

Table 15: Digital forms of the ICH works favored by the public.

		Mean
Ranking by the degree of preference	Character	1.64
	Image	2.37
	Audio	1.88
	Video	3.44
	Animation	2.21
	Interactive game	1.76
	Human-computer interaction	1.02
	Integrated display of sound and light	1.65

Note: the greater the value, the stronger the degree of preference.

$$\text{publicsatisfaction}\,(cs)_3 = \frac{\text{publicsatisfaction}\,(cs)_2 * 100}{5} = 82.8. \quad (18)$$

With reference to the relevant literature on satisfaction evaluation standards, combined with the characteristics of ICH digital display services, the evaluation standards for this evaluation model are set as follows:

When CS < 60, it indicates that the quality of the digital display service of ICH is not good, and the public feels very bad about the quality of the digital display service of ICH; when 60 ≤ CS < 70, it indicates that the service quality of the digital display of ICH is average, and the public has a general perception of the quality of the digital display service of ICH; when 70 ≤ CS < 80, it shows that the service quality of the digital display of ICH is good, and the public feels good about the service quality of the digital display of ICH; and when CS ≥ 80, it shows that the quality of the digital display service of ICH is very good, and the public feels very good about the quality of the digital display service of ICH.

4.3. Countermeasures. The ICH digitization should be service-oriented and emphasize the digitization service quality of ICH works. According to the results of the valid responses, the digital forms of the ICH works visited by the public and favored by the public are ranked in Tables 14 and 15, respectively. In the structural equation model of public satisfaction with the digital display of ICH, the structural variable service perception (fwgz) has the highest direct impact on the structural variable public satisfaction (gzmy), reaching 0.715, which shows that improving the service quality of ICH digital display is also the top priority for improving public satisfaction with the digital display of ICH.

Table 16: Degree of preference for different ICH display forms.

Display form	Mean
Purely physical display	2.88
Purely digital display	1.76
Physical display + digital display	2.89
Field participation of inheritor + digital display	2.43

Note: the greater the value, the stronger the degree of preference.

As shown in Tables 14 and 15, the public mainly visited digital works in the form of video, image, and audio, but rarely visited those in the form of interactive game, human-computer interaction, and integrated display of sound and light. The top 3 most preferred forms are video, image, and animation.

The survey shows that 42.4% of the respondents have visited digital ICH exhibits. Hence, digital display means have not been widely utilized. The public has not comprehensively learned the display forms of ICHs. Table 16 shows the degree of preference of the public for different display forms of ICHs.

Through the empirical research on the Splendid China costume show, it can be seen that the different ICH display design elements act differently on audience satisfaction. This requires that ICH display designers not only have rich ICH knowledge, display theory, and practical skills but also need to study the psychology of ICH audience to understand how the audience's psychology will be affected by different ICH display strategies and feel and develop different design strategies for different types of elements. The following countermeasures were therefore designed:

(1) Application of conventional display media. Based on the research on the ICH project itself, we can understand the way its elements are displayed. In other words, these elements have begun to have the nature of exhibits and can be managed through digital display schemes. No matter what kind of media tool is used, the act of dissemination itself has no value, only when the work obtains useful information in the process of dissemination and affects people's behavior, it has meaning. Therefore, in the process of displaying the existing ICH projects, it is necessary to screen reasonable media and obtain key information from them before spreading.

(2) Emotional positioning in ICH projects. In terms of display form, it is necessary to combine physical display with digital display. Using the art elements of visual language (e.g., equipment modeling; matching lighting and color), the scene needs to be creatively processed according to a certain theme and rationality, creating a cultural atmosphere that matches the ICHs, arouses the interest of the audience, and provides a pleasant experience of the ICHs.

(3) The construction of interactive mode. The operation interaction mode is a multidimensional interactive experience design through multimedia technology, supplemented by computer program processing solutions. The core of ICHs lies in the activation of people's participation. Therefore, ICH designers should not only consider the contents and form of ICHs but also fully explore the interactive features of ICHs with the aid of online multimedia technology. The intricate technical contents of ICHs should be organized into a rich experience effect so that the audience become more satisfied with the experience of ICHs.

5. Conclusions and Suggestions

(1) The construction of a public satisfaction evaluation model for the digital display of ICHs is the key to satisfaction evaluation. Our public satisfaction evaluation model for the digital display of ICHs is in line with China's national conditions. With a strong practical value, the model creates favorable conditions for the research on public satisfaction for ICH digital display.

(2) There is ample room to improve public satisfaction with the digital display of ICHs. According to the ACSI-based public satisfaction evaluation model for ICH digital display, the ICH-related service provider should strengthen the construction of ICH digital service-related projects, understand the public's expectations of and emphasis on ICH digital-related projects, and improve the key links and weak points.

(3) The digital display design of ICH is the product of the era combining ICH protection and digital technology. As an information processing technology, digital technology is the foundation of computer technology, multimedia technology, intelligent technology, and information dissemination technology. It provides various technical support for the display of ICHs. No matter how the digital display design of ICH is carried out, the owner and inheritor of ICH should be the main body. From the perspective of the development trend of ICH digital display design, combined with the theory of audience satisfaction, the ultimate goal of ICH digital display design is to ignore digital technology, that is, to integrate digital technology into ICHs and become a part of its life.

(4) Promoting the dissemination of ICHs is an important measure to further enhance ICH protection. The main weakness lies in the brand image of ICH display. ICH curators should actively improve their own brand awareness; increase publicity through television, radio, Internet, and other channels; and expand the influence of ICHs by hosting large-scale events.

(5) Personalized service is an effective way to promote the digital development of ICHs. Only by understanding the preference of different groups of the public for different types of ICHs, and digitizing ICHs by the digital service methods favored by the public, can we achieve targeted development of ICHs and improve the efficiency and effectiveness of ICH display.

Data Availability

The data that support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

Acknowledgments

This study was supported by the Research Project of Prince Kung's Palace Museum of the Ministry of Culture and Tourism (GBLXFY-2021-Y-01); Special Subject of Practical Skills of China Arts and Crafts Society (CNACS-IV-002); Philosophy and Social Science Research Project of Hubei Province Colleges and Universities (21Q126); and Research Project on the Construction of Yangtze River National Cultural Park of Hubei Province (HCYK2022Y22).

References

[1] B. F. Xiong, "Research on the role of ecological museums in the protection of intangible cultural heritage," *Journal of Lanzhou University*, vol. 33, no. 11, pp. 33–37, 2013.

[2] W. B. Wang, "Experimentation on the intangible heritage exhibition in local museums," *Museum Research*, vol. 41, no. 3, pp. 13–15, 2016.

[3] T. Wu, *Media Communication of the Husa Sword of Achang People in the Context of New media*, pp. 42–47, Kunming University of Science and Technology, Kunming, China, 2015.

[4] C. Y. Yan, "The application of new media technology in digital display," *Art Technology*, vol. 30, no. 6, p. 124, 2017.

[5] J. Meng, "Exploration of technical means of digital display," *Digital World*, vol. 53, no. 10, p. 77, 2017.

[6] D. M. Peng, L. S. Pan, and S. Q. Sun, "Digital conservation-a new means of conservation," *Fine Arts Research*, vol. 23, no. 1, pp. 47–51, 2006.

[7] Y. R. Lv and L. Zhang, "Innovative application of new media technology in digital display of intangible cultural heritage," *Packaging Engineering*, vol. 37, no. 10, pp. 26–30, 2016.

[8] J. S. Bai, "Research on digital display mode and industrialization of museums with contents of intangible cultural heritage," *Journal of Zhejiang Vocational Academy of Arts*, vol. 13, no. 6, pp. 112–117, 2011.

[9] C. Rossella, "Digital cultural heritage projects: opportunities and future challenges original research article," *Procedia Computer Science*, vol. 422, no. 38, pp. 12–17, 2014.

[10] Y. Hong, "The pros and cons about the digital recording of intangible cultural heritage and some strategies, " International Archives of the Photogrammetry," *Remote Sensing & Spatial Information Science*, vol. 43, no. 8, pp. 11–17, 2015.

[11] M. Z. Idris, N. B. Mustaffa, and S. O. S. Yusoff, "Preservation of intangible cultural heritage using advance digital technology: issues and Challenges," *Harmonia: Journal of Arts Research and Education*, vol. 16, no. 1, pp. 1–13, 2016.

[12] T. Kyriacos, "Model reconstruction for 3d visualization of cultural heritage sites using open data from social media: the case study of Soli, Cyprus," *Journal of Archaeological Science: Report*, vol. 24, no. 1, pp. 111–117, 2016.

[13] R. Suarez, A. Alonso, and J. J. Sendra, "Archaeoacoustics of intangible cultural heritage: the sound of the Maior Ecclesia of Cluny," *Journal of Cultural Heritage*, vol. 19, no. 19, pp. 567–572, 2016.

[14] J. F. Dong, "Study on digital protection of intangible cultural heritage of minority nationality in Xiangxi autonomous prefecture," *Resource Development and Market*, vol. 29, no. 12, pp. 1298–1301, 2013.

[15] W. M. Zhang and Mo Zhao, "Problems of inheritance and protection and its countermeasures in Baojing County, western Hunan," *Popular Literature*, vol. 243, no. 21, pp. 4–6, 2014.

[16] L. H. Song, W. S. Li, and T. Dong, "Digital protection and knowledge integration platform construction of intangible cultural heritage," *Library Journal*, vol. 34, no. 1, pp. 73–81, 2015.

[17] Q. Cai, R. X. Ren, and W. B. Qiu, "Digital protection study on cultural heritage of minority nationality in Guizhou province," *Journal of Guizhou University (Natural Science Edition)*, vol. 334, no. 4, pp. 13–18, 2007.

[18] K. Wang, "Establishment and development of wood-block new year picture database——discussion on protecting intangible cultural heritage," *Journal of Tianjin University*, vol. 15, no. 6, pp. 567–570, 2013.

[19] X. Y. Sun, "Digital preservation and display of cultural heritage: the example of traditional Jun porcelain craftsmanship in Yuzhou," *Journal of Xiamen Academy of Arts and Design*, Fuzhou University, vol. 88, no. 3, pp. 58–60, 2013.

[20] E. Selmanovic, S. Rizvic, C. Harvey et al., "Improving accessibility to intangible cultural heritage preservation using virtual reality," *Journal on Computing and Cultural Heritage*, vol. 13, no. 2, pp. 1–19, 2020.

[21] X. J. Zhao, "The use of interactive data visualisation technology in cultural digital heritage display using edge computing," *International Journal of Grid and Utility Computing*, vol. 13, no. 2/3, pp. 118–127, 2022.

[22] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.

[23] G. A. Churchill and C. Supernant, "An investigation into the determinants of consumer satisfaction," *Journal of Marketing Research*, vol. 73, no. 11, pp. 491–504, 1981.

[24] A. Parasuraman, V. A. Zeithaml, and L. L. Berry, "A conceptual model of service quality and its implications for future research," *Journal of Marketing*, vol. 49, no. 4, pp. 41–50, 1985.

[25] C. Fornell and J. L. Liu, *Customer Satisfaction and ACSI*, pp. 141-142, Tianjin University Press, China, 2006.

[26] B. Chen, "A different kind of satisfaction-exhibitions in the eyes of exhibitors and professional visitors," *China Conference &Exhibition*, vol. 51, no. 24, pp. 40–42, 2003.

[27] S. L. Ju, L. Lu, and D. B. Wang, "Estimation of consumption perception of the fair trader at the stage of weak market: exemplified by international trade fair of tourist commodities in Wuhu, China," *Urban Problems*, vol. 123, no. 4, pp. 53–58, 2005.

[28] T. X. He, "A case study on influencing factor of international exhibition visitors' satisfaction in China," *Soft Science*, vol. 22, no. 9, pp. 45–49, 2008.

[29] J. Xu, B. H. Yuan, and P. Hu, "An analysis of exhibitors' satisfaction with the services of the venues: a case study of shanghai everbright exhibition center," *Tourism Science*, vol. 22, no. 6, pp. 61–69, 2008.

[30] Y. Q. Wu and L. Zhang, "A study on MICE attendees' satisfaction using importance-performance analysis: taking the canton fair and Guangzhou fair as example," *Ecological Economy*, Academic Edition, vol. 28, no. 1, pp. 187–192, 2010.

[31] X. S. Lin and C. R. Ai, "Determinants of Chinese residents' demand for medical care——an application of semi-parametric estimation of ordered probit model," *Statistical Research*, vol. 22, no. 11, pp. 40–45, 2008.

[32] J. G. Zhao and L. Miao, "Employment difficulty analysis of university students in Liaoning: based on probit model," *Research on Finance and Economics*, vol. 73, no. 11, pp. 86–91, 2010.

[33] Z. F. Jin, W. Chen, J. L. Chen, and F. Yuan, "Location choice of protection for cultivated land based on probit model in Changshu city," *Geography Research*, vol. 33, no. 12, pp. 2261–2270, 2010.

[34] Y. Guo, "Factors affecting the participation of migrant workers in urban social security system: an empirical analysis using Probit model," *Survey World*, vol. 51, no. 1, pp. 42–45, 2011.

[35] C. Fornell, M. D. Johnson, E. W. Anderson, J. Cha, and B. E. Bryant, "The American customer satisfaction index: nature, purpose, and findings," *Journal of Marketing*, vol. 60, no. 4, pp. 7–18, 1996.

[36] K. Hamayun and S. Hafeez, "Development of customer satisfaction index (CSI) model for Pakistan," *Journal of Asian finance economics and business*, vol. 9, no. 7, pp. 153–171, 2022.

[37] F. Hu, X. Xi, and Y. Zhang, "Influencing mechanism of reverse knowledge spillover on investment enterprises' technological progress: an empirical examination of Chinese firms," *Technological Forecasting and Social Change*, vol. 169, Article ID 120797, 2021.

[38] P. Wangwacharakul, S. Márquez Medina, and B. B. Poksinska, "Cross-cultural comparability of customer satisfaction measurement-the case of mobile phone service providers," *International Journal of quality and service sciences*, vol. 13, no. 2, pp. 236–252, 2021.

[39] T. C. Li and S. R. Wang, "How to improve the public trust of the intelligent aging community: an empirical study based on the ACSI model," *International Journal of Environmental Research and Public Health*, vol. 18, no. 4, pp. 1971–2014, 2021.

[40] Federal consulting Group, *The American Customer Satisfaction Index (ACSI) and its Value in Measuring Customer Satisfaction*, pp. 17–28, ACSI, Washington D.C, 2001.

[41] Y. Li, "Research on customer satisfaction index model and its measurement method," *China University of Mining and Technology (Beijing)*, vol. 63, no. 1, pp. 36–43, 2008.

[42] G. F. Peng, "Research on local government public administration performance evaluation index system," *Hunan People's Publishing House*, vol. 29, no. 3, pp. 16–22, 2004.

[43] J. X. You, "How to correctly use factor analysis for comprehensive evaluation," *Statistics Education*, vol. 213, no. 5, pp. 10-11, 2003.

[44] Q. Cheng, *Research on the evaluation of public satisfaction of digital display of intangible cultural heritage*, vol. 1, pp. 1–62, Huazhong Normal University, Hong Shan Qu, China, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2415914, 10 pages
https://doi.org/10.1155/2022/2415914

Research Article

Container Freight Rates and International Trade Causality Nexus: Evidence from Panel VAR Approach for Shanghai and ASEAN-6 Countries

Xingong Ding and Mengzhen Wang

Department of International Trade, Jeonbuk National University, Jeonbuk, Republic of Korea

Correspondence should be addressed to Mengzhen Wang; wang-1994622@jbnu.ac.kr

Received 1 April 2022; Revised 15 August 2022; Accepted 16 August 2022; Published 27 September 2022

Academic Editor: Emilio Jiménez Macías

Container shipping drives the development of international trade, yet previous studies have not fully appreciated the possible bidirectional causal relationship between container freight rates and international trade. In the context of the "twenty-first Century Maritime Silk Road," we use data on export container freight rates and import/export data from Shanghai to ASEAN-6 countries (Singapore, Vietnam, Thailand, Philippines, Malaysia, and Indonesia) from February 2017 to January 2020 and apply a panel VAR to explore the relationship between maritime transport costs and international trade in the container shipping market. We use the freight rate data are from the Southeast Asia Freight Index, which is used for the first time in an empirical study. The quality and reliability of the freight rate data allow this paper to better identify causal relationships. The results of the panel Granger causality test and the orthogonal impulse response function suggest a bidirectional causal relationship between freight rates and export trade; to further explain, an increase in export trade lowers export freight rates, but an increase in export freight rates hinders export trade, and a growth in import trade unidirectionally raises export freight rates. We believe that international trade may impact freight rates through economies of scale and trade imbalances.

1. Introduction

Since the creation of the WTO, tariff and nontariff barriers have been significantly reduced, and transport costs have become the main factors affecting trade [1–3]. Over 80% of international trade is carried by the sea [4], and high and more volatile maritime transport costs seriously hinder international trade for some countries [5, 6]. Korinek and Sourdin [6] pointed out that a 10% increase in maritime transport costs reduces trade by 6–8% in OECD countries. Conversely, maritime transport costs are also affected by international trade. Maritime transport costs are expressed in the carrier's position as freight rates [7, 8], which depend on the interplay between transport demand and shipping capacity [9]. Among them, transport demand is a derivative of international trade, so freight rates are also affected by international trade [10, 11].

Maritime transport shortens the distance between people and goods in time and space, and thus makes the contact between different countries and regions more and more frequent, and the development of maritime transport is of great significance to the friendly relations between countries and regions. However, with the increasing importance of maritime transport costs to international trade, reducing maritime transport costs to promote international trade has become an issue of concern to transportation and trade policymakers. Therefore, as the country with the world's largest port cargo throughput, the "twenty-first Century Maritime Silk Road" strategy proposed by China has attracted global attention. It aims to enhance trade facilitation and logistics development by using Chinese ports to connect East Asia, Southeast Asia, and Africa [7, 12, 13].

Shanghai Port is vital as the largest integrated port in China in the context of the "twenty-first Century Maritime

Silk Road." Its container throughput has been ranking first globally for nearly a decade, trading spans Asia, America, Europe, and Africa, is internationally renowned, as well as leading the entire export index in China [7, 14, 15]. Therefore, the Shanghai Export Containerized Freight Index (SCFI), which represents Shanghai export freight rates, often reflects the movement of spot rates for Chinese exports [16]. Studying the correlation between export freight rates and international trade in Shanghai can provide policymakers with timely information to help improve and promote the "twenty-first Century Maritime Silk Road" implementation [7]. For this purpose, this study investigates the correlation between freight rates and international trade on Southeast Asian routes departing from Shanghai.

The reason for our research focusing on the Southeast Asian routes from Shanghai is those ASEAN countries, as a bridge to other regions, are an important testing ground for the "twenty-first Century Maritime Silk Road" strategy, and also Shanghai's most significant trade and investment partners. Specifically, we use export container freight rates and import/export data from Shanghai to ASEAN-6 countries (Singapore, Vietnam, Thailand, Philippines, Malaysia, and Indonesia) for the period from February 2017 to January 2020 and take advantage of the dimensionality of the panel data to control for unobserved heterogeneity effects and perform causal analysis.

2. Literature Review

The relationship between maritime transport costs and international trade has received increasing attention from researchers in recent years. Studies on the relationship between maritime transport costs and international trade can be categorized into two genres.

The first genre of these studies focuses on assessing the impact of maritime transport costs on trade. Most of these studies consider transport costs as an exogenous variable and use a gravity model for empirical analysis [7, 17, 18, 19]; Inmacula. The results showed the negative impact of rising maritime transport costs on exports.

The second genre of these studies focuses on the impact of international trade on maritime transport costs. Some of this literature states that a decline in international trade when fleet capacity is constant represents a decline in demand for transport services and can lead to lower freight rates [11, 10]. Luo et al. [11] analyzed time-series data of the world container shipping market from 1980 to 2008 and found that the decline in world trade volume would contribute to the decline in world container freight rates. However, when the studies focus on specific routes and regions, they point out that international trade affects freight rates mainly through economies of scale [2, 20–22]. In other words, economies of scale are prevalent in the maritime industry, and an increase in the volume of trade leads to economies of scale and thus lower freight rates. For example, the use of higher capacity vessels results in lower costs per container to use the access channel at the port [2]. Thus, to better improve economies of scale, carriers deploy higher capacity vessels on routes with greater transport demand, resulting in lower freight rates per container [20]. In addition to the economies of scale mentioned above, trade imbalance is another important factor in international trade affecting maritime transport costs, especially for the container shipping market. Trade imbalance means that carriers need to reposition empty containers [8], and the larger the trade imbalance is, the more significant the cost of empty container repositioning [23]. Most current studies use export and import trade to construct new variables to measure trade imbalances and study their impact on freight rates [2, 20, 21, 24]. However, it is questionable whether such variables can accurately measure trade imbalances [25]. In addition, of course, the different ways of constructing variables across the literature may also lead to the inability to reach an empirical consensus on determining the impact of trade imbalances on freight rates. However, it is worth affirming that maritime practitioners generally agree that trade imbalances significantly impact freight rates [22]. The possible mechanisms of influence between international trade and maritime transport costs covered by the above literature are summarized in Figure 1.

In addition, some studies have argued that the relationship between maritime transport costs and international trade is not unidirectional. Inmaculada Martínez–Zarzoso and Suárez–Burguet [3] pointed out that an increase in exports can reduce transport costs through economies of scale, and conversely, higher transport costs can discourage exports. But they did not consider the impact of import trade on freight rates by changing trade imbalances. Brancaccio et al. [5] analyzed data on dry bulk transport markets and found that increased exports from net exporting countries increase trade imbalances and ultimately lift freight rates, and vice versa. Jiang et al. [7] explored the interrelationship between Shanghai export container freight rates and Shanghai export trade through a VAR model in the context of the "twenty-first Century Maritime Silk Road." They analyzed freight rates and export value from January 2010 to June 2014 for Europe, the Persian Gulf, Southeast Asia, Taiwan, and Hong Kong routes. Likewise, they failed to consider import trade and the disruptions caused by macroeconomics, global shipping market movements, and other unobservable factors. Moreover, in contrast to classic trade theory, which considers trade costs exogenous, current trade theory research has increasingly focused on the endogeneity of trade costs [5, 26, 27]. However, empirical evidence on the endogeneity of trade costs is currently not abundant.

To fill this gap, this paper establishes a panel VAR model for the first time to study the dynamic linkage and feedback effects between container freight rates and import and export trade. The advantage of panel VAR is that export container freight, export trade, and import trade can simultaneously be considered endogenous variables and allow controlling for unobserved heterogeneous effects. Second, this paper is the first empirical study using the Southeast Asia Freight Index (SEAFI), issued by the Shanghai Shipping Exchange (SSE). It is an index reflecting the spot rate changes of export containers on the services from Shanghai to Southeast Asia base ports. The emergence of SEAFI completes the Shanghai Export Container Freight Index

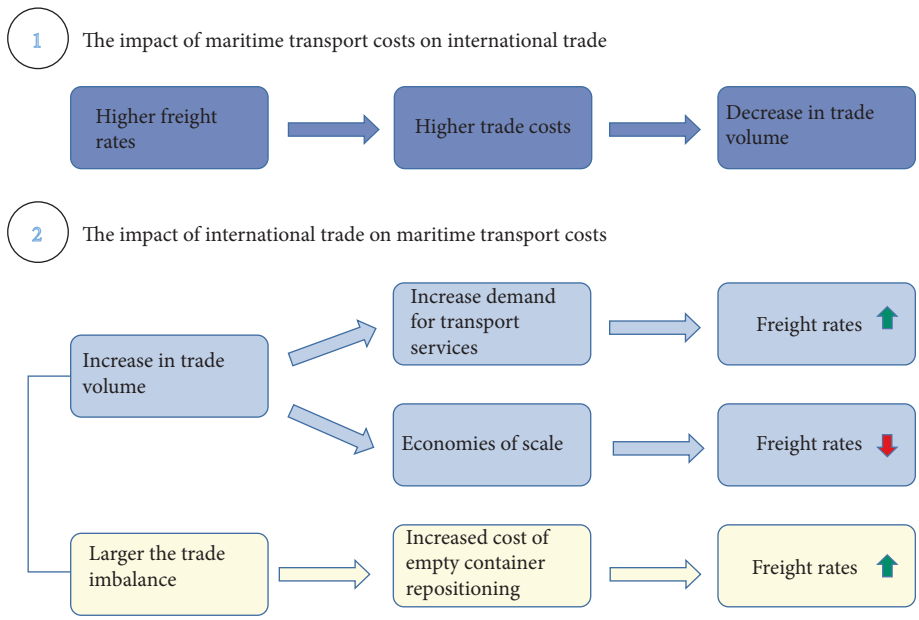


Figure 1: The possible mechanisms of influence between international trade and maritime transport costs.

(SCFI) for Southeast Asia routes. The freight rates published by SEAFI include only direct traffic and are not influenced by transshipment. Each route corresponds to only one country, making it convenient for us to use macroeconomic variables as control variables. SEAFI's freight rate data are collected from 35 world-renowned liner companies, cargo owners, and forwarders, which can fully reflect the market situation in Southeast Asia. In other words, SEAFI is more current and representative than other methods of obtaining freight rate data. Therefore, the quality and reliability of freight rate data make advantages superior to other research in identifying the causal relationship between freight rates and international trade.

3. Data and Methods

3.1. Source of Freight Rate Data. The reliability of the freight rate data is the key to determining the credibility of our empirical results. Most early studies used CIF/FOB ratio data to proxy transport costs. However, due to the differences in how data are collected between countries, the reliability of these data has been widely questioned [3, 20, 28]. Another primary source of freight rate data is databases based on import-charge data from customs declarations, such as the International Transport Database (BTI) created by ECLAC and the Maritime Transport Cost Database created by OECD [3, 6, 17, 18, 22, 24]. Nevertheless, these databases are limited to Latin America and the OECD countries and do not contain data for the last decade. Recently, UNCTAD, the World Bank, and International Maritime Organization (IMO) have developed a Global Transport Costs dataset for International Trade, covering the world, but it currently only has cross-sectional data for 2016 [29].

Due to the lack of publicly available data, some scholars obtained freight rate data by interviewing exporters and shipping lines [19, 20, 25, 30]. Nonetheless, it is not easy to fully represent the movement of the entire seaborne markets using only data from specific shipping lines. Moreover, the freight rate data obtained using the above methods are annual data, which can hardly be used to analyze the short-term changes in freight rates.

Recently, freight rate indices have received increasing scholarly attention. The Baltic Dry Index (BDI), the China (Export) Containerized Freight Index (CCFI), and the Shanghai Export Containerized Freight Index (SCFI) are considered the dominant market indicators for maritime shipping [15, 31, 32]. For example, Jiang et al. [7] selected monthly freight rate data for five branch routes of SCFI (Europe route, Persian Gulf route, Southeast Asia route, Taiwan route, and Hong Kong route) and used a VAR model to examine the interaction between export container freight rate and Shanghai export trade for each of these five routes. However, due to the large number of countries on the route, freight rates are susceptible to the influence of transit ports, and it is challenging to use country-specific macro variables as control variables. Therefore, it is difficult to identify the relationship between freight rates and export trade. The Southeast Asia Freight Index (SEAFI) that we use circumvents these shortcomings.

The Southeast Asia Freight Index (SEAFI) compiled by the Shanghai Shipping Exchange (SSE) reflects the spot rate changes of export containers on the services from Shanghai to Southeast Asia base ports. SEAFI includes freight rates on the six individual shipping routes: Singapore, Vietnam, Thailand, the Philippines, Malaysia, and Indonesia.

SEAFI's published freight rates of individual shipping routes have the following advantages (For more information about SEAFI, as seen in SSE [33]):

(1) The freight rates of individual shipping routes are based on prices in the spot market under the CIF terms, excluding those for long-term agreements and

large customers and are being unaffected by special service requirements.

(2) The freight rates are only for direct service, not transshipment.

(3) The freight rates include basic ocean freight and seaborne surcharges (Seaborne surcharges related to seaborne operational costs as bunker, currency, and equipment reposition and risks as war, port congestion, etc., excluding terminal handling, space-booking, and document charges.)

(4) The freight rate data come from 18 well-known global liner companies and 17 shippers and freight forwarders, which can fully reflect the movement of the freight market.

3.2. Data. Considering the available data and the structural changes in the data due to COVID-19, this paper selects freight rate data from February 2017 to January 2020 for six branch routes of SEAFI (Singapore, Vietnam, Thailand, the Philippines, Malaysia, and Indonesia). Following Jiang et al. [7], we select monthly export and import data for Shanghai and ASEAN-6 countries and convert the weekly freight rate data into monthly freight rate data by simple average calculation.

We also use the macroeconomic variables of the route counterpart countries as control variables. As is widely known, the indices of industrial production (IIP) have a strong correlation with container freight rates [34, 35]. Therefore, we use the industrial production index of ASEAN-6 countries as the control variables. At the same time, the bilateral exchange rate is a key factor affecting bilateral trade and trade balance [34, 36]. For example, when the Chinese Yuan strengthened against the Vietnamese Dong, Chinese cargo lost much of its price competitiveness, and China's exports to Vietnam fell. Therefore, we use the monthly average of bilateral exchange rates between the ASEAN-6 countries and China as a control variable.

Panel VAR can take advantage of the dimensionality of panel data compared to traditional VAR, allowing for the inclusion of individual fixed effects and time effects in the model [37, 38]. Individual fixed effects allow us to control time-invariant factors affecting container rates and international trade, including geographically relevant factors such as distance and islands. In addition, variables such as the market structures on maritime routes, the shipping connectivity of bilateral countries, the location of ports in international liner-shipping networks, and the level of port infrastructure and port efficiency also affect freight rates [2, 8, 24, 25]. However, these variables that define the structure of the shipping routes are only available at the annual base level, and they remain stable in the short term [20]. Instead, we use monthly data, mainly considering short-term changes in freight rates and trade. Therefore, individual fixed effects can also control these variables well. In addition, time-fixed effects can control global time effects, which simultaneously affect all shipping routes and countries. These global time effects include crude oil prices, global macroeconomics, shipbuilding industry, shipping market cycles, and other factors [35, 39, 40]. Table 1, reports the definitions of the variables we used, the data sources, and descriptive statistics.

According to the data we collected, Shanghai's trade with Southeast Asia is a severe trade imbalance. This is because Shanghai's exports to Southeast Asia are much smaller than its imports. Therefore, when exports are constant, an increase in imports will aggravate the trade imbalance. Moreover, when imports are constant, an increase in exports will ease the trade imbalance.

3.3. Methodology. We use a panel VAR model in the generalized method of moments (GMM) framework proposed by Abrigo and Love [41] to investigate the causal direction between export container freight rates, export trade, and import trade.

The specific model is shown as follows:

$$Y_{it} = Y_{it-1}A + X_{it}B + u_i + d_t + e_{it}, \tag{1}$$

where Y_{it} is a vector of dependent variables, including export container freight rates, export trade, and import trade. X_{it} is a vector of exogenous control variables, including the industrial production index and the bilateral exchange rate with China for ASEAN-6 countries. Matrices A and B are parameters to be estimated. The lag order of the model is determined according to MAIC, MBIC, and MQIC information criteria [42]. As shown in Table 2, we chose the first-order lag as the preferred model since the first-order has the smallest criteria values.

$u_i$denotes individual fixed effects. Since the panel VAR contains a lagged term for the dependent variable, using the mean-differencing method, which is commonly used for panel data, to eliminate individual fixed effects would result in bias. Therefore, we use the forward mean difference method to eliminate individual fixed effects [43]. d_t denotes the time dummy variables. We eliminate the time-fixed effects by the intragroup difference of means method [44].

We apply the empirical methodology of panel Granger causality tests to examine the causal relationship between export container freight rates, export trade, and import trade. Granger causality tests provide the direction of causality by determining whether one variable can predict another variable. In the panel VAR model, Granger causality tests are carried out employing Wald tests which are implemented based on the GMM estimate of the A matrix and its covariance matrix.

Then, we investigate the dynamic relationship between the endogenous variables through orthogonalized impulse-response functions. The orthogonalized impulse-response functions allow us to separate the response of export container freight rates to shocks from export trade or import trade. In other words, it is possible to obtain the response of

Table 1: Reports the definitions of the variables we used, the data sources, and descriptive statistics.

Variables	Definitions	Sources	Unit	Mean	Std. Dev.
CFI	Export container freight rates from shanghai to ASEAN-6 countries	Shanghai shipping exchange (SSE)	100 USD/ TEU	1.53	1.12
EX	Shanghai's exports to ASEAN-6 countries	Shanghai custom	Billion dollars	3.39	1.40
IM	Shanghai's imports to ASEAN-6 countries	Shanghai custom	Billion dollars	5.49	2.73
IIP	Indices of industrial production	World bank	Billion dollars	14.09	12.12
ER	Monthly average of bilateral exchange rates	World bank	LCU per CNY	913.1	0.276

export container freight rates to shocks from export trade when holding import trade constant.

The following section presents our empirical results. The causal and dynamic relationships are derived from panel Granger causality tests and orthogonal impulse response plots.

4. Empirical Analysis

4.1. PVAR Model Estimation Results. To ensure the validity of the estimated results of the panel VAR model, we applied the LLC and IPS unit root tests to determine the stationarity of all variables (Table 3).

Before we draw inferences from the estimation results, we checked the system stability of the entire panel VAR model. According to Hamilton [45]; Figure 2 shows that each eigenvalue is inside the unit circle, thus indicating that our model is stable.

Table 4presents the estimation results of our panel VAR model. Hansen's test of overidentifying restriction demonstrates the validity of the instrumental variables used in our study.

We performed a Granger causality test based on the Wald test. The results of the Granger causality test are shown in Table 5.

Combining the estimation results of the panel VAR and the results of the Granger causality test, we summarize the causal relationship between export container freight rates and import and export trade in Figure 3. The results show a bidirectional causal relationship between export container freight rates and export trade. An increase in export trade will reduce export container freight rates. At the same time, a decrease in export container freight rates promotes export trade. This is consistent with the findings of Inmaculada Martínez–Zarzoso and Suárez–Burguet [3]. In addition, there is a unidirectional causal relationship between import trade and export container freight rates. A decrease in import trade decreases export container freight rates, which is consistent with the results of Camisón–Haba and Clemente–Almendros [21].

Table 2: Lag order selection criteria.

Lag	MBIC	MAIC	MQIC
1	−414.163	−102.820	−229.336
2	−376.998	−91.600	−207.573
3	−338.392	−78.940	−184.370

Export container freight rates are a type of trade cost; hence, an increase in trade cost will hinder exports, which is consistent with international trade theory. Conversely, due to economies of scale, an increase in export trade helps reduce operating costs and export freight rates. Economies of scale in the shipping industry are considered the critical determinant of freight rates. At the ship level, the larger the size of the container ship is, the lower the cost of transporting a single container. For example, the cost per TEU for a 19,000 TEU ship is 40–46% less than that for an 8,500 TEU ship [46]. The larger the container ship is, the shorter the total voyage time, the more efficient the operation, and the lower the environmental impact [47]. Therefore, shipping companies will deploy larger ships on routes with higher trade volumes to take advantage of economies of scale at the ship level, resulting in lower average freight rates [2, 20]. In addition, another aspect of economies of scale is that the increase in trade volume on a route may attract more shipping companies to enter, thus increasing competition on the route and resulting in lower freight rates [2, 7, 21].

We add import trade variables to the analysis of Jiang et al. [7]; allowing us to consider the impact of trade imbalances on export freight rates. Trade imbalances imply that carriers are forced to haul empty containers back, a process known as repositioning empty containers. For shipping companies, repositioning empty containers only incur additional costs [48]. Due to high port handling costs, the cost of empty container repositioning has become a core cost for shipping companies [49]. In 2009, empty containers resulted in a total cost of $30.1 billion, accounting for 19% of the shipping industry's global revenue [50]. According to Table 1, we find that Shanghai's exports to the six Southeast Asian countries are much smaller than their imports, which means a severe trade imbalance between them. Therefore, the increase in export trade can also alleviate the trade imbalance, and the rise in import trade will aggravate the trade imbalance. Suppose the trade imbalance of the Shanghai-Southeast Asia route increases. In that case, the operating cost of shipping companies will also increase, and shipping companies will have to raise the freight rates to compensate for the loss.

Papers such as Clark et al. [2], Wilmsmeier et al. [22], Wilmsmeier and Martínez–Zarzoso [24], and De Oliveira [20] argue that when there is a trade imbalance, and carriers need to handle the relocation of empty containers on the leg of the trip with less traffic (exports). Therefore, carriers reduce export freight rates to attract those lower trade volumes and increase freight rates for the leg of the trip with

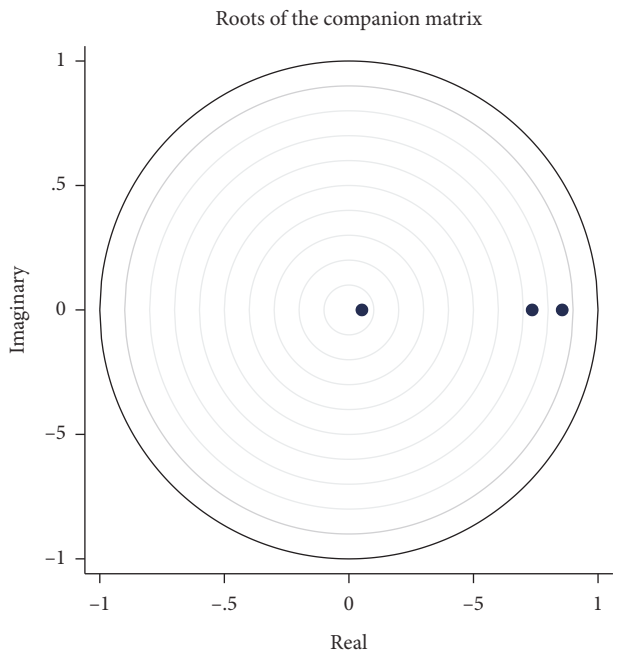


Figure 2: Stability Condition.

Table 3: Panel Unit Root Test Results.

Variables	Levin-Li-chu test Level		Im-pesaran-shin test Level	
	C	C&T	C	C&T
CFI	−3.64***	−2.13***	−3.55***	−2.31***
EX	−3.73***	−2.75***	−4.71***	−3.51***
IM	−6.32***	−7.29***	−7.71***	−6.78***
IP	−8.96***	−8.51***	−8.73***	−9.95***
ER	−1.84**	−2.74***	−1.59*	0.16

Table 4: Estimation results for the panel VAR models.

Variable	Regressand: CFI	Regressand: EX	Regressand: IM
CFI_(t-1)	−0.822*** (0.069)	−0.217** (0.108)	0.151 (0.337)
EX_{t-1}	−0.085** (0.034)	0.145 (0.093)	0.407 (0.250)
IM_{t-1}	0.047*** (0.011)	0.087*** (0.026)	0.675*** (0.084)
IP	0.069** (0.033)	0.159** (0.072)	−0.250 (0.169)
ER	0.0014** (0.00064)	0.00078 (0.0013)	−0.0074* (0.0044)
Time-fixed effects	Control		
Obs.	204		
Hansen's test (*P*-value)	0.155		

Note. ***, ** and * denote 1%, 5%, and 10% significance levels, respectively. Corresponding robust standard errors allowing for intragroup correlation are in parentheses.

more traffic (imports) to compensate for the losses. Thus, the trade imbalance leads to a large freight rate gap between the two directions. However, this claim is not contradictory to our empirical results.

Shanghai and Southeast Asian countries have long been in a trade imbalance where exports are more significant than imports, and therefore export freight rates have remained low for a long time. Among the routes, the Shanghai to Philippines route, where the most severe trade imbalance has long had negative freight rates (the freight rates here do not include all surcharges, and the actual cost to the consignor is a positive amount.). In this case, we believe that an increase in trade imbalances will raise freight rates for imports but will not lead to a decrease in export freight rates. This is because the low export freight rates have made it challenging to cover the costs of transporting the goods. Carriers prefer to ship back empty containers to save time and gain revenue by transporting more imported cargo. Therefore, the export freight rate needs to be increased before the carrier accepts the shipment. Although the increase in trade imbalance will result in the broader gap between import and export freight rates, on average, both import and export freight rates will become higher. For example, the China–US container route was affected by COVID-19. The overlap of China first resuming production and the recovery of U.S. consumer demand has led to a significant increase in U.S. demand for Chinese goods. The surge in imports from China and the growing trade imbalance between the U.S. and China led to a spike in U.S. import freight rates from China, but U.S. export freight rates to China did not decline. As a result, shipping companies rejected many U.S. agricultural exports during October and November 2020, opting to ship empty containers to China [51].

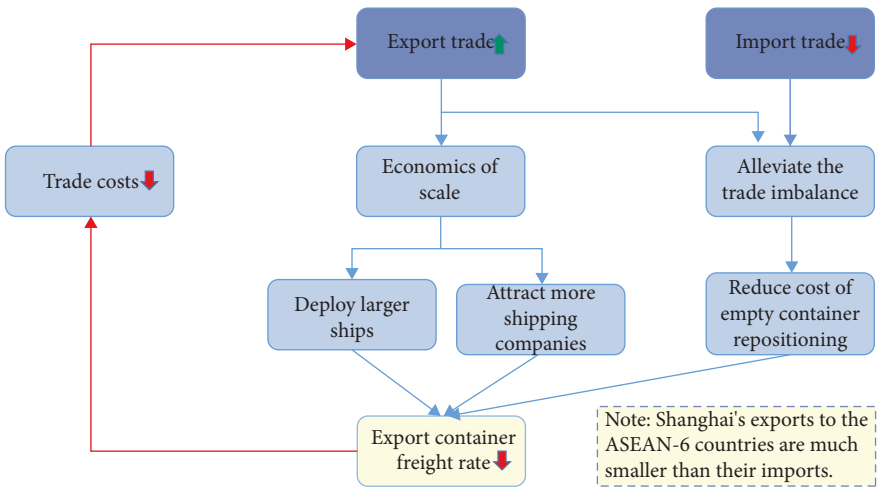


Figure 3: Causal relationships.

Table 5: Wald test of Granger causality.

		x^2	Df	prob>x^2
CFI				
	EX (t-1)	6.136	1	0.013
	IM (t-1)	18.363	1	0.000
	ALL (t-1)	35.036	2	0.000
EX				
	CFI (t-1)	4.003	1	0.045
	IM (t-1)	11.013	1	0.001
	ALL (t-1)	22.739	2	0.000
IM				
	CFI (t-1)	0.203	1	0.653
	EX (t-1)	2.652	1	0.103
	ALL (t-1)	2.698	2	0.259

Note. H0: The excluded variable does not Granger-cause the equation variable. H1: The excluded variable Granger causes the equation variable.

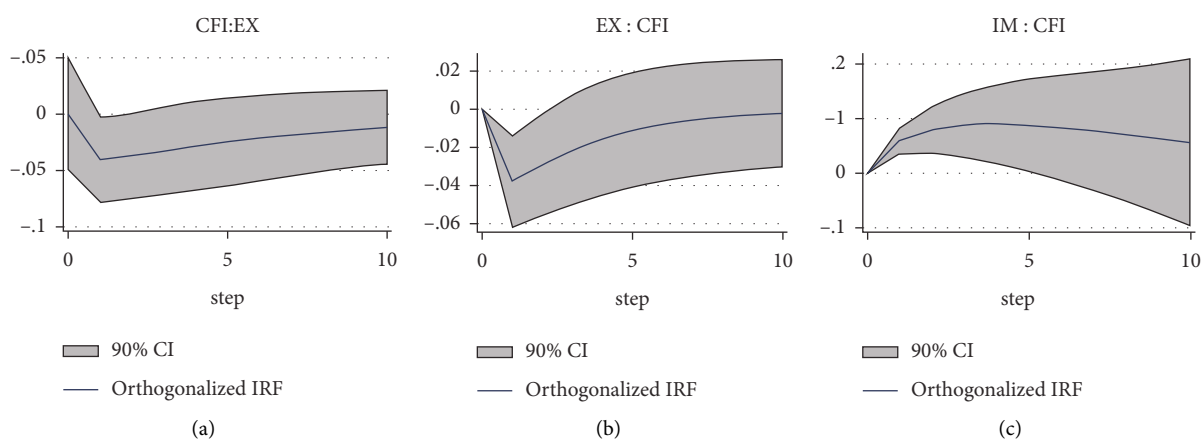


Figure 4: Impulse response graphs.

Shipping companies have indicated that they will not transport unless freight rates are increased.

4.2. Impulse Response Analysis. Impulse response graphs are presented in Figure 4. 90% confidence bounds are based on 300 bootstrap simulations.

Presents the estimation results of our panel VAR model. Hansen's test of overidentifying restriction demonstrates the validity of the instrumental variables used in our study.

In Figure 4(a), an one standard deviation unanticipated positive freight rate shock immediately hurts export trade. A significant impact is observed in the first period, after which it gradually decreases and converges to zero. Thus, we find that the

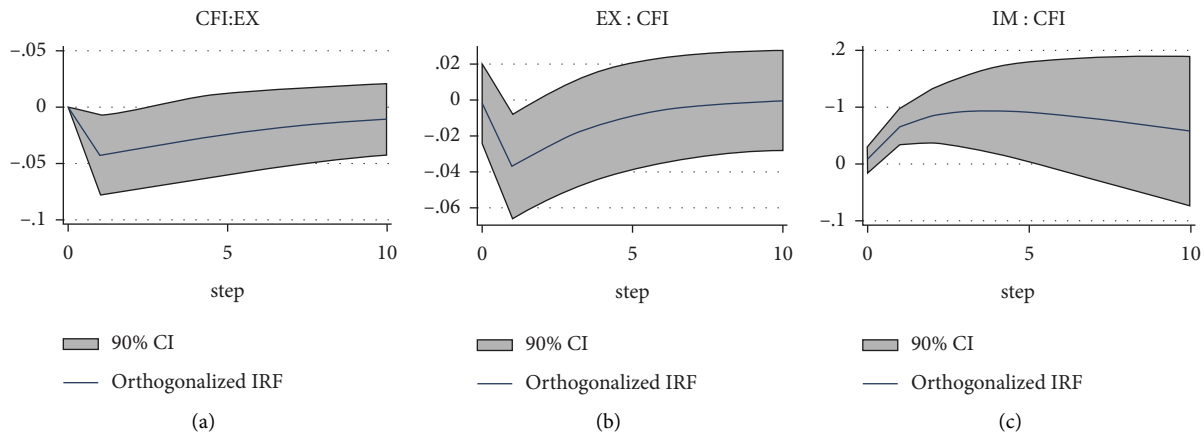


Figure 5: Impulse response graphs.

impeding effect of export container freight rates on export trade takes effect immediately but is not maintained for a long time.

In Figure 4(b), a positive shock to export trade decreases export container freight rates. This effect is maximized in the first period and is statistically significant up to the second period.

In Figure 4(c), a positive shock to import trade significantly contributes to increased export container freight rates for at least five months. This indicates that a larger trade imbalance due to increased import trade can impact export container freight rates for a more extended period. At the same time, the impact caused by import trade is twice as large as that of export trade and lasts longer.

Finally, we performed a robustness test. To identify shocks and keep other shocks zero, we need to give the variables a specific order [45]. The current order of the variables is [CFI, EX, IM]. For a robustness check, we reverse the order of the variables to [IM, EX, CFI]. See Figure 5, where the variable order has no substantial effect on the results.

5. Conclusion

To investigate the relationship between container freight rates and international trade, we analyze the relationship between export container freight rates and imports and exports from Shanghai to ASEAN-6 countries by applying a panel vector autoregression technique. Our study not only considers the relationship between export trade and freight rates but also considers the impact of import trade by changing trade imbalances. The panel vector autoregression technique has advantages in controlling macroeconomic factors and unobservable heterogeneity using individual fixed and time effects. It thus can identify the causal relationship between container freight rates and international trade more accurately.

The results show a bidirectional causal relationship between export container freight rates and export trade. An increase in export trade reduces export container freight rates by achieving economies of scale and improving trade imbalances. Conversely, an increase in export container freight rates implies increased trade costs and hinders export trade. However, the causal relationship between import trade and export container freight rates is unidirectional. The increase in import trade raises export container freight rates by exacerbating trade imbalances.

In addition, this paper also investigates the dynamic effects through orthogonal impulse response functions. We find that the impact of import trade on export container freight rates is larger and longer lasting than that of export trade, indicating the importance of import trade in changing trade imbalances. As well known, trade imbalances are widespread worldwide, with satellite data of ship movements showing that 42% of ships are traveling without cargo [5]. Therefore, trade in both directions needs to be considered when studying trade costs. Overall, our findings validate that trade costs are endogenous and provide empirical evidence for current trade theory research on the endogeneity of trade costs, in contrast to existing literature that interprets trade costs as exogenous based on classic trade theory.

According to the empirical results, we put forward the following suggestions. First, as the leader of serving the construction of the "twenty-first Century Maritime Silk Road," Shanghai should continue to speed up the structure of the international shipping center and form a linkage with the construction of the Shanghai free trade zone to create a shipping development environment with international competitiveness. Second, Shanghai should also seize the opportunity to implement the "twenty-first Century Maritime Silk Road" to promote the integration of trade with ASEAN and other countries, expand trade exchanges, and further highlight the function of Shanghai as an international trade center. Especially after the signing of the RCEP, the economic and trade cooperation between ASEAN and Shanghai has been ushering in more significant development opportunities. The ASEAN region is increasingly becoming the core area for Shanghai to construct the "twenty-first Century Maritime Silk Road," but the structural trade imbalance between Shanghai and ASEAN has hindered the further development of bilateral trade. Therefore, Shanghai should collaborate with the Yangtze River Delta region to participate in global competition and cooperation and create opportunities for industries with comparative advantages to enter the ASEAN market. This initiative utilizes the shipping capacity that was previously wasted due to trade imbalance

and reduces the cost of shipping by reducing empty containers, which ultimately contributes to the development of the trade and shipping industry.

Due to the limitation of the data, this paper only examined the relationship between one direction container freight rates and international trade. However, their relationship may change due to the difference in directions, which would require further data collection and analysis. In addition, many macrodata in the monthly data are not applicable.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] J. E. Anderson and E. van Wincoop, "Trade costs," *Journal of Economic Literature*, vol. 42, no. 3, pp. 691–751, 2004.

[2] X. Clark, D. Dollar, and A. Micco, "Port efficiency, maritime transport costs, and bilateral trade," *Journal of Development Economics*, vol. 75, no. 2, pp. 417–450, 2004.

[3] I. Martínez-Zarzoso and C. Suárez-Burguet, "Transport costs and trade: empirical evidence for Latin american imports from the European Union," *Journal of International Trade & Economic Development*, vol. 14, no. 3, pp. 353–371, 2005.

[4] UNCTAD, *Presentation of the Review of Maritime Transport 2021*, https://unctad.org/meeting/presentation-review-maritime-transport-2021, 2021a.

[5] G. Brancaccio, M. Kalouptsidi, and T. Papageorgiou, "Geography, transportation, and endogenous trade costs," *Econometrica*, vol. 88, no. 2, pp. 657–691, 2020.

[6] J. Korinek and P. Sourdin, "Maritime transport costs and their impact on trade," *Organization for Economic Co-operation and Development TAD/TC/WP*, p. 7, 2009.

[7] B. Jiang, J. Li, and C. Gong, "Maritime shipping and export trade on maritime silk road," *The Asian Journal of Shipping and Logistics*, vol. 34, no. 2, pp. 83–90, 2018.

[8] I. Rojon, N.-J. Lazarou, N. Rehmatulla, and T. Smith, "The impacts of carbon pricing on maritime transport costs and their implications for developing economies," *Marine Policy*, vol. 132, p. 104653, 2021.

[9] M. Stopford, *Maritime economics 3e*, Routledge, 2008.

[10] A. Jugović, N. Komadina, and A. Perić Hadžić, "Factors influencing the formation of freight rates on maritime shipping markets," *Pomorstvo: Scientific Journal of Maritime Research*, vol. 29, no. 1, pp. 23–29, 2015.

[11] M. Luo, L. Fan, and L. Liu, "An econometric analysis for container shipping market," *Maritime Policy & Management*, vol. 36, no. 6, pp. 507–523, 2009.

[12] J. S. L. Lam, K. P. B. Cullinane, and P. T.-W. Lee, "The 21st-century maritime silk road: challenges and opportunities for transport management and practice," *Transport Reviews*, vol. 38, no. 4, pp. 413–415, 2018.

[13] P. T. W. Lee, Z. H. Hu, S. J. Lee, K. S. Choi, and S. H Shin, "Research trends and agenda on the Belt and Road (B&R) initiative with a focus on maritime transport," *Maritime Policy & Management*, vol. 45, no. 3, pp. 282–300, 2018.

[14] J. Yang, M. Luo, and A. Ji, "Analyzing the spatial–temporal evolution of a gateway's hinterland: a case study of shanghai, China," *Transportation Research Part E: Logistics and Transportation Review*, vol. 95, pp. 355–367, 2016.

[15] J. Yin and J. Shi, "Seasonality patterns in the container shipping freight rate market," *Maritime Policy & Management*, vol. 45, no. 2, pp. 159–173, 2018.

[16] UNCTAD, *Review of Maritime Transport 2021*, https://unctad.org/system/files/official-document/rmt2021_en_0.pdf, 2021b.

[17] S. Bensassi, I. Martinez-Zarzoso, and C. Suárez, "The effect of maritime transport costs on the extensive and intensive margins: evidence from the europe–asia trade," *Maritime Economics & Logistics*, vol. 16, no. 3, pp. 276–297, 2014.

[18] J. Korinek and P. Sourdin, "Clarifying trade costs: maritime transport and its effect on agricultural trade," *Applied Economic Perspectives and Policy*, vol. 32, no. 3, pp. 417–435, 2010.

[19] I. Martínez-Zarzoso, E. M. Pérez-García, and C. Suárez-Burguet, "Do transport costs have a differential effect on trade at the sectoral level?" *Applied Economics*, vol. 40, no. 24, pp. 3145–3157, 2008.

[20] G. F. De Oliveira, "Determinants of european freight rates: the role of market power and trade imbalance," *Transportation Research Part E: Logistics and Transportation Review*, vol. 62, pp. 23–33, 2014.

[21] S. Camisón-Haba and J. A. Clemente-Almendros, "A global model for the estimation of transport costs," *Economic Research-Ekonomska Istraživanja*, vol. 33, no. 1, pp. 2075–2100, 2020.

[22] J. Wilmsmeier, J. Hoffmann, and R. J. Sanchez, "The impact of port characteristics on international maritime transport costs," *Research in Transportation Economics*, vol. 16, no. 1, pp. 117–140, 2006.

[23] V. F. Valentine, H. Benamara, and J. Hoffmann, "Maritime transport and international seaborne trade," *Maritime Policy & Management*, vol. 40, no. 3, pp. 226–242, 2013.

[24] G. Wilmsmeier and I. Martínez-Zarzoso, "Determinants of maritime transport costs – a panel data analysis for Latin american trade," *Transportation Planning and Technology*, vol. 33, no. 1, pp. 105–121, 2010.

[25] G. Wilmsmeier and J. Hoffmann, "Liner shipping connectivity and port infrastructure as determinants of freight rates in the caribbean," *Maritime Economics & Logistics*, vol. 10, no. 1-2, pp. 130–151, 2008.

[26] J. Asturias, "Endogenous transportation costs," *European Economic Review*, vol. 123, p. 103366, 2020.

[27] W. F. Wong, *The Round Trip Effect: Endogenous Transport Costs and International Trade*, University of Oregon, Africa, 2018.

[28] V. Oguledo and C. R. Macphee, "Gravity models: a reformulation and an application to discriminatory trade arrangements," *Applied Economics*, vol. 26, no. 2, pp. 107–120, 1994.

[29] UNCTAD, *Why and How to Measure International Transport Costs*, 2020, https://unctad.org/news/why-and-how-measure-international-transport-costs.

[30] I. Martínez-zarzoso, L. García-menéndez, and C. Suárez-burguet, "Impact of transport costs on international trade: the case of Spanish ceramic exports," *Maritime Economics & Logistics*, vol. 5, no. 2, pp. 179–198, 2003.

[31] S. Karamperidis, E. Jackson, and J. Mangan, "The use of indices in the maritime transport sector," *Maritime Policy & Management*, vol. 40, no. 4, pp. 339–350, 2013.

[32] H.-J. Schramm and Z. H. Munim, "Container freight rate forecasting with improved accuracy by integrating soft facts from practitioners," *Research in Transportation Business & Management*, vol. 41, p. 100662, 2021.

[33] SSE, *Shanghai Shipping Exchange about Seafi*, 2021,https://en.sse.net.cn/indices/introduction_seafi_new.jsp.

[34] T. Kawasaki, T. Matsuda, Y.-y. Lau, and X. Fu, "The durability of economic indicators in container shipping demand: a case study of east asia–us container transport," *Maritime Business Review*, 2021, *ahead-of-print*(ahead-of-print).

[35] S. Park, J. Kwon, and T. Kim, "An analysis of the dynamic relationship between the global macroeconomy and shipping and shipbuilding industries," *Sustainability*, vol. 13, no. 24, p. 13982, 2021.

[36] J. Baek and S. Nam, "The South Korea–china trade and the bilateral real exchange rate: asymmetric evidence from 33 industries," *Economic Analysis and Policy*, vol. 71, pp. 463–475, 2021.

[37] G. Caruso, E. Colantonio, and S. A. Gattone, "Relationships between renewable energy consumption, social factors, and health: a panel vector auto regression analysis of a cluster of 12 eu countries," *Sustainability*, vol. 12, no. 7, p. 2915, 2020.

[38] A. Grossmann, I. Love, and A. G. Orlov, "The dynamics of exchange rate volatility: a panel var approach," *Journal of International Financial Markets, Institutions and Money*, vol. 33, pp. 1–27, 2014.

[39] J.-W. Jeon, O. Duru, and G.-T. Yeo, "Modelling cyclic container freight index using system dynamics," *Maritime Policy & Management*, vol. 47, no. 3, pp. 287–303, 2020.

[40] H. Yang and Y. Xing, "Containerships sailing speed and fleet deployment optimization under a time-based differentiated freight rate strategy," *Journal of Advanced Transportation*, vol. 2020, pp. 1–16, 2020.

[41] M. R. M. Abrigo and I. Love, "Estimation of panel vector autoregression in stata," *STATA Journal*, vol. 16, no. 3, pp. 778–804, 2016.

[42] D. W. K. Andrews and B. Lu, "Consistent model and moment selection procedures for gmm estimation with application to dynamic panel data models," *Journal of Econometrics*, vol. 101, no. 1, pp. 123–164, 2001.

[43] M. Arellano and O. Bover, "Another look at the instrumental variable estimation of error-components models," *Journal of Econometrics*, vol. 68, no. 1, pp. 29–51, 1995.

[44] I. Love and L. Zicchino, "Financial development and dynamic investment behavior: evidence from panel var," *The Quarterly Review of Economics and Finance*, vol. 46, no. 2, pp. 190–210, 2006.

[45] J. D. Hamilton, *Time Series Analysis*, Princeton university press, China, 2020.

[46] O. Merk, B. Busquet, and R. Aronietis, *The Impact of Mega-Ships*, Int Transp Forum OECD, Paris, 2015.

[47] R. J. Sánchez, D. E. Perrotti, and A. G. P. Fort, "Looking into the future ten years later: big full containerships and their arrival to south american ports," *Journal of Shipping and Trade*, vol. 6, no. 1, p. 2, 2021.

[48] R. Chen, J.-X. Dong, and C.-Y. Lee, "Pricing and competition in a shipping market with waste shipments and empty container repositioning," *Transportation Research Part B: Methodological*, vol. 85, pp. 32–55, 2016.

[49] D.-P. Song and J.-X. Dong, "Cargo routing and empty container repositioning in multiple shipping service routes," *Transportation Research Part B: Methodological*, vol. 46, no. 10, pp. 1556–1575, 2012.

[50] UNCTAD, *Developments in International Seaborne Trade. Review of Maritime Transport*, 2011, https://unctad.org/system/files/official-document/rmt2011_en.pdf.

[51] L. A. LaRocco, *Shipping Carriers Rejected Tons of u.S. Agricultural Exports, Opting to Send Empty Containers to china*, 2021, https://www.cnbc.com/2021/01/26/shipping-carriers-rejected-us-agricultural-exports-sent-empty-containers-to-china.html.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8650500, 10 pages
https://doi.org/10.1155/2022/8650500

Research Article

Pricing American Options by a Fourier Transform Multinomial Tree in a Conic Market

Weiwei Wang [1] **and Xiaoping Hu** [2]

[1] *School of Applied Technology, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[2] *School of Economics and Management, Southeast University, Nanjing 210096, China*

Correspondence should be addressed to Xiaoping Hu; hxpnj@seu.edu.cn

Received 2 June 2022; Accepted 30 August 2022; Published 26 September 2022

Academic Editor: Lele Qin

Based on FFT, a high-order multinomial tree is constructed, and the method to obtain the price of American style options in the Lévy conic market is studied. Firstly, the nature of the Lévy process and the pricing principle of European-style options are introduced. Secondly, the method to construct a high-order multinomial tree based on Fourier transform is presented. It can be proved by theoretical derivation that the multinomial tree can converge to the Lévy process. Thirdly, we introduce the conic market theory based on the concave distortion function and give the discretization method of the concave distortion expectation. Then, the American option pricing method based on reverse iteration is given. Finally, the CGMY process is used to demonstrate how to price the American put option in the Lévy conic market. We can draw conclusions that the Fourier transform multinomial tree can avoid the difficulty of parameter estimation when using traditional moment matching methods to construct multinomial trees. Because the Lévy process has the analytic form characteristic function, this method is a promising method to calculate the prices of options in the Lévy conic market.

1. Introduction

In the traditional market described by the law of one price, buyers and sellers in the market sell goods at the same price at the same moment. However, the law of one price cannot describe a market with insufficient liquidity or a market using the market maker rule, such as Nasdaq or other OTC markets. The conic finance theory developed in recent years can solve this problem well. In the conic theory, the whole market is treated as a virtual counterparty for zero-transaction costs with non-negative cash flows. There are different prices for the same cash flow at the same time. So the conic market is also known as the two-price market [1]. Contrary to the law of one price that risks can be eliminated through hedging, the conic finance theory argues that the risk in the market will not be eliminated completely but only to a certain acceptable extent, which reflects the reality of the market better . The theory of conic finance is the latest development branch of financial economics and financial engineering. It is a hot research topic spot in theory and application in recent years.

A basic model based on a more realistic balance sheet mode was introduced in Refs. [2], [3], where both the assets and liabilities were found to be risky. Thus, bid and ask prices must be treated separately and prudently. According to this model, contingent capital notes are priced based on the conic theory. Using the acceptability and distorted expectations, the author introduced a capital gap-based trigger and summarized the pricing of seven kinds of capital and noncapital bonds. Dilip Madan and Wim Schoutens [3] solved the parameter correction problem of distortion risk measures by using the bid-ask transaction history data in the options market. Fasen and Svejda [4] gave a dynamic consistency version to ensure that acceptability decisions are consistent over time. One of the static risk measures is the so-called distortion measure. Based on the framework of notions of consistency, these static risk measures can be extended to the dynamic setting, and the acceptable or

unacceptable risks of bank portfolio are studied based on the dynamic risk measure. Rodriguez [5] studied the theory of no-arbitrage pricing and dynamic cone finance in discrete-time markets where the underlying asset pays dividends and carries transaction costs and pointed out that the no-arbitrage condition in this market also implies the existence of a risk-neutral measure. Madan and Schoutens [6] illustrated a two-price market equilibrium theory that allows investors to trade structured products of their design. Competitive pressures in the market cause the market to reduce asking prices and raise bid prices. Bielecki et al. [7] used the theory of dynamic coherent acceptability indices to derive the theoretical framework of dynamic bid-ask prices for derivatives and amplified the dynamic gain loss ratio to calculate the bid and ask prices of some path-dependent options. Madan et al. [8] constructed a Markov chain to modeling the dynamically consistent sequences of the bid and ask prices. These processes are demonstrated by generating dynamically consistent bid and ask sequences for various structured products. Eberlein et al. [9] clarified that nonlinear discounted martingale is associated with no-arbitrage in a two-price economy because the linear discounted martingale is independent of no-arbitrage in the economy and satisfies the law of one price. In Madan and Wang [10], for the dual problem, the acceptability pricing is attributed to convex programming that can be solved by the CVXOPT. The forward-start option is used to describe the acceptability process which is defined by positive expectations at minima var. Obtaining the boundaries is more restrictive than ignoring the repricing constraints or the acceptability support set. Madan [11] constructed a model combining nonlinear discounting and nonlinear martingale, which illustrates the interaction between the severity of the change and its associated discount rate. Mathematical finance relies extensively on martingale, and in some cases, martingale needs to satisfy constraints. For example, they may need to evolve in compact concentrates; if the interest rate is positive, the discounted zero-coupon bond price is [0, 1] in the risk-neutral martingale. Vrins [12] presented conic martingale to solve this problem, and then the SDE of bounded martingale with separable diffusion coefficients is converted into an SDE with the drift process of the autonomous diffusion coefficient. The method is applied to the modeling of survival probabilities and potential applications include CDS options or CVA of the pricing. Eberlein [13] proposed a two-price market model, which is determined in the absence of market equilibrium so that the risk of loss is acceptable. Acceptability is defined by a series of test measures or scenarios. Therefore, the bid price is the lowest point of the valuation of the test, and the asking price is the highest price of such a valuation. The two prices are related to the nonlinear expectations operator, which discussed liquidity measurement and portfolio theory and other aspects. Junike [14] proposed a new definition of concave conditional performance, proving the duality of the conditional risk measure, and established a new dynamic performance measure. Madan and Schoutens [15] gave a comprehensive introduction to the conic theory which also known as two-price theory. Although the law of one price usually eliminates all risks, the concept of acceptable risk is vital to the two-price theory which considers that it is impossible to eliminate risk in the modern financial economy.

In the conic market, the bid-ask spread reflects the market liquidity, and the transaction direction determines the transaction price. Therefore, risk measurement and management and hedging strategies in the conic market are completely different from those in one price market. Corcuera et al. [16] introduced the concept of the implicit liquidity of a market. Implicid liquidity is the ability to describe the liquidity risk embedded in the prices of financial derivatives. Albrecher et al. [17] used the bid and ask model prices to fit their market quotes, and then obtain the implied liquidity of financial instruments which is called Lambda: The lower the lambda, the higher the mobility. Estimating parameters before the credit crisis and after the credit crisis showed that long-term options tend to reduce liquidity, and short-term options enhanced liquidity during troubled times. Masimba et al. [18] presented a method to estimate the bid-ask price based on the LIBOR option, which is used for the determination of the caps and floors premium. In the framework of conic finance, Leippold and Schaerer [19] developed a stochastic fluidity model that extends Madan's (2010) discrete-time constant mobility model. With this extension, it is possible to better describe the term structure such as skewness and kurtosis of bid-ask spreads that are typically observed in the options market. Masimba et al. [20] examined the quantification of the risk of incomplete market trading strategies based on the reasonable price of conic finance, which can be determined only by the probability distributions of cash flows. Madan et al. [21] conducted a study based on the conic finance theory to analyze assets demand, optimal debt level, and the value of return of the loss to the tax payer's option for a firm with a lognormal distribution and assets and liabilities, debt and equity costs, as well as the level of the securities ultimately reported in the balance sheet to analyze and report in detail the relationship between these entities and the risk characteristics of the firm. Madan [2] used all the underlying option surfaces to hedge complex positions on multiple underlies. The hedging goal is to minimize the asking price and the remaining risk after hedging is acceptable at a predetermined level. It indicates that such hedging requires the use of risk-neutral principles for potential risks. The comparison of neutral risk, risk-neutral method, and statistical method to estimate the joint risk of multiple underlying assets from multiple option surfaces shows that risk-neutral is superior to its statistical counterparty, and hedging can significantly reduce the asking price. Based on the conic finance theory, Madan [22] studied the evolution of credit assessment adjustment (CVA) from the counterparty's credit risk, including the influence of its default (DVA), the recognition of risk, and the possibility of joint default. Madan [23] introduced the definition of acceptable risk of loss when supply and demand are defined in different event spaces. The risk of acceptable loss is modeled by the convex cone containing all non-negative variables, and financial balance is usually defined as a two-price economy. Acceptable risk of loss has an impact on accounting and risk management since debt is usually

valued by ask price and the asset is valued at the bid price. In two-price economy, the best of marking to market is marking two prices. Madan et al. [24] used dynamic concave bid prices and convex ask price functions to define a new hedging strategy called dynamic-conic hedging. The main points of these strategies are to maximize the expected position of the nonlinear condition. Guillaume and Schoutens [25] used the calibrated risk for bid-ask pricing and market-oriented cash flow valuation based on the conic theory. Calibration of the different asset pricing models for liquid trading derivatives leads to different risk-neutral measures by using a variety of reasonable calibration methods, which can be viewed as a test measure for evaluating the (not) acceptability of risk. Madan et al. [26] used nonlinear conditional expectations of nonadditive probabilities in the discrete-time Markovian environment to estimate trading strategies by exaggerating the upward caudal loss event and exaggerating the downward tail gain event to obtain conservatism and the steady-state fixed point of the value and strategy. Madan [27] constructed the best portfolio for full-size positions, long-short mix positions, and volatility-constrained portfolios, compared to the mean-variance portfolio, reflecting a lower degree of concentration in the conic portfolio. It has a comparable sample upside performance and higher downside results. Madan [27] examined portfolio selection issues within the framework of conic finance obtaining the level of risk from the market, selecting weights for each asset to maximize the bid price, comparing different distortion measures to achieve the expected cash flows, solving the problem under different constraints of size and weight, and using a variety of algorithms to calibrate the model. In the conic market, the economic equilibrium allows for different trading prices for nontraded positions. Marking the market turns to marking two prices. Madan [28] applied CoCoCoA to continuously contemporary conservative accounting and used these two mark-to-market systems for 77 companies from November 2005 to July 2015 and the average return of trading performance indicators. It showed that the two accounting systems have substantial differences in business rankings. Hellmers et al. [29] reduced the imbalance in order to improve the total profitability of the asset portfolio by increasing the implicit penalty. A comprehensive mathematical model was proposed to study business strategy in two-price economy. It was found that due to the two-price structure of the equilibrium market, the combined strategy is the most profitable. Li [30, 31] studied the European option pricing problem in the conic market. Van [32], Vazifedan [33], and Vega [34] investigated the application of risk measurement, no-arbitrage, and mechanism selection in the pricing of derivatives in conic financial markets and the impact of credit and default on asset values. Michielon [35] proposed a conic theory-based approach that is able to obtain risk-neutral implied volatilities by use of bid-ask quotes and does not require any restrictive assumptions. Madan [36] provided a systematic and in-depth introduction to the pricing of derivatives in conic financial markets.

In recent years, the Fourier transform has become one of the most frequently used tools in derivatives pricing. One reason is that using fast Fourier transform can reduce the amount of computation, which significantly saves the use of computing resources. The other reason is that the Lévy process is considered to be a better description of stochastic movement of risky asset prices. Mordecki [37], Sheu and Tsai [38], and Yamazaki [39] studied optimal stopping time and permanent American option pricing problems based on Fourier transforms. Zhylyevskyy [40] and Gyulov and Valkov [41] focused on the stochastic volatility and American options pricing on finite intervals based on Fourier transform. Pellegrino and Sabino [42], Chan [43], Ruijter and Oosterlee [44] used the multidimensional Fourier transform. Chan [43]studied the derivative pricing by the complex Fourier transform. Wong and Guan [45] obtained a Markov chain for option pricing by the use of FFT. Madan and Yor [46]came up with a type of time-varied Brownian representation theorem about the Lévy process. Asiimwe et al. [47] gave a mechanism to select risk pricing in the Lévy market. Kulczycki and Ryznar [48] studied the problem of estimating the probability transfer function of the Lévy stochastic process. Neufeld and Nutz [49] and Vrins [50] focused on the characteristic functions of Lévy processes. Jovan and Ahčan [51] researched on the Lévy model using structural methods to predict the default. Gong and Zhuang [52] and Lian et al. [53], respectively, studied the Lévy process under the American options and discrete barrier option pricing methods.

Most Lévy processes do not have analytic forms of probability density functions but definitely have analytic forms of characteristic functions. Hu et al. [54] presented an algorithm to create a multinomial tree based on saddle-point approximation for pricing options in the Lévy market. Based on FFT, authors proposed a new method to construct a high-order recombination multinomial tree, which can be applied to the American option pricing in Lévy model conic markets. The algorithm has low computational resource requirements and is very easy to program, which solves the difficulty of constructing a risk-neutral multinomial tree by traditional moment matching methods.

When the market is incomplete, the equivalence martingale measure of pricing is not unique, and thus the traditional pricing theory is also able to obtain the bid-ask spread of prices of the same financial derivatives. In a noncomplete market, the bid-ask price spread determined by the equivalence martingale measure is too broad compared with the actual bid-ask spread in the market. In contrast, the parameters of the distortion measure in conic market theory can be obtained by use of the market data, and the obtained bid-ask spread better reflects the actual market situation. The remainder of this article is organized as follows: Section 2 describes the Lévy process and European option pricing. In Section 3, we present an algorithm to create a multinomial tree based on FFT. Section 4 introduces the concave distortion expectation and pricing in the conic market and gives the discretization method of the concave distortion function. Section 5 gives an American option pricing method based on inverse iteration. Section 6 demonstrates the application of the algorithm to pricing

American put option through the CGMY process. In Section 7, we draw conclusions and provide an outlook.

2. The Lévy Process and European Option Pricing

Given a Lévy process X_t, based on the Lévy–Khintchine formula, the characteristic exponent of X_1 can be presented as follows:

$$\Psi(u) = i\mu u - \frac{1}{2}\sigma^2 u^2 + \int_{\mathbb{R}} \left(e^{iux} - 1 - iux1_{(-1,1)}\right)\nu(dx). \quad (1)$$

The characteristic function of X_t is

$$\begin{aligned}\Phi(u) &= E_{X_t}\left[e^{iux}\right] \\ &= e^{t\Psi(u)}.\end{aligned} \quad (2)$$

Denote the probability density function (PDF) by $f(x)$, and denote cumulative distribution function (CDF) by $F(x)$. The characteristic function is the Fourier transform of the PDF is given by

$$\Phi(u) = \int_{-\infty}^{+\infty} e^{iux} f(x)dx. \quad (3)$$

The PDF and the CDF can be obtained from the characteristic function as

$$\begin{aligned} f(x) &= \frac{1}{\pi}\int_0^{+\infty} \Re\left(e^{-ixu}\Phi(u)\right)du, \\ F(x) &= \frac{1}{2} - \frac{1}{\pi}\int_0^{+\infty} \Im\left(\frac{e^{-ixu}\Phi(u)}{u}\right)du, \end{aligned} \quad (4)$$

$\Re(\cdot)$ is the real part of the complex number, and $\Im(.)$ refers to the imaginary component of the complex number. The mature period is T. When $t = 0$, the price of a European option with the payoff function $g(.)$ is

$$\begin{aligned} C &= e^{-rT}E^Q[g(x)] \\ &= e^{-rT}\int_{-\infty}^{+\infty} g(x)f(x)dx. \end{aligned} \quad (5)$$

But for most Lévy processes, there is no analytic form of the PDF, and you need the help of numerical calculation methods, but the efficiency of doing so is extremely low. Carr and Madan [55], Lewis [56], and Bates [57] used different techniques and all obtained analytical formulas for European option pricing in the Fourier transform space.

For exotic options with path dependence and American options that can be terminated before the mature time, there is no analytic form of pricing formula. In the use of numerical methods to calculate Fourier transform or inverse Fourier transform, FFT (IFFT) reduced to $N\log_2^N$ times to calculate the discrete Fourier transform or inverse Fourier transform which required N^2 times calculation, which greatly improves the computational efficiency. This means that in the pricing of derivatives if the analytic pricing formula of Fourier space can be obtained, it is also called the analytic pricing formula.

3. FFT-Based Multinomial Trees

Compared with the Markov chain, which holds fixed nodes during the whole computation process, the multinomial tree has fewer nodes at the time when price fluctuation is relatively small and has more nodes at a relatively large price fluctuation time and also has higher computational efficiency when calculating the price of derivatives. In the present literature, the moment matching method is applicated to making the moments of the multinomial tree as close as possible to the moments of continuous distribution. Determining the multinomial tree to meet the requirements of the parameters is very difficult, and we often need some extra constraints, such as Yamada and Primbs [58]; the formulation of parameter estimation about a quintuple tree. However, this requires that higher order moments of the continuous distribution must exist and satisfy certain relational constraints; otherwise, the existence of equivalent probability measures for the obtained multinomial trees cannot be guaranteed.

We subject the price of the risky asset to the exponential Lévy process as

$$S_t = S_0 e^{\left(rt - \mu t + X_t\right)}, \quad (6)$$

where S_0 is the stock price when $t = 0$, and $r > 0$ is the risk-free interest rate, X_t is a Lévy process, μ is the constant that makes the expected return of risky asset to be the same as the risk-free interest rate. $T > 0$ is the maturity of the derivatives, and we make $\delta = T/N$ by using the independent-stationary-increments property of the Lévy process, and we have

$$\log(S_{n\delta}) - \log\left(S_{(n-1)\delta}\right) = (r - \mu)\delta + X_\delta. \quad (7)$$

Let $S_n := S_{n\delta}, X_n := X_{n\delta}$. The multinomial tree with $L = 2^k$ is the state which is similar to the Lévy distribution in $[0, \delta]$. The truncation interval X_δ is $[-a, a]$. Let $\Delta = 2a/(L-1)$ and then, we have

$$x_{1,j} = -a + \Delta j, \quad j = 0, 1, 2, \ldots, L-1. \quad (8)$$

The L state of the reorganized multinomial tree, in the first $n\,(n \le N)$ total of $(L-1)n + 1$ nodes, and the j node has

$$x_{n,j} = -na + \Delta j, \quad j = 0, 1, 2, \ldots, (L-1)n. \quad (9)$$

In period n, the truncation interval X_n is $[-na, na]$ because

$$\begin{aligned} X_{n+1,j+k} &= -(n+1)a + (j+k)\Delta \\ &= -na + j\Delta - a + k\Delta \\ &= X_{n,j} + X_{1,k}, \end{aligned} \quad (10)$$

where $k = 0, 1, 2, \ldots, L-1$, so the node j in the period n has L subnodes of the period $(n+1)$: $X_{n+1,j}, \ldots, X_{n+1,j+L-1}$, and the price of the underlying asset at the node j in the period n is

$$\begin{aligned} S_{n,j} &= S_0 e^{\left((r-\mu)\delta n + X_{n,j}\right)} \\ &= S_0 e^{\left((r-\mu)\delta n - na + j\Delta\right)}, \quad j = 0, 1, 2, \ldots, (L-1)n, \end{aligned} \quad (11)$$

where $\Phi(u)$ is the characteristic function of the Lévy process in $[0,\delta]$, and the PDF is discretized as

$$f(x) = \frac{1}{\pi}\int_0^{+\infty} \Re\left(e^{-ixu}\Phi(u)\right)du \approx \frac{1}{\pi}\sum_{j=0}^{L-1} \Re\left(e^{-ixu_j}\Phi\left(u_j\right)\right)\eta. \tag{12}$$

The upper bound of the integral in (11) is $b = L\eta$ and $\Delta\eta = 2\pi/L$. Thus, the FFT calculation formula can be used. FFT returns L and the value x, and then we get

$$x_j = -a + \Delta j, \quad j = 0, 1, 2, \ldots, L-1. \tag{13}$$

When$x_j \in [-a, a]$, further, let $u_j = \eta j$, then the (12) can be expressed as

$$f(x_k) \approx \frac{1}{\pi}\sum_{j=0}^{L-1} \Re\left(e^{-i\Delta\eta kj}\Phi\left(u_j\right)\eta w_j\right), \tag{14}$$

where $k = 0, 1, 2, \ldots, L-1$, and w_j is based on different numerical integration methods to determine the weighting coefficients such as Trapezoidal rule weight, and its weight is $w_j = 1/2$. When $j = 0, L-1$; otherwise, $w_{j=1}$, and then the weighting coefficient of Simpson's rule is

$$w_j = \begin{cases} \frac{1}{3}, j = 0, L-1, \\ \frac{4}{3}, j = 1, 3, 5, \ldots, L-3, \\ \frac{2}{3}, j = 2, 4, 6, \ldots, L-2. \end{cases} \tag{15}$$

Based on FFT, we can obtain the approximate formula of the PDF in $[-a, a]$ an equidistant grid point.

In the L state of the multinomial tree, the probability of occurrence of the j state is

$$P_j = \frac{f\left(x_j\right)}{\sum_{k=0}^{L-1} f\left(x_k\right)}. \tag{16}$$

The denominator in (16) acts as a normalization to ensure that all states in the multinomial tree can form a complete probability space.

Theorem 1. *When $a \longrightarrow +\infty, L \longrightarrow +\infty$, then the distribution of $X_{1,j}$ converges to the continuous distribution X_δ.*

Proof 1. The PDF of X_δ is $f(x), x \in (-\infty, +\infty)$, $X_{1,j}$ is the L aliquot of $[-a, a]$, then the discrete random variable $X_{1,j}$ can be extended to the continuous distribution within $[-a, a]$, and the CDF after the extension is

$$\widetilde{F}(x) = \begin{cases} P_0, & x \le -a, \\ \sum_{k=0}^{j} P_k, & -a + \Delta j < x \le -a + \Delta(j+1), \\ 1, & x \rangle a. \end{cases} \tag{17}$$

(I) When $x \le -a$, by $F(x)$ monotonically increasing, there is

$$\begin{aligned} |F(x) - \widetilde{F}(x)| &\le F(x) + \widetilde{F}(x) \\ &\le F(-a) + \widetilde{F}(-a) \\ &\le F(-a) + f(-a). \end{aligned} \tag{18}$$

$$\because \lim_{-a \longrightarrow -\infty} F(-a) = \lim_{-a \longrightarrow -\infty} f(-a) = 0. \quad \lim_{\substack{-a \longrightarrow -\infty \\ x \le -a}} |F(x) - \widetilde{F}(x)| = 0. \tag{19}$$

(II) When $x \le -a$, then

$$|F(x) - \widetilde{F}(x)| = |F(x) - 1|. \tag{20}$$

$$\because \lim_{a \longrightarrow +\infty} F(a) = 1. \quad \lim_{\substack{a \longrightarrow +\infty \\ x \ge a}} |F(x) - \widetilde{F}(x)| = 0. \tag{21}$$

(III) When $-a + \Delta j \langle x \le -a + \Delta(j+1)$, $j = 1, 2, \ldots, L-1$, then

$$\begin{aligned} \widetilde{F}(x) &= \sum_{k=0}^{j} P_k \\ &= \frac{\sum_{k=0}^{j} f(x_k)}{\sum_{i=0}^{L-1} f(x_i)} \\ &= \frac{\sum_{k=0}^{j} f(x_k)\Delta}{\sum_{i=0}^{L-1} f(x_i)\Delta}. \end{aligned} \tag{22}$$

$\because$ When a is fixed, $L \longrightarrow +\infty$, $\Delta = 2a/L - 1 \longrightarrow 0$, $x_j \longrightarrow x$. $\therefore \lim_{L \longrightarrow +\infty} \widetilde{F}(x) = F(x) - F(-a)/F(a) - F(-a)$. $\because$ $a \longrightarrow +\infty, F(-a) \longrightarrow 0, F(a) \longrightarrow 1$. $\therefore \lim_{a \longrightarrow +\infty} \lim_{L \longrightarrow +\infty} \widetilde{F}(x) = F(x)$.

Combining (i), (ii), and (iii), $\forall x \in (-\infty, +\infty)$, and we conclude that

$$\lim_{\substack{L \longrightarrow +\infty \\ a \longrightarrow +\infty}} \widetilde{F}(x) = F(x). \tag{23}$$

□

4. Distort Expectations, Pricing, and Discretization

Cherny and Madan [59] defined the concave distortion function. The so-called concave distortion function $\Psi(\cdot)$ is in

$[0,1]$ itself a monotone concave function, and there are $\Psi(0) = 0$ and $\Psi(1) = 1$.

The commonly used CDF has CVaR, and the function form is as follows:

$$\Psi^{\lambda}(u) = \min\left(\frac{u}{\lambda}, 1\right). \tag{24}$$

Minmax var and its function form is as follows:

$$\Psi^{\gamma}(u) = 1 - \left(1 - u^{1/1+\gamma}\right)^{1+\gamma}. \tag{25}$$

Wang transform [60] and the function form is as follows:

$$\Psi^{\alpha}(u) = N\left(N^{-1}(u) + \alpha\right). \tag{26}$$

In Figure 1 shows CVaR parameters for the $\lambda = 0.05$, minmax var parameters for the $\gamma = 0.5$, and Wang transformation parameters for the $\alpha = 0.75$.

As can be seen in Figure 1, the concave distortion function amplifies the downside (corresponding loss) of the distribution, while the top of the distribution (upside, corresponding yields) is narrow. This reflects the real decision-making psychology of investors, which can be explained by the prospect theory of behavioral economics [61]. We use the bid and ask price history data of the new financial products to estimate the parameters according to the method given by Bannör and Scherer. Based on the concave distortion function, Madan and Schoutens defined the concave distortion measure, the market receivable cash flow X, the CDF $F(x)$, and the PDF $f(x)$. Using the concave distortion measure, the bid-ask prices of cash flow X are given as

$$\text{bid}(\text{X}) = e^{-rT} \int_{-\infty}^{+\infty} x \, d\psi(F(x)). \tag{27}$$

Then,

$$\text{ask}(X) = -e^{-rT} \int_{-\infty}^{+\infty} x \, d\Psi(F_{-X}(x)). \tag{28}$$

The risk-neutral price is

$$\text{neutral}(X) = e^{-rT} \int_{-\infty}^{+\infty} x \, dF(x). \tag{29}$$

From the nature of the distortion function, we get

$$\text{bid}(X) \le \text{neutral}(X) \le \text{ask}(X), \tag{30}$$

T denotes the mature time, and r denotes the risk-free rate.

To price American options with early execution characteristics, a multinomial, dynamic concave distortion measure must be used. Taking into account the temporal consistency of prices, the multiperiod dynamic uniform concave distortion measure given by Fasen and Svejda [4] is used to obtain the price of American options.

When the cash flow increases with the price of the risky asset, such as the payoff function of call options, the bid price is calculated using the following method of discretization of the concave distortion measure:

$$\begin{aligned} P_{L-l}^{\text{bid}} &= \Psi\left(\sum_{i=0}^{l} P_{L-l+i}\right) - \Psi\left(\sum_{i=1}^{l} P_{L-l+i}\right), \quad l = 1,2,3,\ldots,L-1, \\ P_{L}^{\text{bid}} &= \Psi(P_L). \end{aligned} \tag{31}$$

When calculating the asking price, the ask cash flow can be seen as the negative of negative cash flow expectations of the bid cash flow. So the cash flow increases with the underlying asset price rise. The asking price is calculated using the following concave distortion measure discretization:

$$\begin{aligned} P_{l}^{\text{ask}} &= \Psi\left(\sum_{i=1}^{l} P_{i}\right) - \Psi\left(\sum_{i=1}^{l-1} P_{i}\right), \quad l = 2,3,\ldots,L, \\ P_{1}^{\text{ask}} &= \Psi(P_1). \end{aligned} \tag{32}$$

When the cash flow decreases with the price of the risky asset, such as the put option payoff function, to calculate the bid price, we use the concave distortion measure discretization method given by (31) and use the concave distortion measure discretization method given in (32) to calculate the asking price.

5. American Option Pricing Based on Reverse Iteration

Using the dynamic consistency method given by Fasen and Svejda [4] to price American options, reverse iteration based on dynamic programming can be used. Assume that the American option has a payoff function of $M(S)$, the probability of L nodes corresponding to each node in pricing is $P_1, P_2, \ldots, P_L$, at the period i node j, then the continued holding value of American options remains $C_{(i,j)}$. The American option has the value $H_{(i,j)}$ at the node. So the conic L state reorganization of multinomial tree pricing American options of the specific process is as follows:

Step 1: When $i = N$, then $H_{(N,j)} = M(S_{(N,j)})$, $C_{(N,j)} = 0$, $j = 1, 2, \ldots, (L-1)N + 1$.

Step 2: At the period i and node j, the value of holding the American option is

$$C_{(i,j)} = e^{-r\Delta T} \sum_{k=1}^{L} P_k H_{(i+1,j+k-1)}, \quad j = 1,2,\ldots,(L-1)i+1. \tag{33}$$

The value of American options is

$$H_{(i,j)} = \max\left(M\left(S_{(i,j)}\right), C_{(i,j)}\right), \tag{34}$$

if there is

$$M\left(S_{(i,j)}\right) \ge C_{(i,j)}. \tag{35}$$

(i) The American option is executed ahead of time at this node.

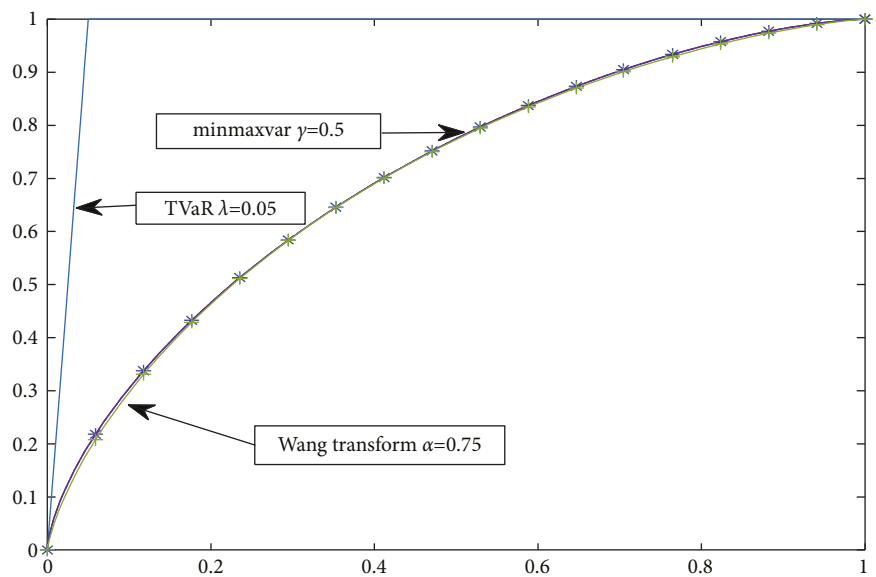


Figure 1: Comparisons of different distortion functions.

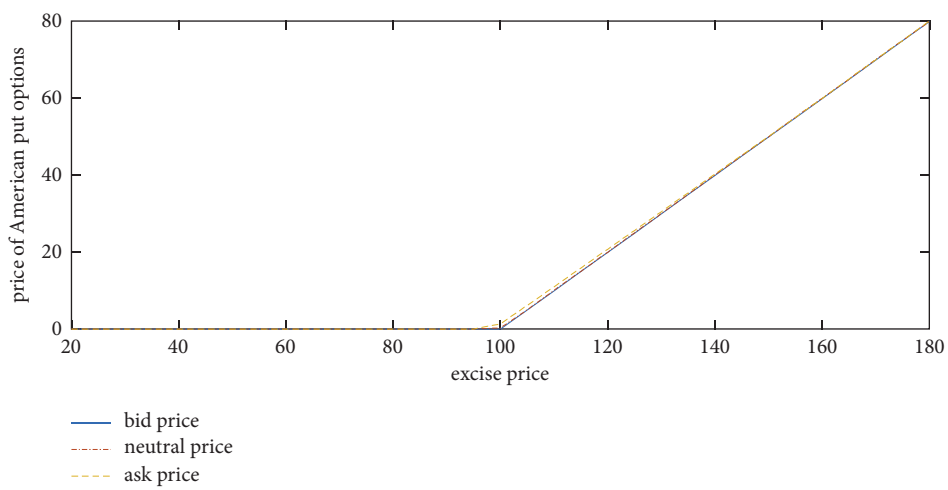


Figure 2: Prices of American put options with different excise prices.

Step 3: If $i = 0$, end; otherwise, $i := i - 1$, turn to step 2.

The American option value at the initial period is $C_{(0,0)}$.

When using conic multinomial tree pricing American options, the early exercise boundaries for American style options are not the same with the continuous-time and not the same with determining the early exercise boundary of the traditional market. In a discrete multinomial tree market, there may not be a node where the immediate execution value is exactly equal to the value of the American option. At the same node, the same American options, the direction of the transaction on the value of American options, and early implementation also have an impact and decisive role. In period i, the long-position owner of an American option decides whether to execute early or not. For American call options, the early execution boundary is determined as follows:

$$\begin{aligned} &\min_{j=1,\ldots,(L-1)i} j \\ &\text{s.t.} \\ &M\left(S_{(i,j)}\right) \geq C_{(i,j)}. \end{aligned} \tag{36}$$

For American put options, the early execution boundary is determined as follows:

$$\begin{aligned} &\max_{j=1,\ldots,(L-1)i} j \\ &s.t. \\ &M\left(S_{(i,j)}\right) \geq C_{(i,j)}. \end{aligned} \tag{37}$$

6. Illustration

The CGMY process proposed by Carr et al. [62] belong to a purely jumping Lévy stochastic process without continuous

motion. Within an appropriate range of parameters, there can be infinite jumps in any given time interval. Infinitely small jumps and a few big jumps constitute the price movement of the risk assets, which is closer to the financial market reality. The characteristic function of CGMY is

$$\Phi(\mu) = e^{C\Gamma(-Y)\left((G+i\mu)^Y - G^Y + (M-i\mu)^Y - M^Y\right)}, \tag{38}$$

where $\Gamma(.)$ is the gamma function, and C, G, M, Y are the parameters of the CGMY distribution $Y\langle 2$, but when $1 \le Y\langle 2$, there is no finite second-moment matrix. When $0 \le Y\langle 1$, then CGMY has infinite jumps. German [63] used PJM's data to obtain the parameters of the CGMY: $C = 0.279627$, $G = 1.497869$, $M = 1.97856$, and $Y = 0.257689$. When $T = 0.5$, the year risk-free interest rate is $r = 5\%$, the beginning of the share price is $S_0 = 100$, and the exercise prices of American options, respectively, are: $K = 95, 100, 105$. The TVaR with parameter $\lambda = 0.95$ is selected as the concave distortion function, and the state $L = 9$, using the method described above to calculate the price of American options in Figure 2.

It can be seen from Figure 2, the bid price is lower than the neutral price, and the neutral price is always lower than the asking price. The imaginary value of the American put option quickly becomes zero because the underlying asset price of the multinomial tree is moving in a limited range. As can be seen from Figure 2, the bid-ask spread obtained by the conic method is close to the actual bid-ask spread in the market. In traditional risk-neutral priced financial derivatives, the bid-ask spreads obtained based on the risk-neutral set are too broad to be of practical value because the risk-neutral measure is not unique.

7. Conclusion

By using FFT to construct high-order restructuring multinomial trees, the pricing of American options in the Lévy model conic market is studied. It proved that the multinomial tree converges in distribution to the Lévy process. It introduces the conic market based on the concave distortions function and pricing and gives the discretization method of the concave distortions function. It gives the American option pricing method based on reverse iteration and demonstrates the American put option pricing in the Lévy-conic market by the CGMY process. It is found that, for the deep-out-of-money American option, the option price obtained by a multinomial tree quickly becomes zero due to the restriction of the price range of the risky asset. The bid price is always less than the risk-neutral price, while the risk-neutral price is always less than the asking price. So with the random concave distortions function parameter changing, bid-ask spreads can be arbitrarily small.

When constructing a high-order restructured multinomial tree using FFT, for the Lévy model in some specific parameter combination, due to the existence of the truncation error, the value of the PDF is sometimes less than zero when calculating the PDF from the characteristic function using IFFT. We must be careful to observe that once the probability density function has a value less than zero, we can consider using the threshold method to make the density function value less than zero to become zero. In the future, we will further study high-precision algorithms, or other alternative methods, and strive to avoid the value of PDF less than zero.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work is partially supported by the National Social Science Fund (16ZDA054).

References

[1] D. B. Madan and A. Cherny, "Markets as a counterparty: an introduction to conic finance," *International Journal of Theoretical and Applied Finance*, vol. 13, no. 08, pp. 1149–1177, 2010.

[2] D. B. Madan and W. Schoutens, "Conic coconuts: the pricing of contingent capital notes using conic finance," *Mathematics and Financial Economics*, vol. 4, no. 2, pp. 87–106, 2011a.

[3] D. B. Madan and W. Schoutens, "Conic finance and the corporate balance sheet," *International Journal of Theoretical and Applied Finance*, vol. 14, no. 05, pp. 587–610, 2011b.

[4] V. Fasen and A. Svejda, "Time consistency of multi-period distortion measures," *Statistics & Risk Modeling*, vol. 29, no. 2, pp. 133–153, 2012.

[5] R. Rodriguez, *Dynamic Conic Finance: No-Arbitrage Pricing and No-Good-deal Pricing for Dividend-Paying Securities in Discrete-Time Markets with Transaction Costs*, Illinois Institute of Technology, Chennai, India, 2012.

[6] D. B. Madan and W. Schoutens, "Structured products equilibria in conic two price markets," *Mathematics and Financial Economics*, vol. 6, no. 1, pp. 37–57, 2012.

[7] T. R. Bielecki, I. Cialenco, I. Iyigunler, and R. Rodriguez, "Dynamic conic finance: pricing and hedging in market models with transaction costs via dynamic coherent acceptability indices," *International Journal of Theoretical and Applied Finance*, vol. 16, no. 01, Article ID 1350002, 2013.

[8] D. B. Madan, M. Pistorius, and W. Schoutens, "The valuation of structured products using Markov chain models," *Quantitative Finance*, vol. 13, no. 1, pp. 125–136, 2013.

[9] E. Eberlein, D. Madan, M. Pistorius, and M. Yor, "A simple stochastic rate model for rate equity hybrid products," *Applied Mathematical Finance*, vol. 20, no. 5, pp. 461–488, 2013.

[10] D. B. Madan and K. Wang, *Acceptability Bounds for Forward Starting Options Using Disciplined Convex Programming*, SSRN, Amsterdam, Netherlands, 2014.

[11] D. B. Madan, "Asset pricing theory for two price economies," *Annals of Finance*, vol. 11, no. 1, pp. 1–35, 2015.

[12] F. Vrins, "Conic martingales," in *Proceedings of the Paper presented at the 8th world congress of the Bachelier Finance Society*, Brussels, Belgium, June 2014.

[13] E. Eberlein, "Two price valuation theory," *Paper presented at the SCF2015 Stochastics & Computational Finance from Academia to Industry*, vol. 17, 2015.

[14] G. Junike, "Dynamic concave performance measures and bid and ask prices with stochastic liquidity," *Browser Download This Paper*, 2016.

[15] D. Madan and W. Schoutens, *Applied Conic Finance*, Cambridge University Press, Cambridge, UK, 2016.

[16] J. M. Corcuera, F. Guillaume, D. B. Madan, and W. Schoutens, "Implied liquidity: towards stochastic liquidity modelling and liquidity trading," *International Journal of Portfolio Analysis and Management*, vol. 1, no. 1, pp. 80–91, 2012.

[17] H. Albrecher, F. Guillaume, and W. Schoutens, "Implied liquidity: model sensitivity," *Journal of Empirical Finance*, vol. 23, pp. 48–67, 2013.

[18] M. Energy Sonono and H. Phillip Mashele, "Estimation of bid-ask prices for options on LIBOR based instruments," *Finance Research Letters*, vol. 19, pp. 33–41, 2016.

[19] M. Leippold and S. Schaerer, "Discrete-time option pricing with stochastic liquidity," *Swiss Finance Institute Research*, vol. 75, pp. 1–6, 2017.

[20] M. E. Sonono and H. P. Mashele, "Assessing the risks of trading strategies using acceptability indices," *Journal of Mathematical Finance*, vol. 03, no. 04, pp. 465–475, 2013.

[21] D. B. Madan, W. Schoutens, and B. Leuven, "Conic financial markets and corporate finance," *Eurandom Report*, 2010.

[22] D. B. Madan, "From credit valuation adjustments to credit capital commitments," *Quantitative Finance*, vol. 12, no. 6, pp. 839–845, 2012a.

[23] D. B. Madan, "A two price theory of financial equilibrium with risk management implications," *Annals of Finance*, vol. 8, no. 4, pp. 489–505, 2012b.

[24] D. B. Madan, M. Pistorius, and W. Schoutens, "Dynamic conic hedging for competitiveness," *Mathematics and Financial Economics*, vol. 10, no. 4, pp. 1–35, 2015.

[25] F. Guillaume and W. Schoutens, *Bid-Ask Spread for Exotic Options under Conic Finance Innovations in Quantitative Risk Management*, pp. 59–74, Springer, Berlin, 2015.

[26] D. B. Madan, M. Pistorius, and W. Schoutens, *Conic Trading in Markovian Steady State*, SSRN, Amsterdam, Netherlands, 2016.

[27] D. B. Madan, "Conic portfolio theory," *International Journal of Theoretical and Applied Finance*, vol. 19, no. 03, Article ID 1650019, 2016.

[28] D. B. Madan, "Marking to two-price markets," *Journal of Asset Management*, vol. 17, no. 2, pp. 100–118, 2016b.

[29] A. Hellmers, M. Zugno, A. Skajaa, and J. M. Morales, "Operational strategies for a portfolio of wind farms and CHP plants in a two-price balancing market," *IEEE Transactions on Power Systems*, vol. 31, no. 3, pp. 2182–2191, 2016.

[30] Z. Li, W. Zhang, Y. Zhang, and Z. Yi, "An analytical approximation approach for pricing European options in a two-price economy," *The North American Journal of Economics and Finance*, vol. 50, Article ID 100986, 2019.

[31] Z. Li and X. T. Wang, "Valuation of bid and ask prices for European options under mixed fractional Brownian motion," *AIMS Mathematics*, vol. 6, no. 7, pp. 7199–7214, 2021.

[32] S. Van Bakel, S. Borovkova, and M. Michielon, "Conic cva and dva for option portfolios," *International Journal of Theoretical and Applied Finance*, vol. 23, no. 05, Article ID 2050032, 2020.

[33] M. Vazifedan and Q. J. Zhu, "No-arbitrage principle in conic finance," *Risks*, vol. 8, no. 2, p. 66, 2020.

[34] E. J. C. Dela Vega and R. J. Elliott, "Conditional coherent risk measures and regime-switching conic pricing," *Probability, Uncertainty and Quantitative Risk*, vol. 6, no. 4, 267 pages, 2021.

[35] M. Michielon, A. Khedher, and P. Spreij, "Liquidity-free implied volatilities: an approach using conic finance," *International Journal of Financial Engineering*, vol. 08, no. 04, Article ID 2150041, 2021.

[36] D. B. Madan and W. Schoutens, *Nonlinear Valuation and Non-gaussian Risks in Finance*, Cambridge University Press, Cambridge, UK, 2022.

[37] E. Mordecki, "Optimal stopping and perpetual options for Lévy processes," *Finance and Stochastics*, vol. 6, no. 4, pp. 473–493, 2002.

[38] Y.-C. Sheu and M.-Y. Tsai, *On the Optimal Stopping Problems for Matrix-Exponential Lévy Processes*, National Chiao Tung University, Hsinchu, Taiwan, 2011.

[39] K. Yamazaki, *Optimal Stopping Problems for Spectrally Negative Lévy Processes and Applications in Finance*, Osaka University, Suita, Japan, 2012.

[40] O. Zhylyevskyy, "A fast Fourier transform technique for pricing American options under stochastic volatility," *Review of Derivatives Research*, vol. 13, no. 1, pp. 1–24, 2010.

[41] T. Gyulov and R. Valkov, "American option pricing problem transformed on finite interval," *International Journal of Computer Mathematics*, vol. 93, no. 5, pp. 821–836, 2016.

[42] T. Pellegrino and P. Sabino, "Pricing and hedging multiasset spread options using a three-dimensional Fourier cosine series expansion method," *The Journal of Energy Markets*, vol. 7, no. 2, pp. 71–92, 2014.

[43] R. Chan, *Pricing Options with Complex Fourier Series*, University of East London, London, UK, 2016.

[44] M. J. Ruijter and C. W. Oosterlee, "Two-dimensional Fourier cosine series expansion method for pricing financial options," *SIAM Journal on Scientific Computing*, vol. 34, no. 5, pp. B642–B671, 2012.

[45] H. Y. Wong and P. Guan, "An FFT-network for Lévy option pricing," *Journal of Banking & Finance*, vol. 35, no. 4, pp. 988–999, 2011.

[46] D. B. Madan and M. Yor, "Representing the CGMY and Meixner Lévy processes as time changed Brownian motions," *Journal of Computational Finance*, vol. 12, no. 1, pp. 27–47, 2008.

[47] P. Asiimwe, C. W. Mahera, and O. Menoukeu-Pamen, "On the price of risk under a regime switching CGMY process," *Asia-Pacific Financial Markets*, vol. 23, no. 4, pp. 305–335, 2016.

[48] T. Kulczycki and M. Ryznar, "Gradient estimates of harmonic functions and transition densities for Lévy processes," *Transactions of the American Mathematical Society*, vol. 368, no. 1, pp. 281–318, 2015.

[49] A. Neufeld and M. Nutz, "Nonlinear Lévy processes and their characteristics," *Transactions of the American Mathematical Society*, vol. 369, no. 1, 2016.

[50] F. Vrins, "Characteristic function of time-inhomogeneous Lévy-driven Ornstein–Uhlenbeck processes," *Statistics & Probability Letters*, vol. 116, pp. 55–61, 2016.

[51] M. Jovan and A. Ahčan, "Default prediction with the Merton-type structural model based on the NIG Lévy process," *Journal of Computational and Applied Mathematics*, vol. 311, pp. 414–422, 2017.

[52] X. Gong and X. Zhuang, "American option valuation under time changed tempered stable Lévy processes," *Physica A: Statistical Mechanics and Its Applications*, vol. 466, pp. 57–68, 2017.

[53] G. Lian, S.-P. Zhu, R. J. Elliott, and Z. Cui, "Semi-analytical valuation for discrete barrier options under time-dependent Lévy processes," *Journal of Banking & Finance*, vol. 75, pp. 167–183, 2017.

[54] X. Hu, Y. Xiu, and J. Cao, "Recombined multinomial tree based on saddle-point approximation and its application to Lévy models options pricing," *Journal of Computational and Applied Mathematics*, vol. 346, pp. 432–439, 2019.

[55] P. Carr and D. Madan, "Option valuation using the fast Fourier transform," *Journal of Computational Finance*, vol. 2, no. 4, pp. 61–73, 1999.

[56] A. L. Lewis, *A Simple Option Formula for General Jump-Diffusion and Other Exponential Lévy Processes*, Finance Press, France, 2001.

[57] D. S. Bates, "Maximum likelihood estimation of latent affine processes," *Review of Financial Studies*, vol. 19, no. 3, pp. 909–965, 2006.

[58] Y. Yamada and J. A. Primbs, "Properties of multinomial lattices with cumulants for option pricing and hedging," *Asia-Pacific Financial Markets*, vol. 11, no. 3, pp. 335–365, 2006.

[59] A. Cherny and D. B. Madan, "New measures for performance evaluation," *Review of Financial Studies*, vol. 22, no. 7, pp. 2571–2606, 2009.

[60] S. S. Wang, "A universal framework for pricing financial and insurance risks," *Astin Bulletin*, vol. 32, no. 2, pp. 213–234, 2002.

[61] W. K. Viscusi, "Prospective reference theory: toward an explanation of the paradoxes," *Journal of Risk and Uncertainty*, vol. 2, no. 3, pp. 235–263, 1989.

[62] P. Carr, H. Geman, D. B. Madan, and M. Yor, "The fine structure of asset returns: an empirical investigation," *Journal of Business*, vol. 75, no. 2, pp. 305–333, 2002.

[63] H. Geman, *Risk Management in Commodity Markets: From Shipping to Agriculturals and Energy*, vol. 445, John Wiley & Sons, New Jercy, NJ, USA, 2009.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5680745, 7 pages
https://doi.org/10.1155/2022/5680745

Research Article

Empirical Analysis on Unexpected Information Effect of Monetary Policy and Stock Price Fluctuation: Taking Military and Defense Enterprises as an Example

Yifei Lyu, Hao Zeng, Jie Wang, and Yuhua Zhang

Military Science Information Research Center, Academy of Military Science, Beijing 100142, China

Correspondence should be addressed to Hao Zeng; 201800210044@uibe.edu.cn

Received 7 July 2022; Revised 5 September 2022; Accepted 9 September 2022; Published 24 September 2022

Academic Editor: Lele Qin

The existing studies have shown that the unexpected information effect of monetary policy (IEOMP) would affect the fluctuation of stock prices. This paper tests the effect of unexpected IEOMP on stock prices in China. Taking Chinese listed military and defense enterprises, for example, the author further explored how the influence of unexpected IEOMP over stock price varies between industries. The empirical analysis reveals that, despite the industrial heterogeneity of the said influence in China, the stock price of Chinese listed military and defense enterprises is still affected by unexpected IEOMP. Our analysis enables Chinese military and defense enterprises to build a more robust market mechanism for the military and defense market, open more effective channels for the industrial chain, capital chain, and private capital, and drive the national economy with the sci-tech results of defense. In addition, policymakers are recommended to keep an eye on the price fluctuation in the stock market and important economic information from stock price fluctuation in order to effectively identify the potential risks in the future economy and to improve the predictability of the feedback mechanism of monetary policy.

1. Introduction

With the development of the stock market, there is a growing concern about the influence of monetary policy over stock prices [1–4]. Information is a major determinant of stock price [5–8]. The information effect refers to the change in the market environment of investors upon receiving important information [9]. The operation of the stock market can be viewed as the process of information processing. The information effect directly affects the price identification and the determination of balanced prices in the stock market, which in turn causes price fluctuation in that market. So, information is one of the main influencing factors that cause stock price fluctuation.

This paper defines the information effect of the release of monetary policy as the information effect of monetary policy (IEOMP), which induces sudden fluctuation of the stock price in the short term. On the microscale, the IEOMP could influence investor expectations and the judgment of corporate value, resulting in a panic in the market [10–12]. On the macroscale, the IEOMP may increase the probability of systemic financial risks arising from fluctuations in stock prices caused by information effects that may lead to changes in the price or value of derivatives. Since 2016, the central bank of China has reiterated in the China Monetary Policy Report that the release of monetary policy should effectively prevent significant fluctuation of asset prices, avoid asset bubbles, and prevent systemic financial risks in time. Hence, the influence of the IEOMP over stock price has become an important research topic.

Traditional financial theory and many previous studies have proven that unexpected IEOMP fuels stock price fluctuation [1, 4, 13, 14]. But the influence of expected IEOMP remains controversial [15]. Specifically, unexpected IEOMP may affect stock price via two channels. Firstly, unexpected IEOMP could sway the investor's judgment of corporate value and further change their expectations and investment options, thereby acting on the stock price of listed enterprises. Secondly, unexpected IEOMP changes the inner value of listed enterprises by affecting the cost of

capital use. As a result, the expansion and investment of enterprises will be changed, leading to stock price fluctuation. In this paper, the stock price fluctuation induced by unexpected IEOMP is defined as the stock price effect of unexpected IEOMP.

The military and defense industry is not only a strategic high ground of national security but also a pillar of economic development. Military and defense enterprises, as core drivers of military development in China, bear the important task of research and development in national defense and lead the development of the Chinese national defense economy. Many bidding and tendering activities are planned for 2022, the second year of the 14th Five-Year Plan for Equipment Procurement. This factor, coupled with the debottlenecking of capacity limits, would herald a lasting boom in the military and defense industry. The industry is expected to grow rapidly in the coming three years. Our analysis enables Chinese military and defense enterprises to build a more robust market mechanism for the military and defense market, open more effective channels for the industrial chain, capital chain, and private capital, and drive the national economy with the sci-tech results of defense.

However, there are several challenges facing the research into the stock price effect of unexpected IEOMP:

Firstly, the expected IEOMP has been reflected in the stock price. To identify the variables of unexpected IEOMP accurately, it is necessary to differentiate between the expected and unexpected parts of IEOMP in China.

Secondly, the IEOMP is an endogenous factor for microenterprises and is related to many factors that drive corporate management [14]. Thus, it is challenging to accurately measure the IEOMP effect.

Thirdly, the IEOMP effect is influenced by complex factors. In theory, the influencing factors include policy instruments (interbank rate or currency growth rate), laws and regulations (provisions on reserve fund and capital), the microstructure of the credit market (matching efficiency, bargaining capacity, or entry cost), and corporate heterogeneity [16]. The interference factors must be excluded during the analysis of the IEOMP effect.

Fourthly, the IEOMP affects the capital market. In return, the fluctuation of the capital market affects the IEOMP effect by changing the formulation and implementation of monetary policy. Besides, the IEOMP and capital market are both influenced by the oscillation of the real economy.

2. Variable Identification

2.1. High-Frequency Identification Strategy. To empirically measure the IEOMP, it is necessary to effectively differentiate between the expected and unexpected parts and to consider the endogeneity problem of the measurement. Referring to Nakamura and Steinsson [14], this paper introduces high-frequency identification with a short time window to separate the unexpected part from the IEOMP. In this way, the endogeneity problem is solved effectively for the corporate-level identification of unexpected IEOMP. When the unexpected IEOMP variable is taken as a regression variable, the regression error only covers the information displayed in the narrow time window. According to the high-frequency identification theory, the limited information is orthogonal to the proposed variables of unexpected IEOMP.

After dividing the IEOMP, the expected part contains the influence of the stock market on monetary policy. The unexpected part was adopted to examine the influence of unexpected IEOMP over the stock price. This effectively excludes the interference from the endogeneity problem of macroscopic factors.

Moreover, the high-frequency identification with a short time window ensures that the factors that both affect the IEOMP and stock price are orthogonal to our variables and greatly alleviate the problem that the IEOMP and capital market are simultaneously affected by the real fluctuation economy.

In summary, this paper constructs a factor model and adopts the high-frequency identification strategy to recognize the variables of unexpected IEOMP in China. Since China's central bank issued policies to relax the control of loan interest rates for financial institutions on July 20th, 2013, the time window was set as 2014–2018. The authors mainly explored the variation of the relevant variables on the issuance day of any major monetary policy (e.g., rate and reserve adjustment) by China's central bank compared with the previous day. For simplicity, this day is referred to as the issuance day in the rest of the paper.

2.2. Variable Construction. Referring to Nakamura and Steinsson [14], this paper builds a factor model to identify the variables of unexpected IEOMP. The strategy of using the factor model to identify the variables affecting monetary policy can be traced all the way back to Gürkaynak et al. [17].

The $T \times n$-order factor model can be expressed as

$$X = MP\text{Shock} * \Lambda + \varpi, \tag{1}$$

where *MP Shock* is a $T \times m$-order latent variable ($m < n$); Λ is an $m \times n$-order factor loading; and ϖ is a $T \times n$-order white noise error.

Firstly, the distances from the covariance matrix of X to the covariance matrices corresponding to the factor model (1) containing n_0 factors are solved to prove that X is generated from n_0 factors, rather than $n(n > n_0)$ factors.

Next, X is assumed as a 16×8-order matrix to estimate the latent variable *MPShock*. The 16 rows correspond to the issuance days of major monetary policies by China's central bank during 2014–2018. For simplicity, such a day is referred to as the issuance day in the rest of the paper. The 8 columns correspond to the variables related to the policy rate and cover the following three parts: the first part is the expected change of monetary policy rate in the market from the issuance day in the current month to the end of the month. In this part, this paper mainly utilizes the data related to the

five-year national bond futures in active futures contracts. For simplicity, these futures are referred to as the target futures in the rest of the paper. To model the change of market expectations from the issuance day in the current month to the end of the month, the number of days in the current month is denoted as m_0; the issuance day in the current month is denoted as d_0. In addition, $p^1_{t-\Delta t}$ and p^1_t are defined as the settlement prices of the target futures before and on the issuance day in the current month, respectively; r_{-1} and r_0 be the mean release rates of the target futures before the issuance day in the current month and from that day to the end of the month, respectively. Then, we have

$$p^1_{t-t} = \frac{d_o}{m_0} * r_{-1} + \frac{(q_0 - d_0)}{m_0} * E_{t-t} r_0, \tag{2}$$

$$p^1_t = \frac{d_0}{m_0} * r_{-1} + \frac{(q_0 - d_0)}{m_0} * E_t r_0. \tag{3}$$

From formulas (2) and (3), it can be derived that

$$E_t r_0 - E_{t-t} r_0 = \frac{(m_0 - d_0)}{m_o} * \left(p^1_t - p^1_{t-t}\right). \tag{4}$$

The second part is the expected change of policy rate before the next release of major monetary policy by the central bank on the issuance day. Similar to the parameter settings for the first part, the number of days in the month of the next release of major monetary policy is denoted as m_1, and the issuance day in that month is denoted as d_1. In addition, $p^n_{t-\Delta t}$ and p^n_t are defined as the settlement prices of the target futures before and on the issuance day in that month, respectively; r_1 is the mean base rate in that month from the issuance day to the end of the month. Then, we have

$$E_t r_1 - E_{t-t} r_1 = \frac{(m_1 - d_1)}{m_1} * \left[(p^n_t - p^n_{t-t}) * \frac{d_1}{m_1} * (E_t r_0 - E_{t-t} r_0) \right]. \tag{5}$$

The third part is about the data related to the forward rate of return of national bonds (NBROR), which reflects the market expectations of rate variation. Let $t_m = 3, 6, 12, 24, 36, 60$ be the relevant time points. Then, the relevant data include 3-month NBROR ($t_m = 3$), 6-month NBROR ($t_m = 6$), 1-year NBROR (($t_m = 12$)), 2-year NBROR (($t_m = 24$)), 3-year NBROR ($t_m = 36$), and 5-year NBROR ($t_m = 60$). Through heteroscedasticity estimation, this paper computes the BNROR change rate on the issuance day compared to the previous day and estimates the variation of relevant variables within a day after the release of major monetary policies.

By applying the above calculations, this paper can effectively identify the IEOMP and separate the unexpected part, thereby obtaining the variables of unexpected IEOMP in China. Specifically, positive IEOMP represents the unexpected constructive IEOMP, while negative IEOMP represents the unexpected expansive IEOMP.

To prove the robustness of our results, this paper modifies the price index used to form IEOMP and uses the 7-day interest rate swap in China (O/N SHIBOR) to reidentify the variables of unexpected IEOMP. The sign of the unexpected IEOMP recognized by the O/N SHIBOR data was kept consistent with those of the unexpected IEOMP generated from the data on the target futures: positive IEOMP still represents the unexpected constructive IEOMP, while negative IEOMP still represents the unexpected expansive IEOMP.

If any data about the target futures, O/N SHIBOR, base rate, or NBROR are missing on the issuance day or the release day of the China Monetary Policy Report, the missing data were replaced with the data on the next day ($day = 1$). If any data are missing on the day preceding the issuance day ($day = -1$), the missing data were filled with the data on the day before that day (($day = -2$)). All the above data come from Wind Database.

3. Empirical Analysis

3.1. Modeling. To verify the stock price effect of unexpected IEOMP in microenterprises, this paper treats the daily change of the stock price of listed enterprises, i.e., the stock yield, as the explained variable. The explained variable was designed for the following reasons.

Firstly, the stock yield can measure the stock price effect of unexpected IEOMP more frequently than the other corporate-level outcome variables. The variable is constructed based on high-frequency data (daily frequency) and the issuance day. The stock yield and IEOMP variation are of the same frequency, and both are discrete variables.

Table 1 lists the variables involved in our empirical analysis.

Secondly, the stock price is forward-looking and brings two additional benefits to our empirical analysis: (1) under the assumptions of rational expectations and rapid market clearance, all predicted information is included in the stock price. Thus, the stock price variation only reveals the impact of new information and manages to effectively measure the influence of unexpected IEOMP on enterprises. (2) The stock yield "absorbs" the changes in the economic environment and thereby covers the short- and long-term effects of unexpected IEOMP.

According to the high-frequency identification theory, when stock yield serves as the explained variable, the unexpected IEOMP is orthogonal to the other factors affecting the stock yield on the current day. This paper predicts that unexpected IEOMP significantly affects the stock price of listed enterprises.

Based on the above settings, this paper verifies the influence of unexpected IEOMP on the corporate stock price. The benchmark model for regression is a fixed effects model based on panel data:

$$\Delta R_{i.t} = \beta_0 + \beta_1 \mathrm{MPShock}_t + \beta_2 Z_{i,t} + \alpha_i + \nu_t + \epsilon_{i,t}, \tag{6}$$

where the explained variable $\Delta R_{i.t}$ is the stock yield composed of stock price data, representing the stock price of listed enterprises on the issuance day, compared with the previous day; the explanatory variable $MPShock_t$ is the unexpected IEOMP; α_i, and ν_t are individual fixed effects and time fixed effects, respectively; $Z_{i,t}$ is control variables, all characteristic variables related to the balance sheet of enterprises [18–21]; and $\epsilon_{i,t}$ is the error term.

Table 1: Variables for empirical analysis.

Type	Code	Name	Definition
Explained variable	ΔR	Stock yield	$(R_t - R_{t-1})/R_{t-1}$
Explanatory variable	*MP* Shock	Unexpected IEOMP	High-frequency identification
Control variable	*Log assets*	Enterprise scale	Log of corporate total assets
	Cash over assets	Cash-assets ratio	Cash/total assets
	Earnings over assets	Income-assets ratio	Operating income/total assets
	Fixed assets over assets	Fixed assets ratio	Fixed assets/total assets
	Log Market-to-Book	Log of book-to-market ratio	Log of book-to-market ratio
	Debt over earnings	Debt-to-income ratio	Total liabilities/operating income
	Earnings over interest expenses	Income-expenditure ratio	Operating income/interest spending

Table 2: Descriptive statistics on control variables.

Name	Code	Observation	Mean	Standard deviation	Minimum	Maximum
Enterprise scale	Log *assets*	30,729	23.55	1.352	20.10	27.72
Cash-assets ratio	*Cash over assets*	30,729	0.008	0.089	−0.264	0.367
Income-assets ratio	*Earnings over assets*	30,729	0.040	0.052	−0.181	0.282
Fixed assets ratio	*Fixed assets over assets*	30,729	0.233	0.176	0.002	0.732
Log of book-to-market ratio	Log *Market-to-Book*	30,729	1.377	0.633	−0.222	3.349
Debt-to-income ratio	*Debt over earnings*	30,729	25.82	53.20	−52.72	313.1
Income-expenditure ratio	*Earnings over interest expenses*	30,729	-1.306	64.29	−390.2	348.5

3.2. Descriptive Statistics. Table 2provides the descriptive statistics about characteristic variables related to the balance sheet of enterprises, i.e., the control variables in our empirical analysis. The data on the corporate level all come from the Wind Database. To ensure the rationality of the results, the micro-enterprise data were cleaned by eliminating the enterprises under special treatment (ST), those in the financial and insurance industries and those with missing values. According to the descriptive statistics, there were 30,729 sample observations on the issuance dates from 2014 to 2018. The characteristic variables in Table 2 include enterprise scale, cash-assets ratio, income-assets ratio, fixed assets ratio, log of book-to-market ratio, debt-to-income ratio, and income-expenditure ratio. The descriptive statistics show that all these variables changed in reasonable ranges.

3.3. Empirical Results. Table 3 shows the regression results of formula (6), where the explained variable is stock yield (ΔR), the explanatory variable is unexpected IEOMP (*MPShock*), and the control variables are the characteristic variables of enterprises (Log *assets, Cash over assets, Earnings over assets, Fixed assets over assets,* Log *Market-to-Book, Debt over earnings, and Earnings over interest expenses*). The bracketed figures are Z-scores; *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively. To control the heteroscedasticity, the cluster-robust standard error was employed in our regression model.

Since the positive IEOMP represents the unexpected constructive IEOMP, the regression results in Table 3 suggest that, on the significance level of 5%, the negative coefficient indicates that the unexpected IEOMP significantly inhibits stock yield; that is, unexpected constructive IEOMP has an average negative effect on the corporate stock price. This means the unexpected IEOMP significantly affects the stock price of Chinese listed enterprises, evoking stock price fluctuation.

Table 3: Stock price effect of unexpected IEOMP.

Variable	ΔR
MP Shock	−4.105** (−2.535)
Log assets	5.577*** (18.75)
Cash over assets	30.58*** (6.407)
Earnings over assets	26.47*** (4.037)
Fixed assets over assets	17.93*** (9.518)
Log Market-to-Book	20.72*** (26.57)
Debt over earnings	0.0180** (2.507)
Earnings over interest expenses	0.00614 (1.253)
Constant	−4.105** (−2.535)
Time FE	Yes
Firm FE	Yes
Observations	30,729
Number of id	3,239

To sum up, it can be concluded that unexpected IEOMP has a significant effect on the stock price of Chinese listed enterprises: it could cause significant stock price fluctuation in these enterprises.

4. Discussion

4.1. Industrial Heterogeneity. Based on unexpected IEOMP, the representative stock price indices of several industries were regressed: the energy industry, medical health industry, optional consumption industry, and military and defense

Table 4: Unexpected IEOMP and stock price indices of different industries.

Variables	(1) Energy	(2) Medical health	(3) Optional consumption	(4) Military and defense
MP Shock	0.0827	−0.744	−0.279	−3.811***
	(0.626)	(−1.227)	(−0.699)	(−20.76)
Constant	2.073***	7.121***	4.066***	4.004***
	(10.79)	(6.567)	(6.521)	(8.138)
Observations	16	16	16	16
R-squared	0.053	0.143	0.070	0.880

industry. These indices were provided by China Securities Index. The estimation model is as follows:

$$\Delta R_t = \alpha_0 + \alpha_1 \times \text{MPShock}_t + \partial_t. \quad (7)$$

Table 4 summarizes the regression results of unexpected IEOMP (*MP Shock*) relative to the stock yield variables established on the selected industry indices. The results mainly reflect the different responses of these stock yield variables to unexpected IEOMP. In Table 4, the bracketed figures are t-values; *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively. To control the heteroscedasticity, the cluster-robust standard error was employed in our regression model.

The regression results show that the stock price of the military and defense industry in China is more sensitive to unexpected IEOMP than that of the other three industries. The regression coefficient of unexpected IEOMP relative to the stock yield established on the stock price index of China's military and defense industry was significantly negative at the significance level of 1%.

Overall, the unexpected IEOMP has a heterogenous effect on the stock price. The stock price indices of different industries respond differently to unexpected IEOMP. The fiercest response belongs to the stock index of China's military and defense industry.

After verifying the industrial heterogeneity of the influence of unexpected IEOMP over the Chinese stock market, the next step is to go deeper to the corporate level and explore how unexpected IEOMP affects the A-share listed Chinese military and defense enterprises.

4.2. Empirical Analysis on Listed Military and Defense Enterprises. To disclose the stock price effect of unexpected IEOMP in the military and defense industry, this paper screens the listed military and defense enterprises in China. The original samples were replaced with testing the robustness of the stock price effect of unexpected IEOMP on Chinese listed enterprises. The benchmark model for regression is formula (6).

Table 5 reports the regression results of formula 6 on listed military and defense enterprises. Note that the bracketed figures are Z-scores; *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively. To control the heteroscedasticity, the cluster-robust standard error was employed in our regression model.

Table 5: Stock price effect of unexpected IEOMP on listed military and defense enterprises.

Variables	(1) ΔR
MP Shock	−1.378***
	(−6.201)
Log assets	2.989
	(1.102)
Cash over assets	21.01
	(0.566)
Earnings over assets	−327.2*
	(−1.860)
Fixed assets over assets	−50.26
	(−1.104)
Log Market-to-Book	30.49***
	(3.417)
Debt over earnings	−0.0116
	(−0.428)
Earnings over interest expenses	0.0402*
	(1.721)
Constant	−191.1***
	(−2.920)
Time FE	Yes
Observations	352
Number of id	32

The regression results in Table 5 show that, on the significance level of 1%, the negative coefficient indicates that unexpected IEOMP significantly suppresses the stock yield of Chinese listed military and defense enterprises. In other words, unexpected IEOMP has a significant effect on the stock price of Chinese listed military and defense enterprises, causing stock price fluctuation in these enterprises. Since positive IEOMP represents the unexpected constructive IEOMP, the regression results indicate that stock price decline will occur in listed military and defense enterprises in the face of unexpected constructive IEOMP.

4.3. Robustness Test. To ensure the robustness of our conclusions, a robustness test was performed on the previous empirical analysis. By replacing the price index of monetary policy, this paper sets up a factor model following the approach of Nakamura and Steinsson [14] and employs the high-frequency identification strategy to obtain the unexpected IEOMP MPShock_swap. This variable was primarily founded on the data related to the interest rate swaps in China from 2014 to 2018. The time points were still the

Table 6: Unexpected IEOMP and stock price of listed enterprises.

Variables	ΔR
MP Shock_swap	−1.655***
	(−4.356)
Log assets	3.690
	(1.471)
Cash over assets	−9.196
	(−0.247)
Earnings over assets	−269.7
	(−1.509)
Fixed assets over assets	−55.90
	(−0.921)
Log Market-to-Book	33.45***
	(3.497)
Debt over earnings	−0.0129
	(−0.510)
Earnings over interest expenses	0.0367*
	(1.684)
Constant	−148.9**
	(−2.274)
Time FE	Yes
Observations	352
Number of id	32

release days of the China Monetary Policy Report. In addition, positive IEOMP represents the unexpected constructive IEOMP, while negative IEOMP represents the unexpected expansive IEOMP.

The explanatory variable was replaced, and the unexpected IEOMP MPShock_swap was introduced to test the robustness of the stock price effect of unexpected IEOMP on Chinese listed enterprises. The benchmark model for regression is a fixed effects model based on panel data:

$$\Delta R_{i.t} = \beta_0 + \beta_1 \text{MPShock\_swap}_t + \beta_2 Z_{i,t} + \alpha_i + \nu_t + \epsilon_{i,t}, \quad (8)$$

where the explained variable $\Delta R_{i.t}$ is the stock yield; the explanatory variable $MPShock\_swap_t$ is the unexpected IEOMP; α_i, and ν_t are individual fixed effects and time fixed effects, respectively; and$Z_{i,t}$ is control variables, all characteristic variables related to the balance sheet of enterprises.

The regression results of formula (8) are displayed in Table 6, where the bracketed figures are Z-scores;*, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively. To control the heteroscedasticity, the cluster-robust standard error was employed in our regression model.

The regression results show that, on the significance level of 1%, the negative coefficient indicates that unexpected IEOMP significantly reduces the stock yield of Chinese listed military and defense enterprises. That is, unexpected IEOMP has a significant effect on the stock price of Chinese listed military and defense enterprises, bringing stock price fluctuation to these enterprises, whereas positive IEOMP represents the unexpected constructive IEOMP, the regression results indicate that stock price decline will occur in listed military and defense enterprises in the face of unexpected constructive IEOMP.

All in all, it can be concluded that unexpected IEOMP has a significant effect on Chinese listed military and defense enterprises and induces stock price fluctuation in these enterprises. This is consistent with our empirical conclusion, indicating that the conclusion is highly robust.

5. Conclusions

The military and defense industry plays a crucial role in China's national strategy and economic development. Stock price fluctuation affects the future opportunities for investment and value growth, as well as the liquidity risks of enterprises. Given these two facts, this paper empirically analyzes and tests the stock price effect of unexpected IEOMP in the military and defense industry. Our analysis enables Chinese military and defense enterprises to build a more robust market mechanism for the military and defense market, open more effective channels for the industrial chain, capital chain, and private capital, and drive the national economy with the sci-tech results of defense. Through the analysis, the authors encouraged policymakers to keep an eye on the price fluctuation in the stock market and important economic information from stock price fluctuation in order to effectively identify the potential risks in the future economy and to improve the predictability of the feedback mechanism of monetary policy. To cope with abnormal fluctuations in the stock market, the designers of monetary policy can combine multiple monetary policy instruments according to the features of the stock market and implement targeted and interval regulations in the context of macro prudence.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] J. Sui and B. Liu, "Mixed-frequency identification of unexpected monetary policy non-neutrality: information effects of actions and language," *The Journal of World Economy*, vol. 43, no. 11, pp. 176–200, 2020.

[2] X. Wang, L. Zhu, and K. Wang, "Does China's monetary policy concern asset prices: based on the markov regime-switching BEKK multivariate GARCH model," *Journal of Financial Research*, vol. 449, no. 11, pp. 1–17, 2017.

[3] Y. Yuan and W. Hu, "Can contractionary monetary policy curb stock market bubbles?" *Economic Research Journal*, vol. 52, no. 10, pp. 82–97, 2017.

[4] X. Zhu and L. Zhou, "Monetary policy surprises and stock returns: evidence from media forecasts," *Journal of Financial Research*, vol. 1, pp. 102–120, 2018.

[5] R. Gong, "Information asymmetry, overconfidence, and stock price changes," *Journal of Financial Research*, vol. 492, no. 6, pp. 152–169, 2021.

[6] B. Guo and R. Zhou, "Information interaction, investment decisions, and stock prices: analysis based on institutional

investor information networks," *Journal of Financial Research*, vol. 472, no. 10, pp. 188–206, 2019.

[7] F. Jiang, Y. Hu, and N. Huang, "Textual information of central bank monetary policy report, macroeconomy and stock market performance," *Journal of Financial Research*, vol. 492, no. 6, pp. 95–113, 2021.

[8] W. Zou, X. Wang, and X. Xie, "Financial market response to central bank communication: event study on stock market," *Journal of Financial Research*, vol. 476, no. 2, pp. 34–50, 2020.

[9] K. G. Lunsford, "Policy language and information effects in the early days of federal reserve forward guidance," *The American Economic Review*, vol. 110, no. 9, pp. 2899–2934, 2020.

[10] H. Ai and D. Kiku, "Volatility risks and growth options," *Management Science*, vol. 62, no. 3, pp. 741–763, 2016.

[11] C. Cao, T. Simin, and J. Zhao, "Can growth options explain the trend in idiosyncratic risk?" *Review of Financial Studies*, vol. 21, no. 6, pp. 2599–2633, 2008.

[12] G. J. Jiang, D. Xu, and T. Yao, "The information content of idiosyncratic volatility," *Journal of Financial and Quantitative Analysis*, vol. 44, no. 1, pp. 1–28, 2009.

[13] M. Jarociński and P. Karadi, "Deconstructing monetary policy surprises—the role of information shocks," *American Economic Journal: Macroeconomics*, vol. 12, no. 2, pp. 1–43, 2020.

[14] E. Nakamura and J. Steinsson, "High-frequency identification of monetary non-neutrality: the information effect," *Quarterly Journal of Economics*, vol. 133, no. 3, pp. 1283–1330, 2018.

[15] C. Carvalho, F. Nechio, and F. Yao, "Monetary policy and real exchange rate dynamics in sticky-price models," 2019.

[16] G. Rocheteau, R. Wright, and C. Zhang, "Corporate finance and monetary policy," *The American Economic Review*, vol. 108, no. 4-5, pp. 1147–1186, 2018.

[17] R. S. Gürkaynak, B. P. Sack, and E. T. Swanson, *Do Actions Speak Louder than Words? the Response of Asset Prices to Monetary Policy Actions and Statements*, The Response of Asset Prices to Monetary Policy Actions and Statements, 2004.

[18] F. Ippolito, A. K. Ozdagli, and A. Perez-Orive, "The transmission of monetary policy through bank lending: the floating rate channel," *Journal of Monetary Economics*, vol. 95, pp. 49–71, 2018.

[19] P. Jeenas, *Monetary Policy Shocks, Financial Structure, and Firm Activity: A Panel Approach," Financial Structure, and Firm Activity*, A Panel Approach, 2018.

[20] P. Ottonello and T. Winberry, "Financial heterogeneity and the investment channel of monetary policy," *Econometrica*, vol. 88, no. 6, pp. 2473–2502, 2020.

[21] A. K. Ozdagli, "Financial frictions and the stock price reaction to monetary policy," *Review of Financial Studies*, vol. 31, no. 10, pp. 3895–3936, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8197239, 14 pages
https://doi.org/10.1155/2022/8197239

Research Article

Government Financial Support and Enterprises' Economic Revitalization and Pollution Discharge Under Normalization of the Epidemic: An Evolutionary Game Analysis Framework

Sen Zhang, Ting Chen, Yilin Liu, Baodong Cheng, and Guangyuan Qin

School of Economics and Management, Beijing Forestry University, Beijing 100083, China

Correspondence should be addressed to Guangyuan Qin; qinguangyuan1107@126.com

Received 8 April 2022; Revised 9 May 2022; Accepted 20 August 2022; Published 20 September 2022

Academic Editor: Lele Qin

The world economy, since the outbreak of the coronavirus epidemic, has undergone profound changes. Especially since the coronavirus became the norm, how to achieve rapid economic revitalization has become a problem that countries have to face. In order to analyze how the government should promote the enterprises' economic revitalization and effectively control pollution under the normalized epidemic situation, this paper analyzes the economic revitalization and pollution control problems faced by enterprises under the normalized epidemic situation by using the evolutionary game method. Through the analysis of the evolutionary game model, we draw the following conclusions: (1) Discovered by comparing two different incentives mechanism and penalties mechanism, the dynamic incentives mechanism, and penalties mechanism has a better effect on the process of enterprises' economic revitalization, and it also can reduce the discharge of enterprises' pollutants. (2) In terms of discharge reduction effect, penalties have a better effect than incentives. Compared with incentives, in the process of the economic revitalization of enterprises, in order to reduce pollution discharge, the government can adopt dynamic penalties strategies. This paper analyzes what the government should do when enterprises face the problems of economic revitalization and pollution control. This study can not only provide suggestions for the government in the process of governance but also provide countermeasures for the economic revitalization of enterprises.

1. Introduction

In recent years the world has experienced unimagined and accelerated changes, from a population death due principally to the coronavirus epidemic, with consequent strains on education, health care, and jobs, to an economic recession, since the outbreak of the coronavirus epidemic in 2019, an event that generated enormous effect and attracted the greatest attention of all the world. According to the epidemic data of Johns Hopkins University, so far, about 200 million people have been infected with coronavirus in the world, and the cumulative death is about 5 million [1]. The International Monetary Fund says, almost all countries in the world experienced negative economic growth in 2020. The economic growth of major developed countries such as the United States, the United Kingdom, Canada, Germany, and Japan was −3.4%, −9.8%, −5.3%, −4.6%, and −4.6%, respectively. Similarly, the economic growth of some developing countries such as India, Mexico, Nigeria, and China was −7.3%, −8.3%, −1.8%, and 2.3%, respectively. Extraordinarily, China was the only country in the world with positive economic growth. This was principally due to the Chinese government's orderly reviving of production and work under the premise of strict control of the epidemic [2]. Undeniably, this was not only China's institutional advantage [3, 4] but also a concrete manifestation of the Chinese government's agility and adaptability [5]. When the World Health Organization declared coronavirus pneumonia a public health event of international concern [6], the Chinese government began to implement strict prevention and control of the epidemic.

The raging epidemic has changed enterprises' production and operation behaviors and even changed the existing business model [7–9]. The traditional competitors have become partners, forming a win-win situation through cooperation [10]. As an important carrier of the economy of various countries, enterprises undertake the important functions of stimulating economic growth, increasing employment, and maintaining social stability. Therefore, the outbreak of the coronavirus epidemic appears to have an impact on the economy, but its essence is an impact on enterprises, as far as the enterprises' market is concerned. Due to the implementation of the blockade policy, more and more consumers were kept behind closed doors, which in turn made the enterprises' products unable to sell, and undoubtedly accelerated the enterprises' bankruptcy [11]. In fact, from February to May 2020, 19% of registered enterprises and 25% of self-employed enterprises in China have permanently closed down [12]. When offline operations were affected by the epidemic, enterprises would use new information or digital technologies, such as mobile applications, to carry out online operations [13, 14]. However, this required technical institutions to provide sufficient technical support to enterprises [15]. At the same time, the traditional enterprises' governance model and management system were no longer suitable for the market environment under the normalized epidemic situation. Adjusting the enterprises' governance model to adapt to the consumer's consumption habits has become an urgent issue facing enterprises development [16]. As far as the enterprises' supply chain was concerned, the strict blockade and the outage of logistics caused many enterprises' supply chains to break, and the enterprises were unable to carry out normal production and operation activities [17, 18]. As far as the capital turnover of the enterprise was concerned, in the face of the epidemic, the biggest concerns of enterprises were financial impact and uncertainty [19], and financial interruption might bring devastating blows to enterprises [20]. The impact of the epidemic has made some enterprises unable to obtain enough funds to carry out normal production and operation activities, which to a certain extent showed that the implementation of financial emergency strategies was of great significance to the production and survival of enterprises [21, 22]. As far as the knowledge level and the abilities of the labor force were concerned, strong personal abilities and good enterprise ecology were important reasons why many enterprises were still growing under the influence of the epidemic [23]. In addition, the impact of the epidemic on enterprises was also different. Because of their different years of establishment, enterprises with a shorter establishment period and a small number of employees would not be severely affected by the epidemic [24].

Policy makers need to maintain the normal operation of the economy while implementing epidemic prevention and control policies [25]. When enterprises faced the above-mentioned problems that cannot be solved by themselves, government financial support was an effective way to help enterprises deal with such problems [26]. The government's financial support for enterprises would give consumers better expectations of the future economy [27], which might help boost confidence in the market economy and restore the enterprises' product sales capabilities. Similarly, when the government implemented restrictions on enterprises, it would produce negative returns, which led to the result of lowering consumers' expectations of the future economy. At the same time, the government ought to increase the promotion of digital technology in the production and operation of enterprises [28]. The government assisted enterprises in establishing emergency management measures for public health incidents and formulating future development strategies, which might help to enhance the resilience of the supply chain and accelerate the process of economic revitalization [29]. Meanwhile, the financial support of the government and supply chain partners was also extremely important for the stability of the supply chain [30]. The countries used various financial, fiscal, or administrative means to support enterprises in order to help them tide over the difficulties. This kind of assistance, to a certain extent, has avoided the phenomenon of a sharp decline in enterprise production [31]. Honestly, it was undeniable that different types of enterprises might be affected differently [32, 33]. For example, the impact of the epidemic on state-owned enterprises was smaller than that on private enterprises [34]. In addition, in the short term, the governments' strict epidemic prevention and control policy might significantly reduce the spread of the epidemic [35]. But in the long run, its economic support could not make up for the cost of long-term suppression [36]. Of course, the actual situation of each country was not the same. The government should not copy the prevention, control, and revitalization experience of other countries in the process of formulating policies but should determine the policy that suits its own country according to its own national conditions [37].

In summary, the current research papers have made great contributions to the analysis of normalized epidemics. But there are still some shortcomings. (1) The current research on the impact of the normalized epidemic on the economy is mainly focused on the level of text analysis. They mainly use structural equation models. Only a small amount of literature uses empirical analysis and evolutionary game methods to analyze the impact of the epidemic on the economy. (2) The current research papers only consider accelerating the pace of economic revitalization of enterprises and did not consider the pollutant discharge enterprises during the revitalization process. (3) The impact of static and dynamic incentives mechanisms and penalties mechanisms on enterprises' economic revitalization is not considered. In view of this, this article uses an evolutionary game model to analyze how government financial support affects the strategic choices and future development of enterprises under the normalized epidemic situation. It also considers the issue of pollutant discharge during the revitalization process of enterprises. At the same time, how enterprises make strategic choices under different incentives mechanisms and penalties mechanisms are analyzed.

The structure of this article is as follows: (1) The internal mechanism of the interaction between different game

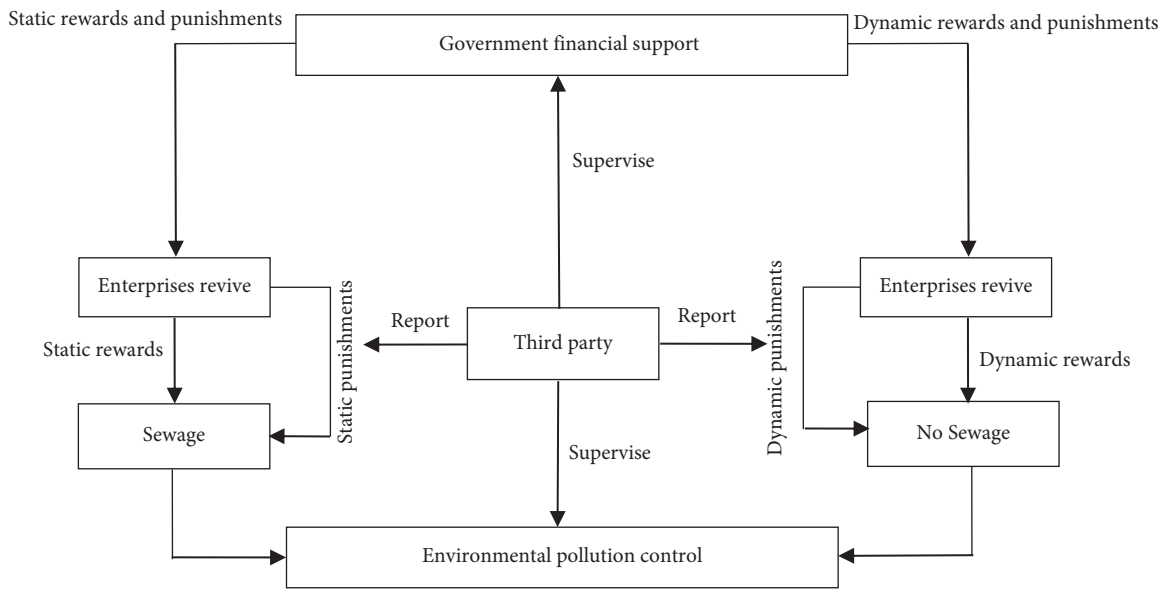


Figure 1: The economic revitalization mechanism of government supported enterprises.

players and the research method of this article are explained. (2) This article establishes an evolutionary game model based on assumptions, and how the enterprise makes strategic choices under the static and dynamic incentives mechanism and penalties mechanism are analyzed. (3) The results are discussed, and the core conclusions of this article are drawn. (4) And at the same time, the limitations of this research are clarified.

2. Material and Method

2.1. Mechanism Analysis. Under the normalization of the epidemic, enterprises not only need to consider their economic revitalization but should also consider making their pollutant discharge meet the standards in the process of economic revitalization. These are two issues that cannot be ignored. In the context of ecological civilization construction, clear waters and green mountains are as good as mountains of gold and silver. Ignoring the pollutant discharge in the process of economic revitalization is tantamount to drinking poison to quench thirst. In addition, the government's use of different types of incentives mechanism and penalties mechanisms in the process of supporting the economic revitalization of enterprises will also have an impact on enterprises' pollution discharge. The following figure shows the internal logic of this mechanism (see Figure 1).

As shown in Figure 1, the government's financial support can indeed make the enterprises realize economic revitalization. But in the process of enterprises' economic revitalization, the issue of pollutant discharge needs to be considered. Under the static incentives mechanism and penalties mechanism, it is difficult for the government to control the discharge of pollutants by enterprises, that is, under the static incentives mechanism and penalties mechanism, enterprises are more tend to discharge pollution. See Figure 1 for details. On the contrary, under the dynamic incentives mechanism and penalties mechanism, enterprises are more tend to choose not to discharge pollution. In addition, third-party supervision and reporting will also play a role in the game. See Figure 1 for details.

2.2. Evolutionary Game Model. Interdisciplinary and multisubject cooperation is one of the effective ways to deal with the epidemic [38]. It is also one of the main issues that we need to fully consider. In the process of economic revitalization, we also need to better understand the relationship between the government, the enterprise market, and various other institutions [39]. An evolutionary game model is an important tool for studying multiagent cooperation, and it is applied in various disciplines [40, 41]. Increasing the government's cost of public social projects will reduce the losses caused by the epidemic [42]. In addition, when faced with the threat of an epidemic, the strengthening of cooperation between various entities will significantly increase their survival rate [43]. For the above reasons, this paper uses the evolutionary game model to analyze whether the government provides financial support for the enterprises in the process of economic revitalization and whether the enterprises discharge pollution. It also introduces a dynamic incentives mechanism and penalties mechanism to analyze the enterprises' strategies.

3. Research Hypothesis

Hypothesis 1. .To simplify the analysis, this study assumes that there are two players in the game of economic revitalization of enterprises, namely the enterprise and the government. We denote the two players by E and G, respectively. According to the evolutionary game theory, the enterprises and governments are subjects with bounded rationality. That is, the goals of both sides are to maximize their own interests, and the strategic choices of both sides are

Table 1: Variable description.

Variable	Description
π_{E1}	Benefits from enterprises discharging pollutants
π_{E2}	Benefits from enterprises not discharging pollutants
ω_1	Financial support from the financial sector when enterprises discharge pollutants
ω_2	Financial support from the financial sector when enterprises do not discharge pollutants
c_{E1}	The cost paid by the enterprise when it discharges pollutants
c_{E2}	The cost that the enterprise pays when it does not discharges pollutants
f	Government fines for pollutants discharged by enterprises
B	Government incentives for enterprise that do not discharge pollutants
ω	Government financial support to enterprises
c_G	The cost paid by the government in the game
s	Losses caused by pollutants discharged by enterprises
π_{G1}	Government revenue when enterprises discharge pollutants
π_{G2}	Government revenue when the enterprises do not discharge pollutants
π_E	Basic revenue of the enterprise
π_G	Basic revenue of the government

constantly adjusted according to the behavior of the other party.

Hypothesis 2. .Further, we assume that in the game process, the strategic space that the enterprises can choose is (no discharge, discharge), and the probability that the enterprise chooses not to discharge is y, and the probability that the enterprise chooses to discharge is 1-y. Similarly, the strategy space that the government can choose is (support, not support), and the probability that the government chooses to support is x, and the probability that the government chooses not to support is 1-x.

Hypothesis 3. .When the enterprise (E) chooses to discharge pollution in the process of economic revitalization, it will get a certain benefit, which is assumed to be π_{E1}. Similarly, when an enterprise (E) chooses not to discharge pollution during the economic revitalization process, it will also get a certain benefit, assuming it is A π_{E2}. At the same time, regardless of whether the enterprise discharges pollution in the process of economic revitalization, it will pay a certain cost. When an enterprise discharges pollutants, its cost is c_{E1}. When the enterprise does not emit pollutants, its cost is c_{E2}. In the process of the economic revitalization of the enterprise, it will receive financial support from the financial sector. When the enterprise discharges pollutants, the support received is ω_1, and when the enterprise does not emit pollutants, the support received is ω_2. In addition, the enterprise will also receive financial support from the government (regardless of whether it discharges pollution or not), assuming it is ω. If an enterprise discharges pollutants in the process of economic revitalization, it will be punished, assuming it is f. And if the enterprise does not discharge pollutants, it will be incentivized, assuming it is B. The enterprise will cause losses if it discharges pollutants, assuming it is s. Similarly, the government will obtain certain benefits in the game process. When an enterprise discharges pollutants, the government's revenue is π_{G1}. When the enterprise does not emit pollutants, the government's revenue is π_{G2}, and the government's cost during the game is c_G. Table 1 is a brief description of the above variables.

We can obtain the game payoff matrix according to the above three assumptions. The payoff matrix of the enterprises and the governments is listed in Table 2 (see Table 2).

4. Evolutionary Game Analysis

4.1. Model Establishment and Solution. According to the payoff matrix in Table 2, we can build an evolutionary game model. First, we need to get the expected benefits for the enterprises. We assume that the expected benefits of the enterprises choosing not to discharge pollution is u_{E1}, and the expected benefits of the enterprises choosing to discharge pollution can be represented by u_{E2}. For details, please refer to the following formulas:

$$u_{E1} = x\left[\pi_E + \pi_{E2} + B - c_{E2} + \omega_2 + \omega\right] + (1-x)\left[\pi_E + \pi_{E2} + \omega_2 - c_{E2}\right], \tag{1}$$

$$u_{E2} = x\left(\pi_E + \pi_{E1} + \omega_1 + \omega - c_{E1} - f\right) + (1-x)\left(\pi_E + \pi_{E1} + \omega_1 - c_{E1}\right). \tag{2}$$

In addition, according to formulas (1) and (2), the average expected benefits of the enterprises can be obtained. We use $\bar{u_E} = yu_{E1} + (1-y)u_{E2}$ to denote the enterprises average expected benefits. For details, please refer to the following formula:

Table 2: Game payoff matrix of economic revitalization enterprises (E) and government (G).

		Economic revitalization enterprise(E)	
		Not discharge y	Discharge 1-y
Government (G)	Support x	$(\pi_G + \pi_{G2} - B - c_G - \omega, \pi_E + \pi_{E2} + B - c_{E2} + \omega_2 + \omega)$	$(\pi_G + \pi_{G1} + f - c_G - s - \omega, \pi_E + \pi_{E1} + \omega_1 + \omega - c_{E1} - f)$
	Not suppor 1-x	$(\pi_{G2} + \pi_G, \pi_E + \pi_{E2} + \omega_2 - c_{E2})$	$(\pi_{G1} + \pi_G - s, \pi_E + \pi_{E1} + \omega_1 - c_{E1})$

$$u_{E1} = y\left[x\left[\pi_E + \pi_{E2} + B - c_{E2} + \omega_2 + \omega\right] + (1-x)\left[\pi_E + \pi_{E2} + \omega_2 - c_{E2}\right]\right] + (1-y)\left[x\left(\pi_E + \pi_{E1} + \omega_1 + \omega - c_{E1} - f\right) + (1-x)\left(\pi_E + \pi_{E1} + \omega_1 - c_{E1}\right)\right]. \tag{3}$$

Second, we need to get the expected benefits of the governments. We assume that the expected benefits of the governments choosing to support is u_{G1}, and the expected benefits of the governments choosing not to support can be represented by u_{G2}. For details, please refer to the following formulas:

$$u_{G1} = y\left[\pi_G + \pi_{G2} - B - c_G - \omega\right] + (1-y)\left[\pi_G + \pi_{G1} + f - c_G - s - \omega\right], \tag{4}$$

$$u_{G2} = y\left(\pi_{G2} + \pi_G\right) + (1-y)\left(\pi_{G1} + \pi_G - s\right). \tag{5}$$

In addition, according to formulas (4) and (5), the average expected benefits of the governments can be obtained. We use $\bar{u_G} = xu_{G1} + (1-x)u_{G2}$ to denote the government's average expected benefits. For details, please refer to the following formula:

$$u_{G1} = x\left[y\left[\pi_G + \pi_{G2} - B - c_{G2} - \omega\right] + (1-y)\left[\pi_G + \pi_{G1} + f - c_G - s - \omega\right]\right] + (1-x)\left[y\left(\pi_{G2} + \pi_G\right) + (1-y)\left(\pi_{G1} + \pi_G - s\right)\right]. \tag{6}$$

Third, we need to get the replication dynamic equations. The computation of replication dynamic equations requires the use of two key things. One is the principle of the Malthusian dynamic equation; the other is the above formula of the average expected benefits of the enterprises and the governments. For details, please refer to the following formulas:

$$Fy = \frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y)\left[x(f+B) + \left(\pi_{E2} - c_{E2} + \omega_2\right) - \left(\pi_{E1} - c_{E1} + \omega_1\right)\right], \tag{7}$$

$$Fx = \frac{\mathrm{d}x}{\mathrm{d}t} = x(1-x)\left[f - c_G - \omega - y(f+B)\right]. \tag{8}$$

Table 3: Parameter value at the equilibrium point.

Equilibrium point	a11	a12	a21	a22
(0, 0)	$f - c_G - \omega$	0	0	$(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})$
(0, 1)	$-c_G - \omega - B$	0	0	$-[(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})]$
(1, 0)	$-(f - c_G - \omega)$	0	0	$f + B + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})$
(1, 1)	$-(-c_G - \omega - B)$	0	0	$-[f + B + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})]$
(x^*, y^*)	0	M	N	0

Table 4: Partial equilibrium analysis.

Equilibrium point	$\det J_e$	trJ_e	Stability
(0, 0)	—	Uncertain	Saddle point
(0, 1)	—	Uncertain	Saddle point
(1, 0)	—	Uncertain	Saddle point
(1, 1)	—	Uncertain	Saddle point
(x^*, y^*)	+	—	Stable point

Finally, we need to solve the replication dynamic equation. Let the two replication dynamic equations be equal to 0, respectively, that is, $Fy = 0$ and $Fx = 0$. At this point, we can find the solutions of the equations, and these solutions are called equilibrium points. These equilibrium points can be expressed as (0,0),(0,1),(1,0),(1,1) and $((\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2})/f + B$, $f - c_G - \omega/f + B)$.

4.2. Stability Analysis. Now that we have obtained the equilibrium point for replication of the dynamic equation, next, we need to analyze the stability of the equation. When performing equation stability analysis, we need to use the Jacobian matrix, which was proposed by Friedman. For details, please refer to the following formula:

$$J_e = \begin{bmatrix} (1-2x)f - c_G - \omega x(1-x)(-f-B) \\ -y(f+B)](1-2y)[x(f+B)+ \\ y(1-y)(f+B)(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})] \end{bmatrix}. \quad (9)$$

According to formula (9), we can get the determinant $(\det J_e)$ and trace (trJ_e) of the Jacobian matrix, which is the key to judging whether the equation is stable. For details, please refer to the following formulas:

$$\begin{aligned} \det J_e = (1-2x)[f - c_G - \omega - y(f+B)] * (1-2y)[x(f+B) \\ +(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E2})] - [x(1-x)(-f-B) * y(1-y)(f+B)]. \end{aligned} \quad (10)$$

$$\begin{aligned} trJ_e = (1-2x)[f - c_G - \omega - y(f+B)] + (1-2y)[x(f+B) \\ +(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E2})]. \end{aligned} \quad (11)$$

Solving (10) and (11), the parameter values at the equilibrium point can be obtained. The specific values of the parameters are listed in Table 3.

This part mainly analyzes the strategy selection problem of enterprises under the static incentives mechanism and penalties mechanism. In this part, we assume that the government's implementation of incentives and penalties to enterprises has reached the maximum level. When $(\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) > f + B$, the government's incentives mechanism and penalties mechanism has lost their effectiveness, because in this case, the enterprise's pollution revenue is far greater than the government's penalties and incentives. While $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) > f + B$ and $f - c_G - \omega > 0$, only (x^*, y^*) is the stable point of the game system, this stable point is not the asymptotic stability point of the game system but a closed-loop curve around (x^*, y^*). The following is an analysis of the local stability of the five equilibrium points (see Table 4).

As shown in Table 4, if the benefits of the enterprises from pollutant discharge during the economic revitalization process are not much different from the incentives and penalties it receives, the enterprise will hover between whether or not to discharge pollutants. Enterprises are neither willing to risk pollution and be punished nor are they willing to choose not to discharge pollution for incentives. At the same time, the government is neither willing to provide financial support to enterprises for reputation nor is it willing to be criticized for not providing financial support to enterprises. Therefore, the game system does not automatically stabilize at the equilibrium point, and the strategies of the two sides of the game always show a closed-loop periodic movement around the equilibrium point. See Figure 2 for details

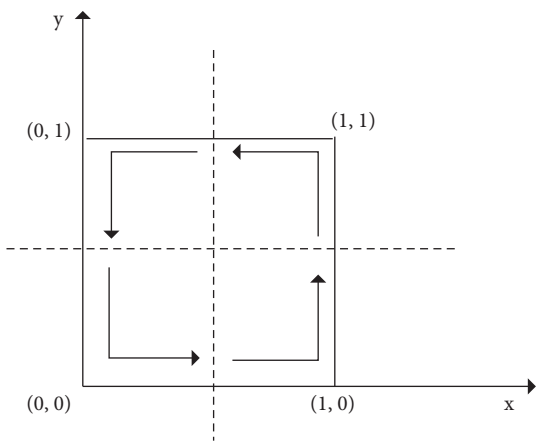


Figure 2: When $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) > f + B$ and $f - c_G - \omega > 0$ Phase diagram.

5. Further Analysis

In the above, we have analyzed the strategy selection problem of enterprises under the static incentives mechanism and penalties mechanism. In this section, the dynamic incentives mechanism and penalties mechanism are introduced. Assuming that during the economic revitalization of the enterprises, the government's incentives and penalties for pollutant discharge are dynamic in nature, that is, the government's incentives and penalties for pollutant discharges are not constant, but change in a certain proportion. When an enterprise discharges more pollutants in the process of economic revitalization, the government will penalize it more strongly. Similarly, when the enterprises discharges fewer pollutants in the process of economic revitalization, the government incentives it more. Suppose that the fixed incentives B above become a linear function $B(y) = yB$; at the same time, the fixed penalties f above become a linear function $f(y) = (1-y)f$. The remaining assumptions are consistent with the above. Replace f and of B in formula (7) and (8) with yB and $(1-y)f$, and the specific expressions are as follows:

$$\begin{cases} Fy = \dfrac{\mathrm{d}y}{\mathrm{d}t}, \\ = y(1-y)\left[x((1-y)f + yB) + (\pi_{E2} - c_{E2} + \omega_2) - (\pi_{E1} + \omega_1 - c_{E1})\right], \\ Fx = \dfrac{\mathrm{d}x}{\mathrm{d}t}, \\ = x(1-x)\left[(1-y)f - c_G - \omega - y((1-y)f + yB)\right]. \end{cases} \tag{12}$$

Similarly, we need to solve the replication dynamic equation. Let the two replication dynamic equations be equal to 0, respectively, that is, $Fy = 0$ and $Fx = 0$. These equilibrium points can be expressed as (0,0), (0,1), (1,0), (1,1) and (x', y') can be obtained.

5.1. Stability Analysis. Now that we have obtained the equilibrium point for replication the dynamic equation, next, we need to analyze the stability of the equation. When performing equation stability analysis, we need to use the Jacobian matrix, which was proposed by Friedman. For details, please refer to the following formula:

$$J_e = \begin{bmatrix} (1-2x)\left[(1-y)f - c_G - \omega x(1-x)(-2fB + 2yf - 2f) \right. \\ -y((1-y)f + B)](1-2y)[x((1-y)f + yB) + \\ \left. y(1-y)((1-y)f + yB)(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})\right] \end{bmatrix}. \tag{13}$$

According to formula (13), we can get the determinant $(\det J_e)$ and trace (trJ_e) of the Jacobian matrix, which is the key to judging whether the equation is stable. For details, please refer to the following formulas:

$$\begin{aligned} \det J_e = {} & \left[(1-2x)\left[(1-y)f - c_G - \omega - y((1-y)f + B)\right]\right] * \\ & (1-2y)\{x((1-y)f + B) + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E2})\right] \\ & - [x(1-x)(-(1-y)f - B) * (y(1-y)((1-y)f + yB))], \end{aligned} \tag{14}$$

$$\begin{aligned} trJ_e = {} & \left[(1-2x)\left[(1-y)f - c_G - \omega - y((1-y)f + yB)\right]\right] \\ & + (1-2y)[x((1-y)f + yB) + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E2})]. \end{aligned} \tag{15}$$

Table 5: Parameter value at the equilibrium point.

Equilibrium point	a11	a12	a21	a22
(0, 0)	$f - c_G - \omega$	0	0	$(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})$
(0, 1)	$-c_G - \omega - B$	0	0	$-[(\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})]$
(1, 0)	$-(f - c_G - \omega)$	0	0	$f + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})$
(1, 1)	$-(-c_G - \omega - B)$	0	0	$-[B + (\pi_{E2} + \omega_2 - c_{E2}) - (\pi_{E1} + \omega_1 - c_{E1})]$
$(x\prime, y\prime)$	0	M	N	0

Table 6: Partial equilibrium analysis.

Equilibrium point	$\det J_e$	trJ_e	Stability
(0, 0)	—	Uncertain	Saddle point
(0, 1)	—	Uncertain	Saddle point
(1, 0)	—	Uncertain	Saddle point
(1, 1)	—	Uncertain	Saddle point
$(xy\prime)$	+	—	ESS

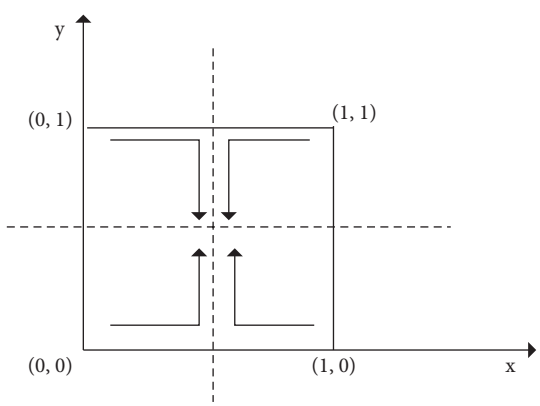


Figure 3: When $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) < (1 - y)f + yB$ and $(1 - y)f - c_G - \omega > 0$ Phase diagram.

Solving (14) and (15), the parameter values at the equilibrium point can be obtained. The specific values of the parameters are listed in Table 5.

When $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) < (1 - y)f + yB$ and $(1 - y)f - c_G - \omega > 0$, only (x', yx') is the stable point of the game system, and this stable point is the asymptotic stability point of the game system. The evolution path at this time is not a closed-loop curve around (xx', yx'), but a spiral curve that is stable at this point. The following is an analysis of the local stability of the five equilibrium points.

As shown in Table 6, the dynamic incentives mechanism and penalties mechanism is more stable than the static incentives mechanism and penalties mechanism. Under the dynamic incentives mechanism and penalties mechanism, the penalties and incentives of enterprises have a linear function relationship with their pollutant discharge, that is, the more pollutants an enterprise discharges, the greater the penalties it receives, and the less pollutants discharge, the higher the incentives it receives. Therefore, under this mechanism, the willingness of enterprises to discharge pollutants in the process of economic revitalization is very low, which is conducive to achieving economic and ecological benefits at the same time. The game phase diagram is shown in Figure 3.

Table 7: Assignment of each parameter.

Parameter	π_{E1}	c_{E1}	ω_1	π_{E2}	c_{E2}	ω_2	f	B	c_G	ω
Assignment situation	5	2	3	3	4	2	3	4	0.5	1

6. Simulation Research

6.1. Static Incentives Mechanism and Penalties Mechanism. This section simulates the above static and dynamic incentives mechanism and penalties mechanism. First, we simulate the static incentives mechanism and penalties mechanism. Before starting the simulation, each parameter needs to be assigned. Under the static incentives mechanism and penalties mechanism, it is necessary to ensure that each parameter value satisfies $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) > f + B$ and $f - c_G - \omega > 0$. See Table 7 for parameter assignment.

As shown in Table 7, Under the static incentives mechanism and penalties mechanism, the probability that the government chooses to support the strategy is x, and the probability that the enterprises chooses not to discharge pollution the strategy is y. According to the parameters in Table 7, the values of x and y can be obtained. $x = 0.714$, $y = 0.214$. When conducting simulation, we need to set the initial probability. In this paper, we use the values of x and y as the initial probability. We assume that the probability of x remains the same, and let y be 0.1 and 0.7, respectively. It is possible to obtain the evolution path of enterprises not to discharge pollution in the process of economic revitalization. For details, please refer to Figures 4 and 5. It can be seen from Figures 4 and 5 that under the static incentives mechanism and penalties mechanism, the evolution path is in a divergent state. This divergent state not only has nothing to do with the probability that enterprises choose not to discharge pollutants, but also has nothing to do with the financial support of the governments. When the probability x that the government implements financial support is equal

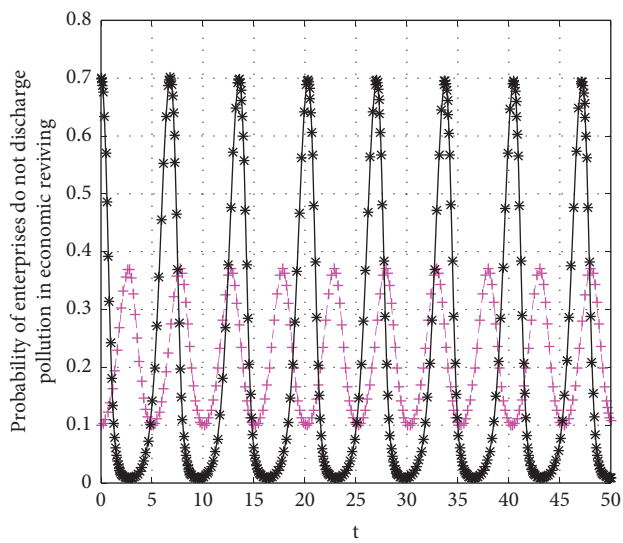


Figure 4: The evolution path of nondischarge in the process of enterprises economic revitalization under the static incentives mechanism and penalties mechanism.

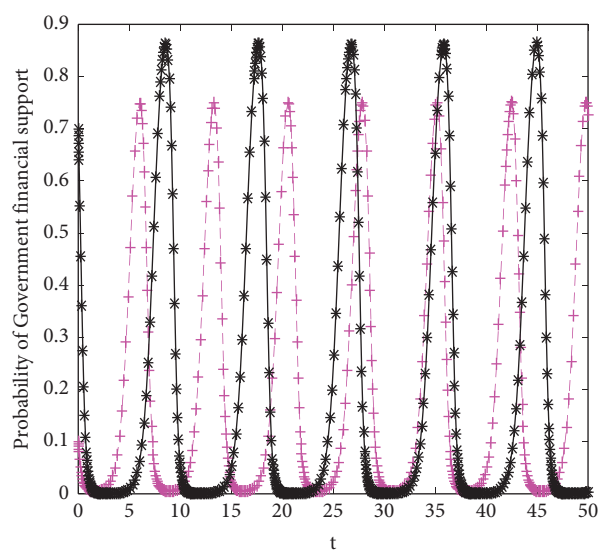


Figure 5: The evolution path of government financial support under the static incentives mechanism and penalties mechanism.

to the probability y that the enterprise chooses not to discharge pollution in the process of economic revitalization. The evolution path of the game will show a closed-loop periodic motion. For details, please refer to Figure 6. This shows that there is no gradual stability point under the static incentives mechanism and penalties mechanism.

Based on the above analysis, it can be seen that under the static incentives mechanism and penalties mechanism, the evolution paths are mostly divergent or closed-loop states. Only under the dynamic incentives mechanism and penalties mechanism does the evolution path show a convergent state. This may also reflect a more stable dynamic incentives mechanism and penalties mechanism.

Table 8: Assignment of parameters.

Parameter	π_{E1}	c_{E1}	ω_1	π_{E2}	c_{E2}	ω_2	f	B	c_G	ω
Assignment situation	5	2	3	3	4	2	7	6	0.5	1

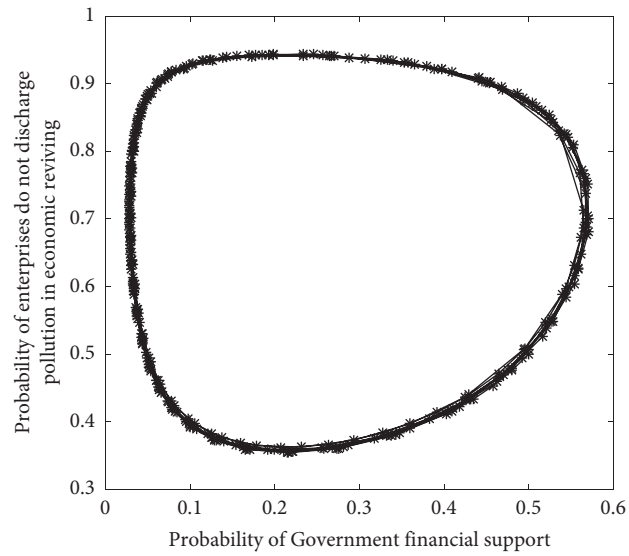


Figure 6: The evolution path when the initial probabilities of both sides of the game are the same under the static incentives mechanism and penalties mechanism.

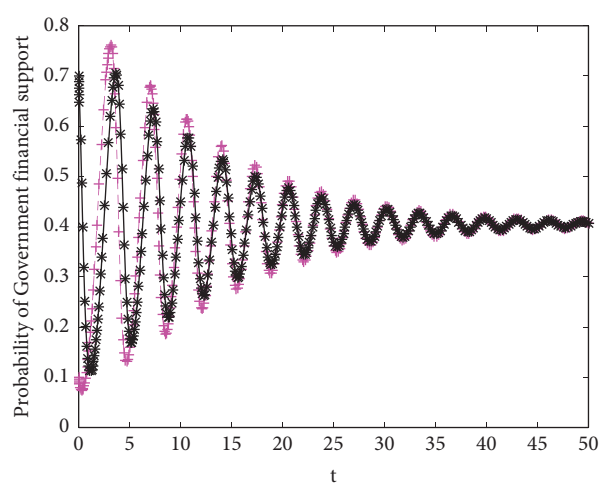


Figure 7: The evolution path of government financial support under the dynamic incentives mechanism and penalties mechanism.

6.2. Dynamic Incentives Mechanism and Penalties Mechanism. The game evolution path under the static incentives mechanism and penalties mechanism is analyzed above. Next, we analyze the evolution path of the game under the dynamic incentives mechanism and penalties mechanism. Similarly, each parameter must also ensure that the following conditions are met, namely $0 < (\pi_{E1} + \omega_1 - c_{E1}) - (\pi_{E2} + \omega_2 - c_{E2}) < (1 - y)f + yB$ and $(1 - y)f - c_G - \omega > 0$. The assignment of each parameter is detailed in Table 8.

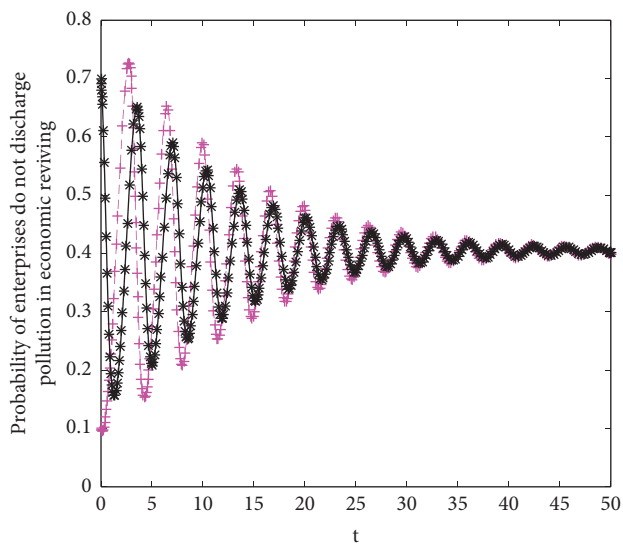


Figure 8: The evolution path of nondischarge in the process of enterprises economic revitalization under the dynamic incentives mechanism and penalties mechanism.

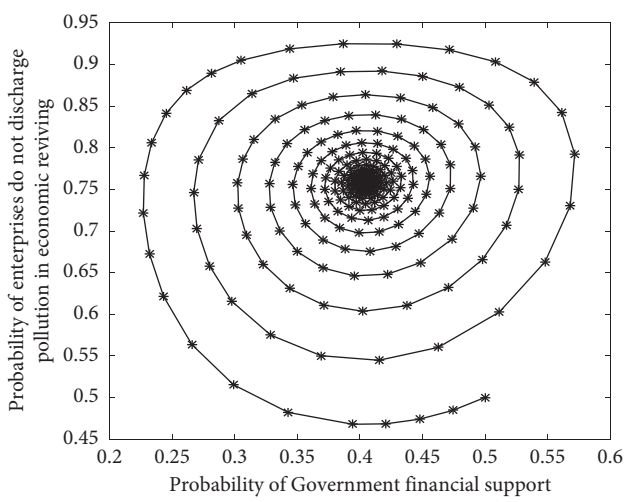


Figure 9: The evolution path when the initial probabilities of both sides of the game are the same under the dynamic incentives mechanism and penalties mechanism.

As shown in Table 8, under the dynamic incentives mechanism and penalties mechanism, the probability that the government chooses to support the strategy is x, and the probability that the enterprises chooses not to discharge pollution the strategy is y. According to the parameters in Table 8, the values of x and y can be obtained. $x = 0.617$, $y = 0.405$. When conducting simulation, we need to set the initial probability. In this paper, we use the values of x and y as the initial probability. We assume that the probability of x remains the same, and let y be 0.1 and 0.7, respectively. It is possible to obtain the evolution path of enterprises not to discharge pollution in the process of economic revitalization. The evolutionary path of the government's financial support can be obtained. For details, please refer to Figure7. It can be seen from Figures 7 and 8 that under the dynamic

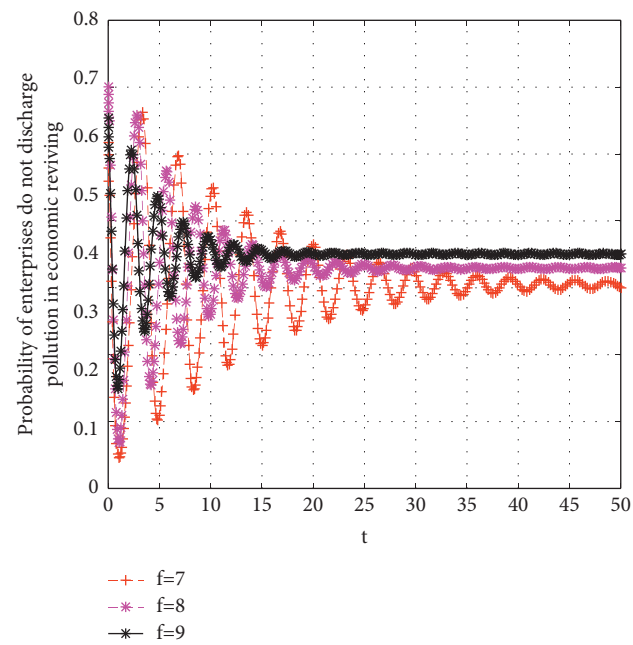


Figure 10: The evolution path of enterprises' nondischarge with increased penalties under the dynamic incentives mechanism and penalties mechanism.

incentives mechanism and penalties mechanism, the evolution path is in a state of convergence. This state of convergence not only has nothing to do with the probability that enterprises choose not to discharge pollutants, but also has nothing to do with the financial support of the governments. When the probability x that the government implements financial support is equal to the probability y that the enterprise chooses not to discharge pollution in the process of economic revitalization. The evolutionary path no longer shows a closed-loop periodic movement, but shows a spiral movement, and finally converges to an equilibrium point. The specific evolution path is shown in Figure 9.

6.3. The Impact of Different Intensities of Penalties and Incentives on Enterprises' Pollution Discharge Strategies. Under the dynamic incentives mechanism and penalties mechanism, as the government's incentives and penalties for enterprises to discharge pollutants are increased, it may have an impact on the strategic choices of whether enterprises discharge pollutants in the process of economic revitalization. This section first analyzes the government's different levels of punishment. When the government's penalties for enterprises' discharge from low to high in the process of economic revitalization, assume that they are 7, 8, and 9, respectively, while other parameters remain unchanged. Figure 10 shows the evolution path of enterprises that do not discharge in the process of economic revitalization at this time. In the same way, when the government's incentives for enterprises not to discharge in the process of economic revitalization go from low to high, they are assumed to be 6, 7, and 8, respectively, while other parameters remain unchanged. At this time, the evolution path of enterprises that

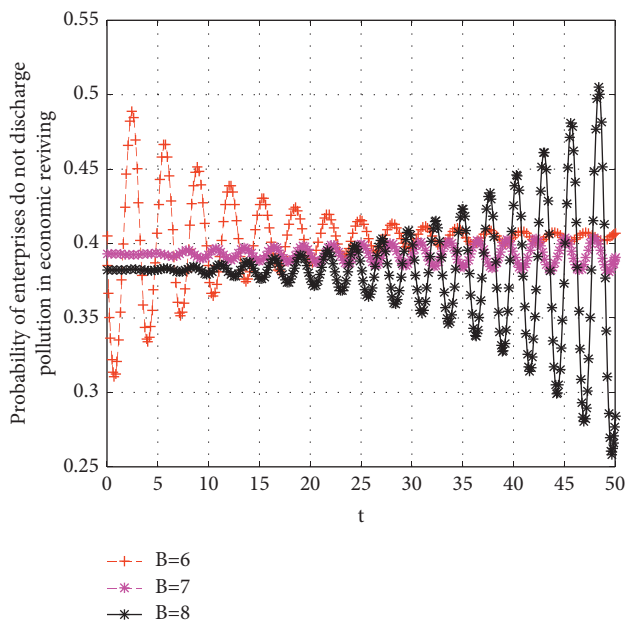


Figure 11: The evolution path of enterprises' nondischarge when increasing the incentives under the dynamic incentives mechanism and penalties mechanism.

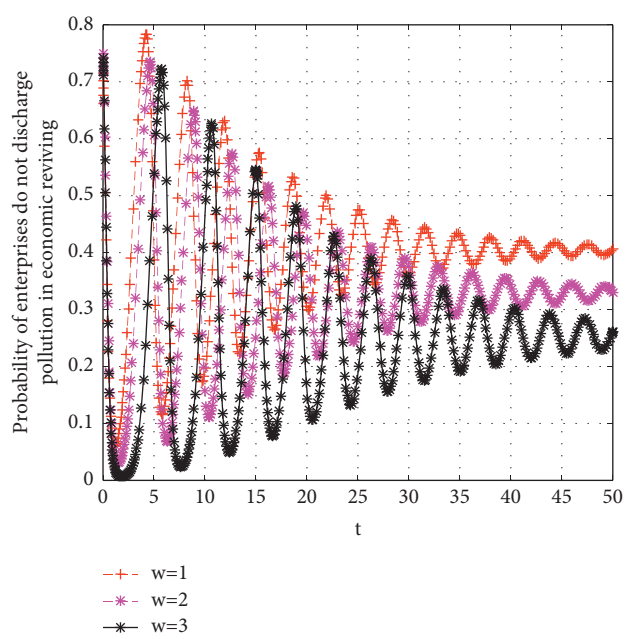


Figure 12: The evolution path of enterprises' nondischarge when government financial support increases under the dynamic incentives mechanism and penalties mechanism.

do not discharge pollution during the economic revitalization process is shown in Figure 11. It can be seen from Figures 10 and 11 that as the government imposes greater penalties on enterprises for pollutant discharge during the economic revitalization process, the probability that enterprises will not discharge pollutants will increase. As the government incentives enterprises for not discharging pollution in the process of economic revitalization, the

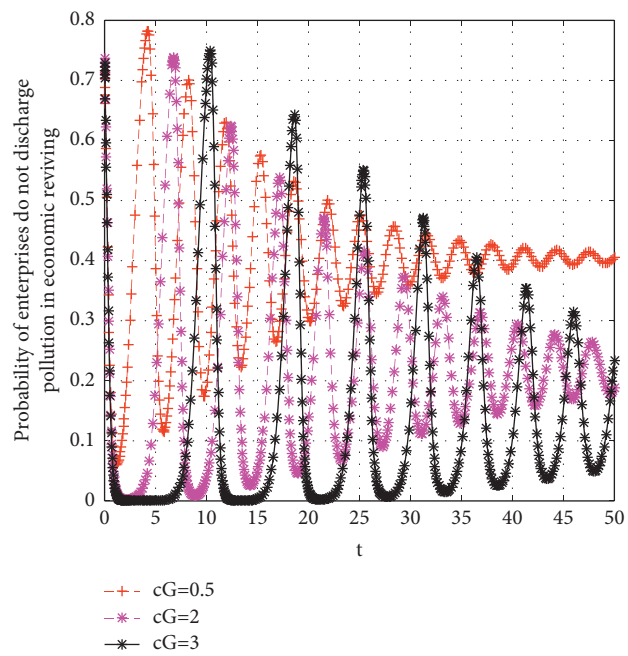


Figure 13: The evolution path of nondischarge of enterprises when government costs increase under the dynamic incentives mechanism and penalties mechanism.

probability of enterprises not discharging pollution will decrease.

6.4. The Impact of Different Levels of Financial Support on Enterprises' Pollution Discharge Strategies. According to formula (12), the probability x that the government implements financial support and the probability y that the enterprises will choose not to discharge pollution in the process of economic revitalization can be calculated. $y = 2f - 2\sqrt{(f-B)c_G + (f-B)\omega + fB}/2(f-B)$. Solve the partial derivative of government financial support ω for probability y, $\partial y/\partial\omega = -1/2$. It can be seen that the probability that an enterprise will choose not discharge pollution during the economic revitalization process y is a decreasing function of government financial support ω. That is, as the government's financial support ω increases, the probability that the enterprise will not discharge pollution during the economic revitalization process y will decrease. This shows that although government financial support will enable the revitalization of the enterprises' economy, it will increase the probability of enterprises' discharge. Similarly, as the partial derivation of the government cost c_G for the probability y, we will also get the probability that the enterprise will not discharge pollution in the process of economic revitalization y is a decreasing function of the government cost c_G. With the increase of government cost c_G, the probability y that enterprises will not discharge pollution in the process of economic revitalization will decrease. The specific situation is shown in Figures 12 and 13.

7. Discussions

According to the analysis of the above-mentioned evolutionary game and simulation research, under different types of incentives mechanisms and penalties mechanism, enterprises will perform differently in the process of economic revitalization. The dynamic incentives mechanism and penalties mechanism is more effective than the static incentives mechanism and penalties mechanism. The reason is that under the static incentives mechanism and penalties mechanism, the incentives and penalties received by enterprises are already at the highest intensity. The amount of pollutant discharge is not necessarily related to the intensity of the punishment, and there is no inevitable connection between the degree of incentives and the intensity of discharge reduction. In this case, enterprises are more likely to choose to discharge pollutants. Under the dynamic incentives mechanism and penalties mechanism, the penalties and incentives that the enterprise receives in the process of economic revitalization is a positive linear relationship with its pollutant discharge. Under the dynamic incentives mechanism and penalties mechanism without an upper limit, the enterprise is more likely to choose not to discharge pollution.

Under the dynamic incentives mechanism and penalties mechanism, the effect of penalties is better than the effect of incentives. The reason is that overly generous incentives have prevented enterprises from using funds to reduce pollutants in the process of economic revitalization, and this has led to the ineffectiveness of government incentives to enterprises. In addition, the incentives for enterprises to reduce discharge are funded by the government, which undoubtedly increases the government's financial burden, reduces the government's willingness to incentives, and increases the probability of enterprises emitting pollutants in the process of economic revitalization. Compared with incentives, it may be a better choice to impose penalties on enterprises' pollution discharge, as unlimited penalties greatly increase the cost of enterprises and may even threaten their survival. Therefore, under the consideration of many parties, enterprises will be more likely to choose a nondischarge strategy.

At the same time, with the increase in government financial support and costs, the probability of enterprises not discharging pollutants in the process of economic revitalization will decrease. This is the same as the decline in the probability of enterprises not reducing discharge when the government increases incentives because these expenditures will increase the government's burden, leading to a decline in its financial support and incentives.

Most of the existing literature uses plain text descriptions in the process of analyzing the economic revitalization of enterprises, but this paper uses an evolutionary game model to analyze the problem. In addition, this paper not only considers the economic revitalization of enterprises but also considers the problem of pollutant discharge in the process of the economic revitalization of enterprises.

8. Conclusions

This paper uses the evolutionary game model to analyze whether the government provides financial support for the enterprise in the process of economic revitalization and whether the enterprise discharges pollution and also introduces a dynamic incentives mechanism and penalties mechanism to analyze the enterprise pollution strategy. Based on the above analysis, the following conclusions can be drawn.

(1) When comparing the static incentives mechanism and penalties mechanism with the dynamic incentives mechanism and penalties mechanism, the dynamic incentives mechanism and penalties mechanism has a better effect on restraining the discharge of pollutants from enterprises. Because under the static incentives mechanism and penalties mechanism, the evolution path is a closed-loop periodic motion, while under the dynamic incentives mechanism and penalties mechanism, the evolution path is a spiral convergent motion.

(2) In the dynamic incentives mechanism and penalties mechanism, the government's penalties mechanism is more effective than the incentives mechanism. Because as the penalties increases, enterprises tend more to not discharge pollution.

(3) The choice of game strategy between the two parties is essentially determined according to their own costs and benefits. From Figures 12 and 13 in the simulation results, it can be seen that the increase in government expenditures leads to an increase in its costs, which in turn leads to a decrease in their willingness to cooperate, and ultimately increases the probability of enterprises' discharge.

However, it has to be admitted that this paper has some limitations. This paper uses the evolutionary game model to analyze the government financial support and the pollutant discharge of enterprises in the process of economic revitalization and introduces static and dynamic incentives mechanisms and penalties mechanisms for further analysis. However, whether an enterprise emits pollutants in the process of economic revitalization will also be affected by many other factors, such as the probability of successful third-party supervision, preferential tax rates implemented by the government, etc. Hence, variables such as the government's preferential tax rate and the probability of third-party supervision can also be added in future research.

Data Availability

The original contributions presented in the study are included within the article/supplementary material and can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors' Contributions

Sen Zhang is responsible for writing the main model of the paper, Ting Chen and Yilin Liu are responsible for evolution simulation analysis, Guangyuan Qin is responsible for the main guidance during the writing process of the paper, and Baodong Cheng is responsible for providing the main idea of the paper.

Acknowledgments

The authors would like to thank the National Natural Science Foundation of China for supporting this research. This research was funded by the National Natural Science Foundation Youth Project (Grant no. 71804013).

Supplementary Materials

The Supplemental files of this article are the code of the static and dynamic incentives mechanism and penalties mechanism. (*Supplementary Materials*)

References

[1] COVID-19 Map, *Johns Hopkins Coronavirus Resource Center*, 2022.

[2] H. Qun-hui, "Impact of COVID-19 epidemic on supply side and countermeasures: short-term and long-term perspectives," *Economic Review Journal*, vol. 2, no. 5, 2020.

[3] Z. Ze-long, "Observing the significant advantages of the socialist system with Chinese characteristics from the fight against COVID-19," *Theory Construction*, vol. 36, no. 1, pp. 5–10, 2020.

[4] L. Yong and D. Jing, "China's institutional advantages in the management of major epidemics," *The Party Building and Ideological Education in Schools*, vol. 15, no. 3, pp. 4–7, 2020.

[5] M. Janssen and H. Voort, "Agile and Adaptive Governance in Crisis Response: Lessons from the COVID-19 Pandemic," *International Journal of Information Management*, vol. 55, Article ID 102180, 2020.

[6] S. Wang, C. Chen Xiao, and C. Lin, "Consumer privacy protection with the growth of AI-empowered online shopping based on the evolutionary game model," *Frontiers in Public Health*, vol. 9, Article ID 705777, 2021.

[7] N. Donthu and A. Gustafsson, "Effects of COVID-19 on business and research," *Journal of Business Research*, vol. 117, pp. 284–289, 2020.

[8] S. Verma and A. Gustafsson, "Investigating the emerging COVID-19 research trends in the field of business and management: a bibliometric analysis approach," *Journal of Business Research*, vol. 118, pp. 253–261, 2020.

[9] T. Laing, "The economic impact of the Coronavirus 2019 (Covid-2019): implications for the mining industry," *The Extractive Industries and Society*, vol. 7, no. 2, pp. 580–582, 2020.

[10] S. Markovic, "Business-to-business Open Innovation: COVID-19 Lessons for Small and Medium-Sized Enterprises from Emerging Markets," *Technological Forecasting and Social Change*, vol. 170, 2021.

[11] Y. Yang, "The government-led mechansim for enterprise's resumption of work and production under major public health incidents," *Journal of Public Management*, vol. 18, no. 2, pp. 70–82+169, 2021.

[12] R. Dai, H. Feng, L. Jin, W. W. Xu, and X. Zhang, "The impact of COVID-19 on small and medium-sized enterprises (SMEs): evidence from two-wave phone surveys in China," *China Economic Review*, vol. 67, no. 3, Article ID 101607, 2021.

[13] S. Rakshit, M Islam, and T. Paul, "Mobile apps for SME business sustainability during COVID-19 and onwards," *Journal of Business Research*, vol. 135, no. 1, pp. 28–39, 2021.

[14] O. Khlystova and M. Belitski, "The impact of the COVID-19 pandemic on the creative industries: a literature review and future research agenda," *Journal of Business Research*, vol. 139, pp. 1192–1210, 2022.

[15] C. BaiBai, M. Quayson, and J. Sarkis, "COVID-19 pandemic digitization lessons for sustainable development of micro-and small- enterprises," *Sustainable Production and Consumption*, vol. 27, pp. 1989–2001, 2021.

[16] P. Carracedo and L. Marti, "Research lines on the impact of the COVID-19 pandemic on business. A text mining analysis," *Journal of Business Research*, vol. 132, pp. 586–593, 2021.

[17] S. Singh, P. Kumar, and M. K. Tiwari, "Impact of COVID-19 on logistics systems and disruptions in food supply chain," *International Journal of Production Research*, vol. 59, no. 7, pp. 1993–2008, 2020.

[18] R. S. Gray, "Agriculture, transportation, and the COVID-19 crisis," *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, vol. 68, no. 2, pp. 239–243, 2020.

[19] A. D. Alonso, "COVID-19, Aftermath, Impacts, and Hospitality Firms: An International Perspective," *International Journal of Hospitality Management*, vol. 91, Article ID 102654, 2020.

[20] A. Moretto and F. Caniato, "Can Supply Chain Finance help mitigate the financial disruption brought by Covid-19?" *Journal of Purchasing and Supply Management*, vol. 27, no. 4, Article ID 100713, 2021.

[21] B. Obrenovic and I. DuGodinicTsoyKhanJakhongirov, "Sustaining enterprise operations and productivity during the COVID-19 pandemic: enterprise effectiveness and sustainability model," *Sustainability*, vol. 12, no. 15, p. 5981, 2020.

[22] J. Ratnasingam, "How Are Small and Medium Enterprises in Malaysia's Furniture Industry Coping with COVID-19 Pandemic? Early Evidences from a Survey and Recommendations for Policymakers," *BIORESOURCES*, vol. 15, no. 3, pp. 5951–5964, 2020.

[23] D. KotsopoulosKotsopoulos and S. KaragianakiBaloutsos, "The effect of human capital, innovation capacity, and Covid-19 crisis on Knowledge-Intensive Enterprises' growth within a VC-driven innovation ecosystem," *Journal of Business Research*, vol. 139, pp. 1177–1191, 2022.

[24] S. Nordhagen, R Igbeka, H Shine, and J. Tench, "COVID-19 and small enterprises in the food supply chain: early impacts and implications for longer-term food system resilience in low- and middle-income countries," *World Development*, vol. 141, no. 2, Article ID 105405, 2021.

[25] R. Wei, X. Chen, and C. P. Chang, "Does COVID-19 pandemic hurt stock prices of solar enterprises?" *Economic Analysis and Policy*, vol. 72, pp. 41–57, 2021.

[26] C. Wang and C. Pan Wan Tan Xu McIntyre Choo Tran Ho Sharma Ho, "A longitudinal study on the mental health of general population during the COVID-19 epidemic in China," *Brain, Behavior, and Immunity*, vol. 87, pp. 40–48, 2020.

[27] B. N. Ashraf, "Economic impact of government interventions during the COVID-19 pandemic: international evidence from financial markets," *Journal of Behavioral and Experimental Finance*, vol. 27, Article ID 100371, 2020.

[28] T. Papadopoulos and M. E. Balta, "The use of digital technologies by small and medium enterprises during COVID-19: implications for theory and practice," *International Journal of Information Management*, vol. 55, no. 4, Article ID 102192, 2020.

[29] P. T. Narasimha and R. Majhi, "Impact of COVID-19 on the Indian seaport transportation and maritime supply chain," *Transport Policy*, vol. 110, no. 1, pp. 191–203, 2021.

[30] C. L. Karmaker, A. M Ahmed, and G. Kabir, "Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: exploring drivers using an integrated model," *Sustainable Production and Consumption*, vol. 26, pp. 411–427, 2021.

[31] M. Jiang and X. Li, "Financial support for small and medium-sized enterprises in China amid COVID-19," *Financial Theory and Practice*, vol. 24, no. 5, pp. 6–14, 2020.

[32] A. E. E. Sobaih, H Elshaer, and A. S. Abdelaziz, "Responses to COVID-19: the role of performance in the relationship between small hospitality enterprises' resilience and sustainable tourism development," *International Journal of Hospitality Management*, vol. 94, no. 1, Article ID 102824, 2021.

[33] J. Clark and S. W. Pruitt, "The financial impact of COVID-19: evidence from an event study of global hospitality firms," *Research in International Business and Finance*, vol. 58, Article ID 101452, 2021.

[34] H. Wu and B. Xu, "Did state-owned enterprises do better during COVID-19? Evidence from a survey of company executives in China," *Journal of Economics and Business*, vol. 115, no. 4, Article ID 105991, 2021.

[35] A. Atalan, "Is the lockdown important to prevent the COVID-19 pandemic? Effects on psychology, environment and economy-perspective," *Annals of Medicine and Surgery*, vol. 56, pp. 38–42, 2020.

[36] M. R. Keogh-Brown, E Jensen, and R. D. Smith, "The impact of Covid-19, associated behaviours and policies on the UK economy: a computable general equilibrium model," *SSM - Population Health*, vol. 12, Article ID 100651, 2020.

[37] C. G. Chidume, C. N. Oko-Otu, and G. C. Aro, "State fragility and covid-19 pandemic: implications on the political economy of Nigeria," *Social Sciences & Humanities Open*, vol. 3, no. 1, Article ID 100127, 2021.

[38] K. Goniewicz, H Khorram-Manesh, N Goniewicz, and F. M. Burkle, "Current response and management decisions of the European union to the COVID-19 outbreak: a review," *Sustainability*, vol. 12, no. 9, p. 3838, 2020.

[39] J. E. Stiglitz, "The proper role of government in the market economy the case of the post-COVID revitalization," *Journal of Government and Economics*, 2021.

[40] D. G. Zhang, C. Chen, and T. Zhang, "New method of energy efficient subcarrier allocation based on evolutionary game theory," *Mobile Networks and Applications*, vol. 26, no. 2, pp. 523–536, 2018.

[41] A. Js, B. Wz, and B. Bz, "The coordination of stakeholder interests in environmental regulation: lessons from China's environmental regulation policies from the perspective of the evolutionary game theory - ScienceDirect," *Journal of Cleaner Production*, vol. 249, 2020.

[42] K. M. A. Kabir and J. Tanimoto, "Evolutionary game theory modelling to represent the behavioural dynamics of economic shutdowns and shield immunity in the COVID-19 pandemic," *Royal Society Open Science*, vol. 7, no. 9, Article ID 201095, 2020.

[43] M. J. Gelfand, "The Relationship between Cultural Tightness-Looseness and COVID-19 Cases and Deaths: A Global Analysis," *The Lancet Planetary Health*, vol. 5, no. 3, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9812891, 1 page
https://doi.org/10.1155/2023/9812891

Retraction

Retracted: An Empirical Study of Blended Teaching Mode Based on SPOC in the Postpandemic Era

Discrete Dynamics in Nature and Society

Received 22 August 2023; Accepted 22 August 2023; Published 23 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] X. Chen, J. Guo, and H. Xu, "An Empirical Study of Blended Teaching Mode Based on SPOC in the Postpandemic Era," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7094272, 8 pages, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7094272, 8 pages
https://doi.org/10.1155/2022/7094272

Research Article

An Empirical Study of Blended Teaching Mode Based on SPOC in the Postpandemic Era

Xiaoning Chen, Jin Guo, and Hongyan Xu

Tianfu College of Southwestern University of Finance and Economics, Mianyang 621000, China

Correspondence should be addressed to Jin Guo; guojing@tfswufe.edu.cn

Received 26 May 2022; Revised 30 June 2022; Accepted 18 August 2022; Published 16 September 2022

Academic Editor: Lele Qin

The COVID-19 pandemic broke the normal of school education and sounded the horn for future education reform. This paper designs the online and offline mixed teaching mode of the SPOC platform in the postpandemic era according to the actual situation of teaching at application-oriented colleges and universities, and the blended teaching mode is applied to real teaching scenarios. The teaching effect and students' behaviors are analyzed in such scenarios. Empirical research shows that the situational teaching model based on mixed SPOC for course design, teaching resources are more abundant, and task assessments are more reasonable. Through the questionnaire survey, about 95% of the students think that the learning mode based on SPOC has improved their learning interest, autonomous learning ability, and problem-solving ability, which is much higher than the assessment of traditional courses. The exploratory practice has shown that the online and offline blended teaching mode based on SPOC can dramatically improve teaching quality.

1. Introduction

Blended teaching is a teaching method that integrates face-to-face teaching and online learning and has drawn increasing attention in recent years. Under this teaching mode, the students' ability of self-adjustment and their mastery of the learning techniques are put to the test. Meanwhile, the teachers are also faced with the challenges of how to better apply the new technologies to teaching. The education institutions are expected to offer adequate training for teachers on the teaching techniques and other skills that are needed under this blended teaching mode [1]. Since the global outbreak of COVID-19, nearly every educational institution has resorted to online teaching or online and offline blended teaching. New requirements have arisen for teaching in the postpandemic era. All three parties involved, namely, students, teachers, and teaching institutions, must work together to face up to the new challenges. Along with the updates of teaching theories and techniques, the individualized aspect of the blended teaching mode has become a subject of intense interest [2]. Literature [3] discussed the development of the teaching profession and the rapid undergoing transition towards digital teaching and learning during the COVID-19 pandemic. It was pointed out in literature [4] that higher education institutions are confronted with the demand of making a rapid transition towards online teaching. The new teaching mode is centered around students. It prioritizes instructive learning based on interactions and communications as well as student feedback. Literature [5] discussed the five challenges facing higher education during COVID-19 as it moved towards online education: synchronous/asynchronous learning tool integration, access to technology, faculty and student online competence, academic dishonesty, and privacy and confidentiality. These are also the crucial factors to be addressed and emphasized in the curriculum construction of blended teaching. Many outstanding teaching methods and styles designed specifically for the blending teaching mode have emerged worldwide. The scholars have conducted a large number of dialectical analyses regarding the opportunities and challenges facing this new mode. Apart from the above, extensive empirical studies also offer valuable clues.

So far, the global outbreak of COVID-19 has caused a significant impact on medical education, which further

brings about enormous pressure for project managers and clinical education work. It is now urgent to maintain and continue training education and evaluation. One research [6] offers an overview of the influence of the unprecedented COVID-19 lockdown on education. Some international perspectives were introduced to analyze the influence on rheumatology training. Besides, some retrospective thoughts are described concerning the challenges and opportunities associated with using social media in online education. Finally, it was concluded that the blended teaching mode might be an ideal mode for student learning in the future. Literature [7] introduced how to organize the teaching activities in premedicine and clinical radiology. In one example, the students were required to participate in offline courses regularly and attend the teaching sessions for resident physicians. Literature [8] described a self-adaptive blended teaching method, which was then applied to the neurology course. The teaching effect improvement was significant compared with the traditional face-to-face learning. Some studies [9–11] argued that the COVID-19 pandemic made medical teaching and education difficult. Nevertheless, the innovation of medical teaching by new technologies is expected to give rise to a long-lasting blended teaching mode.

Apart from medicine, some impressive teaching experience in the engineering field has already been reported. Literature [12] pointed out that the COVID-19 pandemic is a great challenge for the entire society and the industry. Under the context of Industry 4.0, engineering courses should incorporate real cases while turning towards the blended teaching mode. Abundant experience is now available for a variety of topics in this field, ranging from theme design to curriculum implementation and from examples of practice to teaching methods. The University of St. Thomas [13] designed a blended teaching mode (discovery, learning, practice, collaboration, and evaluation) for chemical engineering students during the pandemic. The implementation results proved this strategy manageable and effective. Their success also lays a foundation for blended teaching in the postpandemic era. Another research [13] suggested the ease of transferring the teaching of theories and concepts to a blended learning environment as opposed to the difficulty of practical teaching in such an environment. This research also described building a new international teaching platform beyond the conventional laboratory. The experience in platform collaboration sheds some light on building a global education community with shared concerns and interests. Some researchers [14] designed the chemical engineering courses with teams and projects as the basic units. The final report, final exam, and oral evaluation were restructured to support students' learning achievements. Some retrospective thoughts were given to the construction of an online practice community to ensure the quality of students' learning experience and academic achievements.

Many schools and research institutions have been conducting teaching reform based on their respective situations and putting blended teaching mode into practice. In the meantime, scholars worldwide have carried out empirical studies of the implementation effect of the blended teaching mode. Their finding offers useful information for reference. School of Medicine of Alfaisal University in Saudi Arabia [15] administered an online questionnaire survey to over one thousand students and teachers, which covered the following dimension: communication, student evaluation, technical tools used, and online experience. In this survey, 76% of the respondents planned to incorporate the professional knowledge they learned online into their practice. At ESIC Business and Marketing School [16], there has been a change from the face-to-face teaching environment to a virtual or semivirtual or blended learning environment. The norms of communication, education, organization, evaluation, and planning have been revolutionized. All these changes are favorable for transforming the learning process under the context of teaching innovation. A Spanish scholar [17] believed that innovative teaching methodologies begat blended learning, facilitating competence attainment among engineering students. In another [18] literature, the blended teaching mode at two universities in India during the pandemic was evaluated. Students' performance in the curriculum taught under the conventional mode and the blended mode was compared. It was found that a large number of tools, technologies, frameworks, and models were available for use in the blended teaching mode to improve the learners' competence. Another researcher [19] employed the SPSS software to survey and evaluate students at an Indian college. It was confirmed that the students had a significantly different perception of the prepandemic learning and postpandemic learning methods. This indicates that students have a higher perception of the prepandemic learning blended learning than that of the postpandemic learning web-assisted learning. Hong Kong Polytechnic University [20] carried out a survey among students on the blended teaching mode during the pandemic. It was found that the students had a better learning experience through synchronized or asynchronized online learning. Other researchers adopted different perspectives for their study. Literature [21] analyzed in the light of the lifecycle of incident theory. Literature [22] discussed the efficiency of the online neurology training curriculum under the SPOC and blended learning mode during the COVID-19 pandemic. Another study [23] assessed the psychological health of participants in blended-mode teaching during the pandemic. The results indicated the necessity for strengthening cooperation and communication between relevant parties apart from drawing onto conventional and online learning advantages. In addition to the above-given theory, a large number of recent studies [24–26] have offered guidance on the implementation of the blended teaching mode during the pandemic.

Since the COVID-19 pandemic, it has made a significant impact on normal teaching in universities at home and abroad. Whether in the medical field or in the engineering field, many colleges and universities have adopted the hybrid teaching mode to ensure the normal development of teaching tasks. During this period, many innovative teaching modes and teaching methods have appeared. A large number of studies prove that the implementation of a mixed teaching mode is conducive to the cultivation of

students' self-learning ability and the achievement of professional skills. With full reference to excellent teaching methods, Tianfu College of Southwestern University of Finance and Economics also actively carries out online and offline mixed teaching based on SPOC and has gained certain experience.

2. The Online and Offline Blended Teaching Mode Based on the SPOC Platform in the Postpandemic Era

In early 2020, COVID-19 hit the whole world unexpectedly. The Southwest University of Finance and Economics Tianfu College responded actively to the Guiding Opinions on Online Teaching Organization and Management at Ordinary Colleges and Universities during COVID-19 Pandemic Prevention and Control released by the Ministry of Education. It was required in this opinions that the "schools should not stop teaching and the students should not stop learning even the offline classes are closed. All schools should carry out online teaching activities." The authors put into practice the following aspects of online teaching: selection of the online teaching platform, utilization of the online teaching resources, design of the teaching process, and diversified evaluation of students' performance in the curriculum. Based on large-scale online teaching practice, the authors think retrospectively and prospectively on the teaching mode reform [27]. On this basis, we design a blended mixing mode based on the SPOC platform according to the teaching situation of our school in the postpandemic era.

Based on the teaching practice of our college, the design of the SPOC-based online and offline blended teaching mode in the postpandemic era is illustrated in Figure 1. The blended teaching mode is realized with the SPOC platform as the carrier. The teacher plays a leading role, and the students are at the center of all teaching and learning activities. The teacher first analyses the objects, contents, and environment of teaching. Then, the teacher designs the curriculum and prepares the teaching resources according to the conclusions of front-end analysis. The teacher dominates the implementation of the entire teaching process. Before the class, the teacher prepares high-quality online learning resources to guide self-learning and discussion among the students [28, 29]. During the class, catechetical teaching is carried out with the focus placed on challenging problems. Guidance is performed for the inquiry learning of the students. After the class, instructions are offered to assist the students in summarizing what has been learned and in the mastery of the knowledge points and skills. The students' performance in the course is evaluated based on assignments, quizzes, the number of online course visits, and classroom discussion. Therefore, the students' performance can be evaluated in a diversified manner. The blended teaching mode achieves a profound fusion of information technology and teaching. The teacher is responsible for reshaping the course contents and reconstructing teaching design and teaching procedures. Once the learning process is restructured, the teaching-learning relationship is also remodelled.

3. An Empirical Analysis of the Teaching Effect for the Course Operating Systems: Principles and Practice

The SPOC-based flipped classroom and the mobile terminals offer robust support for students doing mobile and fragmented learning via mobile terminals [30]. The teaching situation of one specific course, Operating Systems: Principles and Practice, offers a good example for empirical study. We empirically analyze the learning situation of students under the blended teaching mode and assess the teaching effect.

3.1. Design Case of a SPOC-Based Course. Front-End Analysis. This course is oriented towards students who minor in information management and usually have a poor knowledge base in computer science. However, these students are highly motivated in learning and strong in self-learning ability and self-discipline. However, the students' learning motivation may be dampened if too much theoretical knowledge is imparted through the operating system principle and practice course. In the real world, this course is intended to train the patients to apply what they learn to practice. Contents with strong practicability are prioritized to enhance ability and quality training. The teaching of theoretical knowledge is of lesser importance. As to the teaching environment, 100% of the students in the class have personal computers and use smartphones.

3.1.1. Curriculum Design. The teaching is conducted in a theme-oriented manner. One theme and one task are assigned per week. The teacher prepares microvideo, PPT, and reference materials for instructions in the knowledge points easily accessible for students. The curriculum content mainly includes Windows server configuration and Linux server configuration. The thematic decomposition is shown in Table 1. Here, the theme of Windows FTP server configuration and administration is taken as an example. The knowledge point decomposition and course design are shown in Table 2. The syllabus, courseware, and microvideo for each knowledge point in this theme are prepared and uploaded, along with the reference materials and learning tasks.

3.1.2. Teaching Organization. The students are divided into groups based on the difficulty of the tasks. The competitive mechanism is set up between the groups. That is, question answering and presentation are undertaken competitively. A reward and punishment mechanism is also set up to promote the motivation to learn in each group. Theme-related tasks are assigned before class. Members of each group first learn the assigned contents by themselves by watching the microvideo and PPT. The teacher and the teaching assistant are responsible for students' raising questions on the SPOC

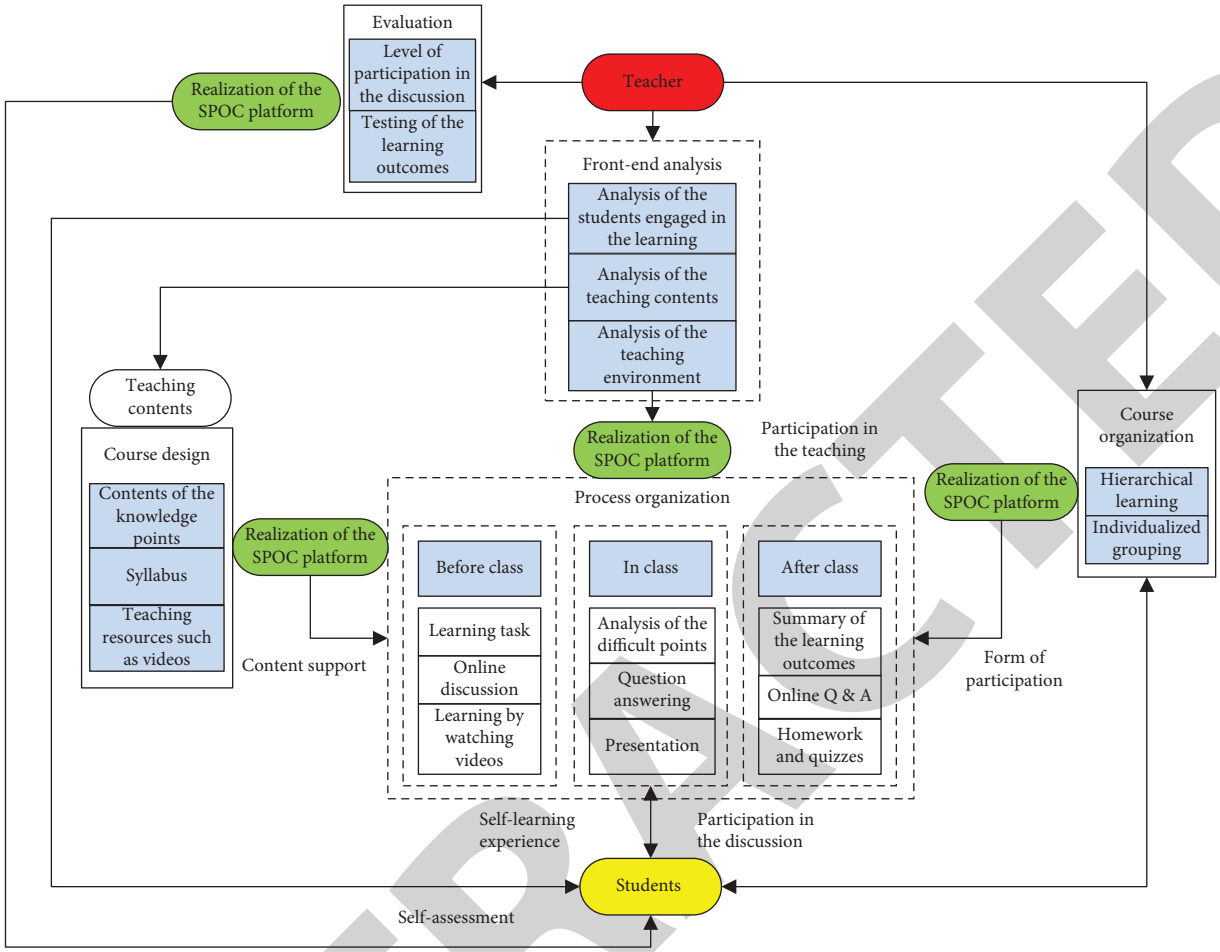


Figure 1: In the postpandemic era, the design of the blended teaching mode is based on the SPOC platform.

Table 1: Table of thematic decomposition of the Operating System Principle and Practice course.

Windows server configuration and administration		Linus server configuration and administration	
Theme 1	Discussion on virtual machine installation and the three online modes	Theme 1	Linux installation and usage
Theme 2	Windows DNS server configuration and administration	Theme 2	Linux commands and vi editor
Theme 3	Windows FTP server configuration and administration	Theme 3	Linux samba server configuration and administration
Theme 4	Windows WEB server configuration and administration	Theme 4	Linux NFS server configuration and administration
Theme 5	Windows MAIL server configuration and administration	Theme 5	Linus remote access connection server

platform and answering these questions. The group leader is responsible for managing the group's learning and task completion and realizing hierarchical teaching. The teacher is a director and the students are actors in a flipped classroom. Driven by the theme-related task, each group can choose a presentation or lecturing for in-class discussion and analysis of the difficult points. The teacher is the director responsible for teaching organization and offering summary and analysis when appropriate. After class, the students complete the experiment, and the teacher holds an online discussion on the relevant themes. The emergence of the blended teaching mode has changed the face of the conventional cramming method of teaching. In this context, the students are motivated for the learning, and the learning is also more pertinent.

3.1.3. Teaching Evaluation. The SPOC platform records the number of logs onto the curriculum, number of courseware downloads, number of views, number of participations in the discussion, assignment submission and completion, and test scores. All of these are included in the appraisal of student's participation in SPOC-based teaching. The teacher gives part of the scores for students' performance in flipped classroom teaching according to the students' participation and discussion in group assignments and offline classroom

Table 2: The knowledge point decomposition and content design of the course themes.

Theme 1	Task and guidance on learning (before class: Teaching contents)	Knowledge point decomposition (before class: Course design)	Resources (before class and in class: SPOC platform)	Discussion and expansion (In class: Process organization)	Assignment (after class: Answer questions)
Windows FTP server configuration and administration	1.For the FTP server constructed by the company, the employees of different departments are only allowed to access the FTP catalogs of their own department 2.For the FTP server constructed by the school, different users have different read and write permissions to FTP	Theme 1–1: Construction of the basic FTP site Theme 1–2: Construction of isolated user sites Theme 1–3: The issue of FTP permission Theme 1–4: Permission setting for different users	Theme 1.1: Microvideo PPT Theme 1.2: Microvideo PPT Theme 1.3: Microvideo PPT Theme 1.4: Microvideo PPT	Discussion on the issue of FTP permission setting Learning of FTP commands	Provide guidance for the experiment of constructing FTP sites

activities. Weights are assigned to each evaluation indicator. Thus, the final appraisal is conducted from different dimensions.

3.2. Student Behavior Analysis and Teaching Performance. More than 60 thousand pieces of click data generated during the SPOC-based learning process are collected from 150 students. These data are sorted, cleaned, and converted for the following purposes: to explore the blended teaching mode based on the SPOC platform; study the learning habits of students; get acquainted with the learning motivation and psychological features of the students in learning; improve the teaching mode and the management method; formulate a targeted teaching strategy. The collected data are analyzed statistically to delineate the learning behaviors and habits of the students. We focus on the distribution of the learning hours, contents of students' interest, the influence of the teaching resources on learning, and the use effect of different teaching resources.

Among many indicators of data analysis, the students' weekly activeness and their interest in different teaching resources are analyzed here by citing them as examples. Students' weekly activeness is as follows: the students are more ready to learn on Mondays, Tuesdays, and Sundays. The number of clicks on Friday and Saturday is relatively low (3,546 and 2,990 times, respectively). The number of clicks on Monday and Tuesday is relatively high (8,427 and 10,926 times, respectively), which is about triple that of Friday and Saturday. By contrast, the students feel tired to learn on Fridays and Saturdays, which are holidays. With the overall class schedule unchanged, the online curriculum arrangement can be adjusted based on the students' readiness to learn and according to the learning law to mobilize the learning motivation and maximize the learning outcomes (see Figure 2). The click rate of each type of teaching resources per semester is as follows: microvideo offers a more intuitive way of learning and has become the type of teaching resources with the highest click rate. However, PPT no longer draws interest from the students as it once did. Watching microvideos has become students' favorite way of learning, with a total of 11,970 times played and an average

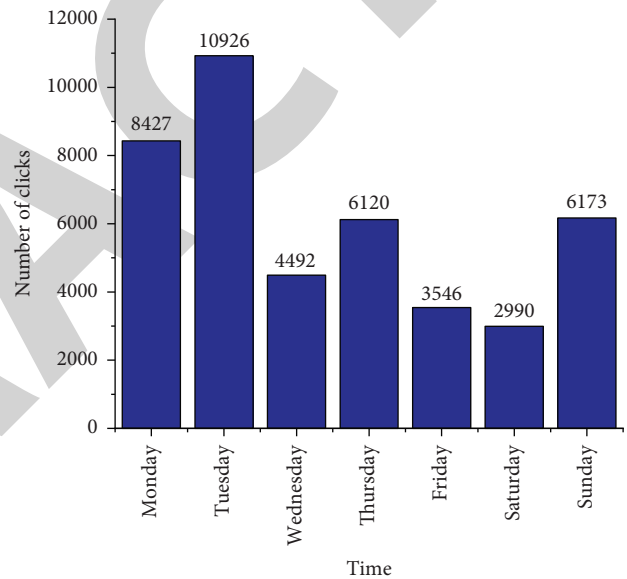


Figure 2: The number of clicks made by students per week.

of 1.2 times played per video. Students prefer to quickly acquire knowledge by watching videos on mobile devices. On the SPOC platform, the students prefer participating in curriculum discussions and forums, which accords with the expectation about flipped classroom teaching, with 11,400 responses to the discussion topics, that is almost twice as many as PPT presentations. Teachers and students are engaged in a more active interaction via this teaching mode, which promotes active thinking from the students (see Figure 3).

In this study, 248 students from 3 classes under SPOC-based blended teaching (150 students) and 2 classes under conventional teaching (98 students) were included for comparison within one semester [31]. They were compared in the following dimensions: classroom performance, completion of group task, test-based evaluation, and scores. A questionnaire survey was conducted in students' learning hours, attainment of problem-solving ability, achievement of learning outcomes, feedback concerning the teaching method, and acquirement of the self-learning ability. A total

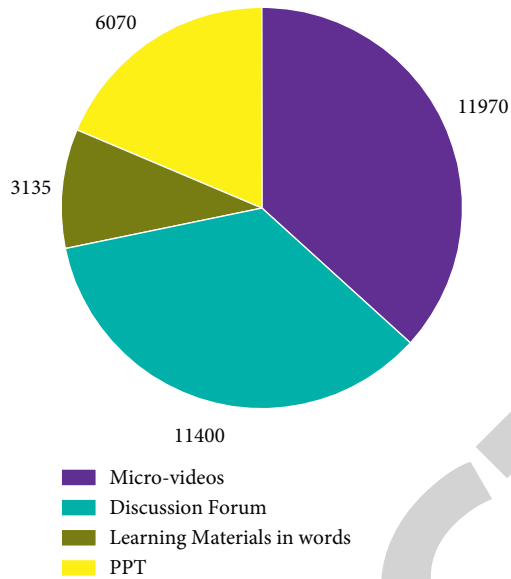


Figure 3: A total number of clicks on each learning resource per semester.

Table 3: Positive responses (options 4-5) of students to course evaluations in both types of courses.

Items	SPOC		Conventional	
	n	%	*n*	%
The course has a clear curriculum objective	132	88.00	85	86.73
The course has rich teaching resources	135	90.00	82	83.67
The content design of the curriculum is very good	142	94.67	76	77.55
The course assessment is reasonable	130	86.67	77	78.57
The completion effect of course tasks	132	88.00	85	86.73
The help of course process assessment to master the course content	128	85.33	80	81.63
The interactive part of the course helps to improve learning	145	96.67	77	78.57
Master the ability that the course needs to cultivate	131	87.33	82	83.67
Interest in study has been improved	142	94.67	77	78.57
Self-study ability has been improved	144	96.00	83	84.69
Problem solving skills has been improved	145	96.67	83	84.69

Note. All items were rated on a 5-point Likert scale with 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Only the positive responses (options 4–5) are shown.

Table 4: Comparison of the SPOC-based teaching mode and the conventional teaching mode.

Item under comparison	Blended teaching based on the SPOC platform	Conventional teaching mode
Classroom performance	Active in class and feeling free to discuss	Lack of vitality, communications and interactions in class
Completion of the theme-related task	Satisfactory completion of the theme-related task	Less satisfactory completion of the theme-related task
Test-based evaluation	High average performance score	Low average performance score
Learning hours	High motivation to learn, with fragmented learning encouraged and facilitated	Shorter learning hours after class
Attainment of the problem-solving ability	Problem-solving ability satisfactorily attained	Problem-solving ability less satisfactorily attained
Achievement of learning outcomes	Learning outcomes satisfactorily achieved	Learning outcomes less satisfactorily achieved
Acquirement of the self-learning ability	Self-learning ability very much improved	Self-learning ability less effectively improved
Acceptance of the learning method	Welcome among the students	Boring learning method

of 248 copies of the questionnaire were distributed and retrieved. The positive responses of students to the evaluation of the two courses (options 4–5) are shown in Table 3. It is easy to see that SPOC courses have a situational design for the content, provide richer teaching resources, and make the task assessment more reasonable and the course objectives more clear. Compared with the traditional course, the interactive part of the course is helpful to improve the learning. About 95% of the students think that the learning mode based on SPOC has improved their learning interest, autonomous learning ability and problem-solving ability, which is much higher than the assessment of traditional courses. The comparison results are shown in Table 4. As shown by the comparison, the effect of SPOC-based teaching is very much improved. The classroom atmosphere is more animated and lively, and the self-learning ability of the students is more effectively trained.

4. Conclusions

The empirical study on the mixed teaching mode of Tianfu College of Southwestern University of Finance and Economics shows that it is necessary to establish a set of mixed teaching mode to cope with the changes in teaching means and information transmission after the outbreak of the epidemic. Of course, first of all, it should conform to the learning situation of most students. Student-centered and output-oriented concept is the core of the design of mixed teaching mode. In order to fully improve students' initiative and sense of participation in learning, teachers need to reconstruct course organization. Students' learning efficiency has been improved, the learning effect is also very obvious, and the ability training has been achieved. Our empirical study has shown that the online and offline blended teaching mode based on the SPOC platform efficiently improves the overall teaching quality.

The COVID-19 pandemic has brought about unprecedented challenges to teaching and broken the conventional teaching pattern. It is time that we think about the future trend in teaching development. As to the teaching contents, the students have easy access to massive, high-quality online learning resources, which is helpful for expanding their scope of knowledge. As to process organization, the online teaching platform offers various interaction tools, including bullet screen, online discussion, and quizzes. The students are more active in class, and the teachers can analyze and respond more rapidly. This feature makes up for the defects with conventional offline classes and improves teaching efficiency. As to teaching evaluation, the online platform provides intact online learning data to track students' completion of assignments and learning hours. Therefore, the teachers can assess the teaching effect and teach the students according to their aptitude more conveniently. In the postpandemic era, the teaching concepts such as individualized and exploratory learning have taken roots along with the rapid development of the mobile Internet. Teachers and students have widely accepted the online and offline blended teaching mode based on the SPOC platform due to its school-based, mobile and fragmented features.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Research project of online open courses (MOOC) in Sichuan colleges and universities: Design and research of blended teaching mode based on SPOC platform taking Southwestern University of Finance and Economics as an example (Project no. SCKC2019041).

References

[1] R. A. Rasheed, A. Kamsin, and N. A. Abdullah, "Challenges in the online component of blended learning: a systematic review," *Computers & Education*, vol. 144, Article ID 103701, 2020.

[2] Q. Xie and S.-B. Tsai, "An empirical study on innovation of college blended teaching under big data analysis," *Mathematical Problems in Engineering*, vol. 2021, pp. 1–9, Article ID 3752037, 2021.

[3] B. B. Lockee, "Shifting Digital, Shifting Context: (Re)considering Teacher Professional Development for Online and Blended Learning in the COVID-19 Era," *Educational Technology Research and Development ETR & D*, vol. 69, no. 1, pp. 17–20, 2020.

[4] A. Istenic, "Online learning under COVID-19: re-examining the prominence of video-based and text-based feedback," *Educational Technology Research & Development*, vol. 69, no. 1, pp. 117–121, 2021.

[5] D. Turnbull, R. Chugh, and J. Luck, "Transitioning to E-learning during the COVID-19 pandemic: how have higher education institutions responded to the challenge?" *Education and Information Technologies*, vol. 26, no. 5, pp. 6401–6419, 2021.

[6] A. B. Dua, A. Kilian, R. Fantus et al., "Challenges, collaboration, and innovation in rheumatology education during the COVID-19 pandemic: leveraging new ways to teach," *Clinical Rheumatology*, vol. 39, no. 12, pp. 3535–3541, 2020.

[7] K. E. Darras, R. J. Spouge, A. B. H. de Bruin, A. Sedlic, C. Hague, and B. B. Forster, "Undergraduate radiology education during the COVID-19 pandemic: a review of teaching and learning strategies," *Canadian Association of Radiologists Journal*, vol. 72, no. 2, pp. 194–200, 2021.

[8] T. I. Nathaniel, R. L. Goodwin, L. Fowler, A. C. Black Jr, and B. McPhail, "An Adaptive Blended Learning Model for the Implementation of an Integrated Medical Neuroscience Course during the Covid-19 Pandemic," *Anatomical sciences education*, vol. 14, no. 6, pp. 699–710, 2021.

[9] S. M. Schmitz, S. Schipper, M. Alizai et al., "Development of a tailor-made surgical online learning platform, ensuring surgical education in times of the COVID19 pandemic," *BMC Surgery*, vol. 21, no. 1, 196 pages, 2021.

[10] D. A. Fitzgerald, K. M. Scott, and M. S. Ryan, "Blended and e-learning in pediatric education: harnessing lessons learned from the COVID-19 pandemic," *European Journal of Pediatrics*, vol. 181, no. 2, pp. 447–452, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8733002, 12 pages
https://doi.org/10.1155/2022/8733002

Research Article

Evaluation Index System Construction of High-Quality Development of Chinese Real Enterprises Based on Factor Analysis and AHP

Jiawei Wang,[1] Xiaoxuan Gao,[1] Ruhai Jia,[2] and Lisan Zhao[1]

[1]*School of Management of Hebei University, Baoding, China*
[2]*Housing Provident Fund Management Center of Handan, Handan, Hebei, China*

Correspondence should be addressed to Lisan Zhao; hbuzhaolisan@126.com

Received 14 July 2022; Revised 1 August 2022; Accepted 1 September 2022; Published 12 September 2022

Academic Editor: Lele Qin

China's economic development has shifted from high-speed to high-quality. The fundamental of promoting the high-quality development of the real economy lies in real enterprises. Therefore, it is urgent to measure the high-quality development of real enterprises scientifically and reasonably. Herein, we construct a comprehensive evaluation index system for the high-quality development of real enterprises based on the existing research and combined with the characteristics of real enterprises. Then, the high-quality development index for real enterprises is created using factor analysis and AHP. Moreover, we measure and analyze the high-quality development of real enterprises in 2020. The results show that the high-quality development level of Chinese real enterprises remains to be further upgraded. Meanwhile, there are obvious contrasts in the high-quality development index of real enterprises in industries and regions. Finally, we put forward some related policy recommendations, such as enhancing policy relevance, insisting on innovative development, and increasing financial sustainability.

1. Introduction

China's economic development has undergone a historic transformation after the 19th National Congress of the Communist Party of China (CPC) first proposed that China's economic development has shifted from high-speed to high-quality. Achieving the high-quality development of real enterprises is fundamental to promoting the high-quality development of the real economy, which is an important way for China as an economic power to move from large to strong. Then, what is the high-quality development of real enterprises and how to measure it. Hence, the construction of a high-quality development evaluation system for real enterprises is the cornerstone to measuring whether real enterprises have achieved high-quality development and showing how to promote the high-quality development of real enterprises.

The construction of an evaluation system for high-quality development has become a hot research issue since the 2017 China Central Economic Work Conference expressed its importance. However, the existing studies on the evaluation index system of high-quality development focus on the macroeconomics [1–5] and middle-view industry levels [6–9]. Among the few studies at the company level, Wang et al. used AHP to construct high-quality development indicators of enterprises [10] without empirical studies. Besides, the evaluation index system for the high-quality development of state-owned enterprises [11] and local state-owned enterprises [12] was also studied. Nevertheless, the high-quality development of real enterprises cannot be effectively measured in existing studies for the lack of a targeted, systematic, microbased evaluation index system of high-quality development.

Herein, based on the existing research and combined with the characteristics of real enterprises, we construct an evaluation system of high-quality development for real enterprises, which includes 4 primary indicators, 11 secondary indicators, and 23 tertiary indicators. We then

calculate the index of high-quality development for real enterprises using the comprehensive weight model of factor analysis and AHP. Last, we measure the high-quality development of real enterprises in 2020 and put forward relevant policy suggestions.

Firstly, most of the existing studies on high-quality development evaluation systems focus on the macro and meso-views. We supplement the construction of high-quality development evaluation indexes of real enterprises with a microview. Secondly, it is significant to maintain a reasonable asset structure for the operation and growth of a company, so we take high-quality financial information as an important factor to measure the high-quality development of real enterprises. In particular, the asset structure is included in the evaluation system. Finally, we use the subjective and objective weight models to construct a high-quality development index for real enterprises. Herein, the research gap of using factor analysis and AHP to construct a high-quality development evaluation system is supplemented.

2. Selection of Evaluation Indicators for High-Quality Development of Real Enterprises

2.1. The Connotation and Characteristics of High-Quality Development of Real Enterprises. The Resolution of the Central Committee of the Communist Party of China on the Major Achievements and Historical Experiences of the Party over the Past Century (hereinafter referred to as the Resolution) emphasizes that achieving high-quality development is the fundamental path to achieving the second 100-year goal and starting a new journey of building a modern socialist country in China. Meanwhile, the resolution points out that competitive enterprises are the foundation of high-quality development. Enterprises are not only the micro-subjects of macroeconomic development but also the basic organizations of meso-industrial development. Furthermore, the high-quality development of enterprises is a key to high-quality economic development [13]. During the visit to Guangxi in April 2021, the general secretary of the CPC Central Committee, Xi Jinping, pointed out that "the development of the real economy is a solid foundation for building a modern economic system and an important support for building future development strategies." The outline of the 14th Five-Year Plan (2021–2025) and the Long-Range Objectives through the year 2035 proposed that "focus on the real economy to boost economic development." Therefore, constructing a high-quality development evaluation system to evaluate the high-quality development of real enterprises scientifically, systematically, and effectively is needed. The real economy, in a broad sense, refers to all industries in the entire national economy, excluding finance and real estate [14]. The real economy is the basis for the development of society and human beings, so the realization of high-quality development of real enterprises is the cornerstone for promoting high-quality economic development. Research shows that the high-quality development of real enterprises is a new paradigm for real enterprises to pursue higher-level economic and social values and a new development state of sustainable development and value creation [13, 15, 16]. This paper holds that high-quality development is a comprehensive target for real enterprises to achieve high-quality innovation development, financial information, benefit creation, as well as green and sharing.

2.1.1. High-Quality Innovative Development. Xi Jinping pointed out that innovation is at the core of Chinese modernization and the primary driving force for high-quality development. However, weak innovation is the "Achilles' heel" of Chinese real economic development. Therefore, innovation is not only a development issue but also a survival issue for real enterprises, and high-quality innovation is the power source of high-quality development for real enterprises. As the core element of sustainable development, innovation is an important engine to cultivate competitive advantages and lead the transformation and upgrading of real enterprises. Unlike the pursuit of high-speed growth in the past, the high-quality development of real enterprises should not only have advantages in quantity but also in the quality of products and services. Only by taking innovation as the power source of development can entity enterprises improve their technological content and gain market competitiveness.

2.1.2. High-Quality Financial Information. Accounting information is an important basis for evaluating the quality of economic operation and development [17], and high-quality financial information is the embodiment of real enterprises to achieve high-quality development. It is more accurate to portray the quality of corporate development than the microaccounting information because financial indicators can intuitively reflect the degree of development of an enterprise. Moreover, enterprise development often interacts with financial information. The development of business management activities promotes the demand for financial information, while the improvement of accounting information timeliness continuously promotes business management. Hence, high-quality financial information is the reflected result of high-quality development for real enterprises, which can further promote high-quality development for real enterprises.

2.1.3. High-Quality Benefit Creation. Only competitive enterprises can achieve long-term development in the fierce market competition. Improving the quality of benefit creation of real enterprises is an effective means to gain competitiveness and achieve high-quality development. High-quality benefit creation means that companies possess high-quality products and services, a high percentage of market share, a high degree of open development, and a bright prospect of market development. Only by continuing to improve the quality of products and services and promoting open development can real enterprises form stronger competitive advantages, unique brand value, and sustainable development capabilities.

Table 1: The original high-quality development evaluation index system.

Primary indicators	Secondary indicators	Tertiary indicators	Formula
High-quality innovative development	Innovation input	The intensity of R&D investment $Q1$	R&D investment/Operating income
		R&D personnel ratio $Q2$	R&D staff/Total employees
		Capitalization rates $Q3$	Capitalized R&D investment/R&D investment
	Innovation output	Patent per capita $Q4$	Number of patents granted/Number of employees
		Patent authorization $Q5$	The logarithm of patents authorization
High-quality financial information	The rationalization of asset structure	Operating asset structure $Q6$	(Fixed assets + construction in progress)/total assets
		The proportion of financial assets $Q7$	Financial assets/total assets
		Intangible asset density $Q8$	Net intangible assets/net fixed assets
	Solvency	Current ratio $Q9$	Current assets/current liabilities
		Gearing ratio $Q10$	Total liabilities/total assets
	Operation capability	Total asset turnover ratio $Q11$	Operating income/average total assets
		Gross profit ratio $Q12$	(Operating income − operating costs)/operating income
	Profitability	ROA $Q13$	Net profit/average total assets
		ROE $Q14$	Net profit/average net assets
	Development capabilities	Revenue growth $Q15$	Δ operating income/operating income for the previous period
		Capital accumulation ratio $Q16$	Δ shareholder equity/shareholder equity at the beginning of the year
High-quality benefit creation	Products and services	ROS $Q17$	Net profit/operating income
	Open development	Overseas income growth ratio $Q18$	Overseas income/overseas income for the previous period
		Overseas income $Q19$	The logarithm of overseas income
		Foreign investment $Q20$	The logarithm of the net profit of overseas affiliates
High-quality green sharing	Green development	Environmental protection awareness $Q21$	Logarithm of the environmental protection investment
	Socially shared	Payroll payable $Q22$	Employee salaries payable/employee salaries payable for the previous year
		Social donations $Q23$	The logarithm of the total social donation

2.1.4. High-Quality Green and Sharing. Green is the bottom color of high-quality development, and sharing is the purpose of high-quality development. On the one hand, "lucid waters and lush mountains are invaluable assets." High-quality development should be a green development with ecological priority. Enterprises should be more imperious to seek the quality of economic growth instead of speed, which is at the expense of environmental pollution and unsustainability. To achieve green development, enterprises should enhance the awareness and responsibility of energy conservation and emission reduction, as well as environmental protection, and further accelerate the formation of resource-saving production modes. On the other hand, value sharing and win-win cooperation are the goals for the high-quality development of real enterprises. Society sharing means that real enterprises undertake more social responsibilities to achieve high-quality development and create social benefits while creating economic benefits.

2.2. Selection of Evaluation Indicators for High-Quality Development of Real Enterprises. The selection of the basic index set is the basis for constructing the high-quality development evaluation index system for real enterprises. Referring to the "Enterprise High-quality Development Rating Indicators" of the China Enterprise Reform and Development Research Association and the existing work [10], combining with development practices and the characteristics of real enterprises and following the principles of scientific, systematic, dynamic, and data availability, we put forward the high-quality development evaluation index system of real enterprises, which consists of 4 primary indicators, 11 secondary indicators, and 23 tertiary indicators related to high-quality development and innovation, high-quality financial information, high-quality benefit creation, and high-quality green sharing (The calculation formula of each index is shown in Table 1).

2.2.1. Innovative Development Indicators. Enterprise innovation capacity is mainly measured by innovation input and output. Innovation input refers to the investment in new products, new processes, and the transformation of fixed assets. Here, three indicators are selected to measure innovation input, including intensity of R&D investment, R&D personnel ratio, and capitalization rates. The intensity of R&D investment reflects the number of R&D funds an enterprise invested in that year. R&D personnel ratio reflects

the proportion of research personnel to all employees of an enterprise. Capitalization rates refer to the proportion of the amount of R&D investment that may generate revenue in the future, reflecting the possibility of getting output from R&D inputs in the future. High innovation input does not mean high innovation output, and the degree of innovation development also needs to be measured by innovation output. The innovation output of enterprises is represented by the new products, technologies, and processes resulting from innovation. Hence, it is reflected as patented technologies of enterprises, which are measured by the two indicators of patent per capita and patent authorization.

2.2.2. Financial Information Indicators. The high-quality development of real enterprises should be manifested in the rationalization of asset structure and the continuous optimization of solvency, operation capability, profitability, and development capabilities.

Firstly, maintaining a reasonable capital structure is one of the important financial decisions of an enterprise, which is of great significance to its production, operation, and sustainable development [18]. A reasonable asset structure can improve business performance and prevent risks. On the contrary, it will reduce the efficiency of corporate resource utilization, lead to a decline in performance, and eventually fall into financial distress [19, 20]. Here, the operating asset structure, the proportion of financial assets, and the intangible asset density are chosen to measure the asset structure of enterprises. Operating asset structure refers to the allocation structure of enterprise assets, which is the choice of enterprise strategic decision-making. Generally, enterprises can be divided into heavy-asset enterprises and light-asset enterprises according to the structure of operating assets [21]. Assets can be classified into operating assets and financial assets according to the nature of enterprise activities, which reflects the sensitivity of assets to changes in the external environment and the ability of different assets to create wealth [18]. Here, the degree of financialization of enterprises is measured by the proportion of financial assets. The total financial assets are represented by the sum of trading securities, loans and advances, financial derivatives, available-for-sale securities, held-to-maturity securities, and investment properties [22–24]. Intangible asset density refers to the ratio between intangible and tangible assets, which affects the enterprise's production, technology, investment structure, and market value [25]. Asset-light enterprises can obtain higher profits according to the "smile curve" [26]. Hence, the lower the operating asset structure and the higher the intangible assets density, the better. Besides, it showed that the deepening of financialization would reduce real investment, harm the future core business performance, and inhibit the innovation of real enterprises [27–29], leading to a negative financial asset ratio indicator.

Secondly, the solvency of an enterprise reflects its ability to repay debts and resolve risks. Stronger solvency means lower financial risk and a lower possibility of falling into financial distress [10]. Here, the current and gearing ratios are chosen to measure the enterprises' short-term solvency and long-term solvency, respectively.

Thirdly, improving operating capacity is the basis for enterprises to improve their profitability and long-term development capability. Here, the total asset turnover ratio and gross profit ratio are selected to measure the operation capability of enterprises. The total asset turnover ratio, one of the important indicators to examine the efficiency of asset operation, reflects the efficiency and utilization of asset management and the flow rate of assets from input to output during the period of continuous operation. The gross profit ratio affects the profit of sales revenue while also determining the room for companies to invest in research and development, advertising, and sales. The higher the gross profit margin, the more high-end products the company provides, which is more conducive to promoting sustainable development.

Fourthly, this paper selects return on total assets (ROA) and return on equity (ROE) as the tertiary indicators for profitability. ROA reflects the relationship between the efficiency of capital utilization and the efficiency of asset utilization, determines the stability and durability of corporate earnings, and reflects the level of comprehensive business management. ROE measures the efficiency of capital invested by shareholders. Analyzing the difference between ROA and ROE can reflect the level of operational risk of a company.

Finally, development capabilities, measured by the revenue growth and capital accumulation ratio, are the necessary conditions for an enterprise to be able to establish sustainable development. Among them, revenue growth is an important indicator to evaluate the development ability and growth status of an enterprise, which reflects its operation and market share and predicts its ability for future business expansion. The capital accumulation rate can characterize the growth of an enterprise and reflect the value preservation and appreciation of the capital invested by investors.

2.2.3. Benefit Creation Indicators. High-quality benefit creation can be reflected in the good quality of enterprise products and services as well as excellent open development capability. Return on sales (ROS) characterizes the quality of products and services and reflects the level of revenue generated from sales. Meanwhile, the degree of open development is measured by overseas income, overseas income growth ratio, and foreign investment.

2.2.4. Green Sharing Indicators. Achieving green development and sharing operating results with society is a sure way to ensure the sustainable development of enterprises. Therefore, environmental protection awareness is used here as a tertiary indicator of green development. Meanwhile, payroll payable and social donations are used to measure whether the enterprise is socially shared.

3. Construction of an Evaluation System for High-Quality Development of Real Enterprises

3.1. Selection of Evaluation Methods. Based on the selection of high-quality development indicators for real enterprises, the appropriate method to comprehensively process the indicators is further selected, the core content of which is to calculate the weight. The index weight methods of the comprehensive evaluation indicators include the subjective weighting method and the objective weighting method. The subjective weighting method sets index weights according to subjective experience, which is a qualitative evaluation method and commonly includes AHP, experts grading method, and such. The advantage is that experts can rank the indicators more reasonably according to the actual situation and can effectively determine the importance of the indicators to a certain extent, but it is highly subjective and arbitrary. The objective weighting method, including factor analysis, the entropy weight method, and gray relational analysis, is a quantitative evaluation method that uses statistical and mathematical methods to determine the weights of indicators based on their intrinsic links. Compared with the subjective weighting method, the objective weighting method can avoid the subjectivity of the evaluation subject.

Both the subjective and objective weighting methods have one-sidedness. Therefore, the use of the combined evaluation method can reduce the bias resulting from the single method so that the constructed index system is not only more in line with the actual situation but also helps to improve the objectivity of the evaluation results [30]. The combination of factor analysis and AHP as the weighting method is used here to comprehensively evaluate the high-quality development of real enterprises according to the studies [31–34]. Among them, the factor analysis method integrates indicators by using the correlation between variables [31]. AHP can fully consider the practical significance of the indicators by decomposing the evaluation objectives layer by layer and judging the weights of each indicator by experts [35]. The factor analysis method makes up for the lack of objectivity of the AHP and ensures that the evaluation results are more reasonable, scientific, and effective [34]. Finally, the arithmetic mean of the weights calculated by the two methods is used as the final combined weight [35, 36].

3.2. Steps to Build an Evaluation System. First, the factor analysis method is used to reduce the dimension and eliminate the repeated information between the indicators of the evaluation index system constructed above. Then the common factors are named and hierarchical structure models are established for the evaluation index system. After obtaining the three-level structure model, the factor analysis and AHP are further used for weighting. Finally, the arithmetic mean of the weights obtained by the two methods is taken as the weight coefficient of the final high-quality development index of real enterprises.

3.2.1. Factor Analysis

(1) Index Positive Processing. Most indicators selected in this paper are positive, except for the operating asset structure ($Q6$), the proportion of financial assets ($Q7$), and the gearing ratio ($Q10$), which need to be positively processed.

(2) Standardization of Indicator Data. Factor analysis was conducted using SPSS 26.0 software, and indicators were automatically standardized during factor analysis.

(3) Correlation Test between Variables. The KMO test and Bartlett's test of sphericity are usually selected for the correlation test between variables. The closer the KMO value is to 1, the stronger the correlation between the variables. It is generally believed that the original variable is suitable for factor analysis when the KMO value is greater than 0.5. If the Pvalue corresponding to the Bartlett's test is less than the given significance level, the null hypothesis that the correlation coefficient matrix is a unit matrix is rejected, and the original variables are suitable for factor analysis.

(4) Establishing a Component Matrix to Extract Common Factors. The most common method of the component matrix is principal component analysis, which determines the number of factors according to the characteristic root and the cumulative variance contribution rate. Firstly, establish an original factor component matrix for the extracted common factors. Then rotate the original matrix by the varimax-rotation method to obtain the rotated component matrix and rename the common factors according to the rotated factor component matrix. Finally, establish a hierarchy model M for high-quality development evaluation of real enterprises.

(5) Calculation of Factor Scores and Overall Evaluation Scores. The least squares regression estimation method is used to derive the factor score coefficient matrix, and the information contribution of each factor is used as the weight.

3.2.2. Analytic Hierarchy Process

(1) Construction of Hierarchical Structure Model. The model M, constructed in the fourth step of the factor analysis method above, is a hierarchical structure model for the high-quality development evaluation of real enterprises.

(2) Building a Comparison Judgment Matrix. A group of five university professors was selected to set the weights and compare the importance of each level of indicator through a pairwise comparison between the indicators. According to the 1–9 scale method, the comparison and assignment are carried out. The relationship between the indicators is shown in Table 2, in which the intermediate values between the scales shown in the table are 2, 4, 6, and 8, and the importance of indicator j compared with indicator i should be the reciprocal of the importance of indicator i compared with indicator j, i.e., $A_{ji} = 1/A_{ij}$.

Table 2: Judgment matrix comparison scale.

Indicator importance	A_{ij} assign
Indicator i and j are equally important	1
Indicator i is slightly more important than j	3
Indicator i is more important than j	5
Indicator i is deeply more important than j	7
Indicator i is definitely more important than j	9

If it contains n indicators, a comparative judgment matrix $A = (A_{ij})_{n\times n}$ can be obtained, where A_{ij} indicates the importance ratio of indicator i to indicator j.

(3) Consistency Test and Calculation of Weights. The formula for calculating the degree of the comparison matrix consistency is $CR = CI/RI$, where $CI = \lambda_{\max} - n/n - 1$, and RI is the random consistency index of the comparison matrix, which can be obtained by looking up the table. The consistency degree of the judgment matrix A is considered acceptable if $CR < 0.1$. While the consistency degree of matrix A is unacceptable when $CR \geq 0.1$, and the importance degree between the two indicators needs to be adjusted until the criterion $CR < 0.1$ is satisfied.

(4) Comprehensive Scoring Based on Hierarchy Structure. From top to bottom, each level is calculated separately to obtain the weight of each indicator toward the upper level, and then the weight value of the bottom indicator toward the uppermost level is finally determined.

4. Empirical Research on High-Quality Development of Real Enterprises

4.1. Data. Here, the financial annual reports of 2020 Chinese A-share real enterprises from the China Stock Market and Accounting Research (CSMAR) database were selected. According to Huang's (2017) research on the real economy and the industry classification of the China Securities Regulatory Commission in 2012 [13], the financial industry and real estate industry were excluded as the original data set of real enterprises for empirical analysis. Some observations, including ST companies, outliers, and missing samples, were removed. The descriptive statistics of the variables are shown in Table 3. SPSS 26.0 and Yaahp 10.0 were used to conduct factor analysis and AHP, respectively.

4.2. Building Hierarchical Structure Models. Table 4 shows the KMO test and Bartlett's test of sphericity before factor analysis, indicating that the data in this paper are suitable for factor analysis, where the KMO value is 0.691 greater than 0.5 and the Bartlett's sphericity test Sig value = 0.000 < 0.05.

The factors were extracted using principal component analysis, and the number of factors was determined based on the post-rotation eigenvalues and the cumulative variance contribution of the factors. Table 5 shows that there are 8 factors with eigenvalues greater than 1 after rotation, and the cumulative variance contribution rate is 66%. While the 9th common factor has an eigenvalue of 0.935 close to 1 after rotation, and the cumulative variance contribution rate is 70.5%. As a result, 9 common factors are extracted in this paper, and the cumulative variance contribution rate is 70.5%, which can represent most of the information from the original data.

Table 3: Descriptive statistics of variables.

Variables	N	Mean	Sd	Min	Max
$Q1$	1969	0.05	0.03	0.00	0.24
$Q2$	1969	0.14	0.10	0.00	0.59
$Q3$	1969	0.05	0.13	0.00	0.90
$Q4$	1969	0.00	0.01	0.00	0.06
$Q5$	1969	0.57	1.35	0.00	5.46
$Q6$	1969	0.26	0.15	0.02	0.73
$Q7$	1969	0.04	0.06	0.00	0.32
$Q8$	1969	0.31	0.42	0.01	4.20
$Q9$	1969	2.16	1.59	0.37	14.20
$Q10$	1969	0.42	0.17	0.06	0.89
$Q11$	1969	0.63	0.33	0.12	2.52
$Q12$	1969	0.28	0.15	0.01	0.82
$Q13$	1969	0.04	0.06	−0.22	0.22
$Q14$	1969	0.07	0.10	−0.60	0.36
$Q15$	1969	0.08	0.25	−0.49	1.71
$Q16$	1969	0.12	0.23	−0.44	2.13
$Q17$	1969	0.07	0.11	−0.72	0.44
$Q18$	1969	0.64	0.83	0.00	8.88
$Q19$	1969	11.23	9.78	0.00	23.60
$Q20$	1969	1.79	5.18	0.00	19.54
$Q21$	1969	0.18	1.17	0.00	9.65
$Q22$	1969	1.22	0.52	0.30	7.66
$Q23$	1969	1.24	2.22	0.00	7.60

Table 4: KMO and Bartlett's test of sphericity.

KMO sampling suitability quantity		0.691
Bartlett's test	Approx. Chi-square	17964.122
	Degree of freedom (df)	253
	Significance	0.000

The influencing factors of the extracted 9 common factors can be classified and named by analyzing Table 6. Factor $F1$, named as the "profitability and development factor," has a higher load in ROE, ROA, ROS, and capital accumulation ratio. Factor $F2$, named as the "solvency factor," has a high load to current ratio, gearing ratio, and proportion of financial assets. Factor $F3$, named as the "innovation and operational factor," has a high load on the intensity of R&D investment, R&D personnel ratio, total asset turnover ratio, and gross profit ratio. Factor $F4$, named as the "overseas income factor," has a higher load in the overseas income growth ratio and overseas income. Factor $F5$, named as the "innovation output factor," has a higher load of patents granted and patents per capita. Factor $F6$, named as the "asset structure factor," has a higher load in the operating asset structure and intangible asset density. Factor $F7$, named as the "shared growth factor," has a higher load in payroll payable and revenue growth. Factor $F8$, named as the "social responsibility factor," has a higher load in environmental protection awareness and social donations. Factor $F9$, named as the "innovation input factor," has a higher load in capitalization rates and foreign investment.

Table 5: Total variance explained.

	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance	Cumulative (%)	Total	Variance	Cumulative (%)	Total	Variance	Cumulative (%)
1	3.897	16.945	16.945	3.897	16.945	16.945	3.302	14.356	14.356
2	2.531	11.005	27.950	2.531	11.005	27.950	2.076	9.027	23.383
3	2.208	9.600	37.550	2.208	9.600	37.550	2.073	9.013	32.396
4	1.679	7.301	44.851	1.679	7.301	44.851	1.866	8.112	40.508
5	1.443	6.272	51.123	1.443	6.272	51.123	1.778	7.729	48.237
6	1.272	5.532	56.656	1.272	5.532	56.656	1.501	6.528	54.765
7	1.152	5.008	61.663	1.152	5.008	61.663	1.364	5.928	60.694
8	1.090	4.738	66.402	1.090	4.738	66.402	1.139	4.953	65.646
9	.935	4.064	70.465	.935	4.064	70.465	1.108	4.819	70.465

Table 6: Rotated component matrix.

	*F*1	*F*2	*F*3	*F*4	*F*5	*F*6	*F*7	*F*8	*F*9
*Q*14	0.940	0.041	−0.091	0.032	0.001	0.028	0.052	0.067	−0.037
*Q*13	0.934	0.219	−0.030	0.021	−0.006	0.018	0.045	0.059	−0.060
*Q*17	0.883	0.249	0.116	−0.036	0.000	−0.058	−0.039	0.034	0.013
*Q*16	0.554	−0.067	0.033	0.064	0.008	−0.026	0.362	−0.021	−0.030
*Q*9	0.152	0.804	0.187	−0.067	0.013	0.056	−0.004	−0.015	−0.145
*Q*10	0.231	0.791	0.219	−0.080	−0.015	−0.112	−0.031	−0.014	−0.068
*Q*7	−0.011	−0.668	0.112	−0.092	0.052	−0.190	0.005	−0.016	−0.045
*Q*1	0.018	0.075	0.814	0.159	0.063	0.247	0.082	−0.034	0.020
*Q*2	−0.006	−0.044	0.669	0.148	0.073	0.450	0.133	−0.024	−0.137
*Q*11	0.171	−0.148	−0.640	0.150	−0.026	0.291	0.167	0.036	−0.198
*Q*12	0.395	0.330	0.555	−0.119	−0.033	−0.018	−0.039	0.000	0.204
*Q*19	−0.011	−0.044	0.023	0.898	0.018	0.004	−0.024	0.053	−0.008
*Q*18	0.072	−0.003	0.100	0.839	0.030	−0.021	0.170	0.019	−0.020
*Q*5	0.012	−0.056	0.002	0.068	0.938	−0.012	−0.009	0.021	0.000
*Q*4	−0.011	0.002	0.087	−0.010	0.936	0.067	0.013	−0.019	−0.023
*Q*6	−0.018	0.221	0.062	0.041	0.034	0.815	0.028	−0.049	−0.074
*Q*8	−0.008	−0.054	0.132	−0.108	0.014	0.634	−0.119	−0.009	0.282
*Q*22	−0.003	0.054	0.038	0.025	−0.012	−0.083	0.857	0.039	0.049
*Q*15	0.413	−0.125	−0.030	0.135	0.024	0.082	0.611	−0.054	−0.105
*Q*21	−0.018	0.028	−0.071	−0.059	0.014	−0.028	0.095	0.767	0.263
*Q*23	0.130	−0.034	0.005	0.094	−0.010	−0.031	−0.094	0.690	−0.269
*Q*3	−0.062	−0.151	0.192	−0.051	−0.041	0.102	0.001	0.081	0.702
*Q*20	−0.002	0.057	−0.209	0.440	0.041	−0.003	−0.037	−0.211	0.492

The evaluation index system for high-quality development of real enterprises was initially constructed by extracting, analyzing, and naming the public factors, which contains 9 public factors as secondary indicators and 23 variables as tertiary indicators as shown in Table 7.

4.3. Calculation of Index Weights

4.3.1. Weight of Factors Analysis. Table 8 shows the score coefficient matrix of high-quality development factors for real enterprises obtained using the least squares regression, and the expressions of 9 common factors can be obtained.

The weights of calculating the high-quality development index of real enterprises $(F-1)$ are the information contribution rate of each public factor. The formula is as follows:

$$F-1 = 0.204F_1 + 0.128F_2 + 0.128F_3 + 0.115F_4 + 0.110F_5 + 0.093F_6 + 0.084F_7 + 0.070F_8 + 0.068F_9. \quad (1)$$

4.3.2. Weight of AHP. Each of the five professors in the expert group set the weights of each layer of indicators, which are compared in pairs and assigned according to the 1–9 scale method. Finally, the weighted arithmetic mean method is used to aggregate the ranking vectors of each expert. Here, the Yaahp 10.0 software is used to perform a comprehensive evaluation.

The corresponding comparison matrix is constructed according to the index weight comparison values set by 5 experts, and the consistency test on the comparison matrix is carried out. The CR values are all less than 0.1, indicating that the matrix composed of the indicators set by the expert group

Table 7: Evaluation hierarchy model.

Primary indicators	Secondary indicators	Tertiary indicators
High-quality development of real enterprises (HDQ)	Profitability and development $F1$	ROE
		ROA
		ROS
	Solvency $F2$	Capital accumulation ratio
		Current ratio
		Gearing ratio
	Innovation and operational $F3$	The proportion of financial assets
		The intensity of R&D investment
		R&D personnel ratio
		Total asset turnover ratio
	Overseas income $F4$	Gross profit ratio
		Overseas income growth ratio
		Overseas income
	Innovation output $F5$	Patents granted
		Patent per capita
	Asset structure $F6$	The operating asset structure
		Intangible asset density
	Shared growth $F7$	Payroll payable
		The revenue growth
	Social responsibility $F8$	Environmental protection awareness
		Social donations
	Innovation input $F9$	Capitalization rates
		Foreign investment

Table 8: Component score coefficient matrix.

	1	2	3	4	5	6	7	8	9
$Q1$	−0.012	−0.067	0.405	0.072	−0.018	0.056	0.026	−0.001	−0.056
$Q2$	−0.015	−0.123	0.328	0.049	−0.021	0.226	0.051	0.012	−0.200
$Q3$	0.025	−0.062	0.051	−0.045	−0.016	0.042	0.039	0.086	0.626
$Q4$	−0.007	0.025	−0.011	−0.044	0.532	0.005	0.013	−0.009	0.002
$Q5$	0.009	0.005	−0.040	0.003	0.535	−0.040	−0.017	0.019	0.029
$Q6$	−0.034	0.103	−0.100	−0.008	−0.006	0.564	0.019	0.002	−0.077
$Q7$	0.092	−0.410	0.186	−0.069	0.005	−0.131	−0.054	−0.040	−0.094
$Q8$	0.043	−0.062	−0.026	−0.081	−0.009	0.437	−0.090	0.023	0.228
$Q9$	−0.066	0.412	−0.007	−0.010	0.025	0.002	0.048	0.004	−0.091
$Q10$	−0.030	0.393	0.029	−0.008	0.015	−0.121	0.022	−0.008	−0.018
$Q11$	0.052	−0.018	−0.358	0.047	−0.008	0.295	0.081	0.021	−0.126
$Q12$	0.112	0.061	0.248	−0.055	−0.026	−0.086	−0.045	−0.005	0.175
$Q13$	0.298	−0.002	−0.044	0.002	0.001	0.025	−0.079	0.004	0.002
$Q14$	0.326	−0.096	−0.057	−0.001	0.002	0.044	−0.090	0.005	0.017
$Q15$	0.081	−0.074	−0.019	−0.008	0.001	0.051	0.409	−0.066	−0.052
$Q16$	0.160	−0.089	0.024	−0.015	−0.002	−0.025	0.203	−0.050	0.009
$Q17$	0.291	−0.002	0.037	−0.017	0.005	−0.048	−0.130	−0.017	0.054
$Q18$	−0.012	0.022	0.058	0.453	−0.018	−0.067	0.030	0.023	−0.026
$Q19$	−0.011	0.005	0.024	0.507	−0.026	−0.036	−0.126	0.056	−0.027
$Q20$	0.021	0.108	−0.176	0.243	0.038	−0.018	−0.038	−0.181	0.478
$Q21$	−0.060	0.079	−0.056	−0.039	0.028	0.017	0.120	0.687	0.271
$Q22$	−0.133	0.121	−0.005	−0.078	0.002	−0.084	0.715	0.043	0.104
$Q23$	0.012	−0.046	0.055	0.073	−0.018	0.016	−0.120	0.604	−0.251

is relatively consistent, and the calculated weights are valid. According to the calculation results of Yaahp 10.0 software, the high-quality development index of real enterprises ($F-2$) based on AHP is obtained. The formula is as follows:

$$F-2 = 0.205F_1 + 0.177F_2 + 0.164F_3 + 0.108F_4 + 0.113F_5 + 0.073F_6 + 0.062F_7 + 0.056F_8 + 0.044F_9. \quad (2)$$

4.3.3. Final Calculation of Factor Weights. The weights of the influencing factors affecting the high-quality development of real enterprises are determined using the comprehensive weight model of factor analysis and AHP, and the final factor weights are obtained by calculating the arithmetic mean of the two methods, as shown in Table 9.

The Kendall-W coordination coefficient is used for consistency testing to ensure the consistency of the weights calculated by the factor analysis and AHP. The results

Table 9: Factor weights.

Factor	Weights under factors analysis	Weights under AHP	Final weights
$F1$	0.204	0.205	0.204
$F2$	0.128	0.177	0.153
$F3$	0.128	0.164	0.146
$F4$	0.115	0.108	0.111
$F5$	0.110	0.113	0.111
$F6$	0.093	0.073	0.083
$F7$	0.084	0.062	0.073
$F8$	0.070	0.056	0.063
$F9$	0.068	0.044	0.056
Total	1.000	1.000	1.000

Table 10: Indicator descriptive statistics.

	N	Mean	Sd	Min	Max
$F1$	1969	−0.21	0.21	−1.26	0.44
$F2$	1969	1.03	0.89	−0.36	5.94
$F3$	1969	−0.09	0.92	−4.00	1.15
$F4$	1969	6.39	5.66	−0.50	17.59
$F5$	1969	0.09	0.77	−0.76	3.21
$F6$	1969	−0.33	0.49	−1.54	1.73
$F7$	1969	−0.57	1.37	−3.53	4.67
$F8$	1969	1.28	1.97	−3.44	11.91
$F9$	1969	0.30	2.54	−2.91	10.69
HQD	1969	0.85	0.57	−0.03	2.34

Table 11: Top 10 enterprises.

Company	HQD
Juhua Co., Ltd	2.34
Intretech	2.33
ESTUN	2.26
Bright dairy	2.25
Xin'an Co., Ltd	2.23
Topstar	2.23
SJ environmental protection	2.33
Hytera	2.20
Runtu Co., Ltd	2.19
Joincare	2.18

obtained from SPSS 26.0 show that the asymptotic 2-sided significance p value $= 0.044 < 0.05$. Hence, the null hypothesis that the Kendall-W is 0 does not hold, and the weighting results calculated by the two methods are consistent. Meanwhile, Kendall-W is 0.992, greater than 0.8 and close to 1, indicating a high level of consistency between the weight results calculated by the two methods and that the data results are credible. The final factor weights are the arithmetic average of the weights obtained from the two methods, thus the formula for the high-quality development index of real enterprises (HQD) is

$$\begin{aligned} \mathrm{HQD} = {} & 0.204F_1 + 0.153F_2 + 0.146F_3 + 0.111F_4 \\ & + 0.111F_5 + 0.083F_6 + 0.073F_7 + 0.063F_8 + 0.056F_9. \end{aligned} \tag{3}$$

4.4. Analysis of the Current Situation Based on the HQD

4.4.1. Descriptive Analysis. The 2020 China Shanghai and Shenzhen A-share real enterprises HQD index is obtained based on formula (3), which is positively correlated with the degree of high-quality development of the enterprises. Table 10 presents the results of descriptive statistics of each factor and the HQD index for the 1969 real enterprises. In 2020, the mean of the high-quality development index of real enterprises in the range of −0.03 to 2.34 is 0.85, indicating that there are differences in the HQD index among them. Although the average value of the HQD index of these 1969 enterprises is greater than 0, which reflects the overall good development status of Chinese real enterprises, it can be seen that the HQD index is at a lower level, so the high-quality development of Chinese real enterprises needs to be further promoted. Analysis of the descriptive statistics of factors reveals that the standard deviation of "overseas income $F4$" is the largest, indicating that the differences in the high-quality development of Chinese 2020 real enterprises mainly stem from the differences in overseas income. Meanwhile, the standard deviations of "innovation investment $F9$," "social responsibility $F8$" and "shared growth $F7$" also indicate some differences among Chinese real enterprises in these three aspects.

4.4.2. Analysis of the Top 10. Table 11 shows the top 10 companies in the HQD Index. Among them, four companies, including Juhua Co., Ltd (600160), Xin'an Co., Ltd (600596), SJ Environmental Protection (300072), and Runtu Co., Ltd (002440), belong to the chemical industry. Intretech (002925) and Hytera (002583) belong to the industry of computer, communications, and other electronic equipment manufacturing. The ranking of each factor corresponding to different entity enterprises is not completely consistent with the final ranking. The development of these enterprises is unbalanced in each factor affected, which in turn affects the comprehensive ranking.

4.4.3. Subindustry Analysis of HQD Index. After calculating the mean value of the HQD index of real enterprises according to the industry classification, the top 5 industries in 2020 are the research and development industry (M73),

mining auxiliary activities industry (B11), Internet and related services industry (I64), cultural and educational, industrial, sports and entertainment supplies manufacturing industry (C24), as well as the textile industry (C17). The bottom rankings are the accommodation industry (H61), broadcast, television, film, and video recording production industry (R86), public facilities management industry (N78), press and publishing houses (R85), and road transportation (G54). There are differences in the development status among industries, with maximum and minimum mean values of 1.55 and 0.10, respectively. At the same time, it can be seen that the average of HQD index of each industry is greater than 0, indicating the steady development of the Chinese real industry in 2020 and a bright future for the real economy. Under the crisis of the US-China trade war and Covid-19, the Chinese real economy withstood the heavy pressure and still achieved notable results.

4.4.4. Regional Analysis of HQD Index. The 31 provincial-level regions in the Chinese mainland are divided into three major regions, including the eastern, central, and western regions. Among them, the eastern region has the largest HQD index with an average of 0.91, the lowest in the western region is 0.63, and the central region is 0.71. Therefore, there are differences in the average HQD index in different regions, which is consistent with the current situation of Chinese regional development. The uneven distribution of Chinese geographical resources has caused different development conditions in each region, manifesting as the most developed in the eastern regions, followed by the central regions, and more backward in the western regions.

5. Conclusion

High-quality development is a new paradigm of entity enterprise development, a model for real enterprises to pursue higher-level economic and social value creation, as well as a new development state of continuous growth. Thus, high-quality development is a comprehensive target for real enterprises to achieve high-quality innovation development, financial information, benefit creation, and green sharing. Following the principles of science, systems, dynamics, and data availability, the evaluation index system for the high-quality development of real enterprises is constructed by selecting the basic indicators. These include 4 primary indicators, 11 secondary indicators, and 23 tertiary indicators. Firstly, the common factors are extracted and named by the factor analysis method, and the hierarchical structure model for high-quality development evaluation of real enterprises is reconstructed. Secondly, the weight of each common factor is calculated using the factor analysis and AHP, followed by taking the arithmetic average of the two as the final common factor weight to obtain the HQD index. Finally, the HQD index of Chinese in 2020 is calculated and analyzed.

The empirical results show that the factors of profitability, solvency, innovation, and operations have a greater impact on the HQD than others. High-quality financial information is an important manifestation of the high-quality development of real enterprises. Meanwhile, innovation is the power source for the high-quality development of real enterprises, and only innovation-driven development is provided with vitality. The HQD index of 1,969 Chinese real enterprises in 2020 is further calculated with a mean value greater than 0, indicating that the development of real enterprises is in good condition. However, the generally low indices also indicate that the high-quality development of Chinese real enterprises remains to be further promoted. Moreover, the development status varies among different enterprises, industries, and regions.

The following policy recommendations are proposed to promote high-quality development and give full play to the role of government.

The first is to strengthen policy pertinence, focus on targeted regulation, and increase support for the real economy. For enterprises with disadvantaged development status, the government can appropriately strengthen financial and tax support. For the western and central regions with relatively backward development, the government can increase resource adjustment. In this way, the rich-poor gap between real enterprises in different industries and regions will be narrowed, and high-quality development will be steadily promoted.

The second is to insist that "innovation is the primary force guiding development" and that "talent is the first resource" and adhere to an innovation-driven development strategy. The innovation capacity of real enterprises should be enhanced to support and lead high-quality economic development with high-tech innovation. Innovation-driven is actually talent-driven, so further improvement of the mechanism for cultivating and motivating talent is needed. Meanwhile, enterprises are the main body of innovation, whose innovation incentives, policy guidance, and development environment should be optimized.

The last is to take financial sustainability as the basic requirement for sustainable and healthy development. The quality of financial information is mainly evaluated on asset structure, solvency, operating ability, profitability, and development ability. Timely and high-quality financial information reporting will further promote the healthy development of enterprises. Hence, it is of great significance in the evaluation of the high-quality development of real enterprises.

Data Availability

The company-level data in this paper are from the CSMAR database (https://www.gtarsc.com/csmar).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of the paper.

Authors' Contributions

J.W. and L.Z conceptualized the study; J.W. was in charge of methodology, validation, investigation, data curation, and

analysis; J.W., X.G., and R.J were in charge of software and resources; J.W. prepared the original draft; J.W. and X.G reviewed, edited, and visualized the paper; L.Z. supervised the work and acquired the funds; and J.W. and L.Z. handled project administration. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

This research was funded by the National Social Science Found of China (grant number 15AZD006).

References

[1] S. Limin and M. Xiangwen, "Construction of evaluation index system for high-quality economic development," *Statistics and decision*, vol. 38, no. 02, pp. 36–40, 2022.

[2] S. Yang and L. Xianjun, "The theoretical connotation and evaluation system of high-quality economic development under the new development pattern," *Guizhou social sciences*, vol. 11, pp. 120–129, 2021.

[3] L. Qiang, "Construction and measurement of high-quality economic development evaluation index system," *Statistics and decision*, vol. 37, no. 15, pp. 109–113, 2021.

[4] W. Wei, "Study on the construction and measurement of the evaluation system of China's high-quality economic development," *Ningxia social sciences*, no. 06, pp. 82–92, 2020.

[5] S. Yongwei and C. Chibo, "Construction and demonstration of evaluation index system for high quality economy development," *Statistics and decision*, vol. 35, no. 24, pp. 38–41, 2019.

[6] H. Cui, H. Wu, and Y. Zhu, "Construction and practice of evaluation index system for high-quality development of service industry," *Taxation and economy*, vol. 01, pp. 85–91, 2022.

[7] D. Guorui, "Yu Liang. Construction and measurement of manufacturing high-quality development evaluation system: a case study of Shandong Province," *Statistics and decision*, vol. 37, no. 18, pp. 99–102, 2021.

[8] Yu Ting and Yu Fawen, "Evaluation of agricultural high-quality development and diagnosis of obstacle factors based on entropy weight TOPSIS method," *Social Sciences in Yunnan*, vol. 05, pp. 76–83, 2021.

[9] X. Ling, "An Xiaoning. Construction and empirical analysis of agricultural high-quality development evaluation system in China," *Economic Review Journal*, vol. 05, pp. 109–118, 2019.

[10] W. Yao, "Huang Xianhuan. The index system construction and realization path of enterprise high-quality development," *Statistics and decision*, vol. 37, no. 12, pp. 182–184, 2021.

[11] Li Jingming and Z. Zeyu, "Construction and demonstration for evaluation index System of state-owned enterprises' development quality," *Statistics and decision*, vol. 37, no. 12, pp. 166–169, 2021.

[12] Z. Jianjun, "Hu Youlin. Research on evaluation index system of high-quality development of local state-owned enterprises," *Social Sciences in Hunan*, vol. 06, pp. 58–63, 2021.

[13] H. Sujian, "Xiao Hongjun, Wang Xin. Study on high-quality development of the state-owned enterprises," *China industrial economics*, vol. 10, pp. 19–41, 2018.

[14] H. Qunhui, "On the development of China's real economy at the new stage," *China industrial economics*, vol. 09, pp. 5–24, 2017.

[15] Li Ping and Fu Yifu, "Can the productive service industry become new momentum for China's economic growth," *China industrial economics*, vol. 12, pp. 5–21, 2017.

[16] J. Bei, "Study on the "high-quality development" economics," *China industrial economics*, vol. 1, no. 04, pp. 5–18, 2018.

[17] W. Zhuquan, J. Weiying, S. Xiaobin, and S. Wu, "High-quality development and comprehensive evaluation on macro accounting information quality of China," *Accounting research*, vol. 38, no. 04, pp. 39–48, 2021.

[18] Z. Yongji, "Meng Qingbin. Expected inflation and corporate assets sructure," *Accounting research*, vol. 52, no. 07, pp. 27–34, 2016.

[19] B. W. Ambrose and W. L. Megginson, "The Role of Asset Structure, Ownership Structure, and Takeover Defenses in Determining Acquisition Likelihood," *The Journal of Financial and Quantitative Analysis*, vol. 27, no. 4, pp. 575–589, 1992.

[20] M. Campello, E. Giambona, A. Real, and C. Structure, "Real Assets and Capital Structure," *Journal of Financial and Quantitative Analysis*, vol. 48, no. 5, pp. 1333–1370, 2013.

[21] Z. Xinmin, "Zhu Jigao. Does operating asset structure affect the value of high goodwill firm? Evidence from A-share listed companies," *Nankai Business Review*, vol. 22, no. 02, pp. 114–127, 2019.

[22] F. Demir, "Financial liberalization, private investment and portfolio choice: Financialization of real sectors in emerging markets," *Journal of Development Economics*, vol. 88, no. 2, pp. 314–324, 2009.

[23] Du Yong and X. Jin, "Chen jianying. CEO's financial background and the financialization of entity enterprises," *China Industrial Economics*, vol. 5, pp. 136–154, 2019.

[24] C. Junyi, "Zhou Yuanyuan, Zhu Xi'an. An empirical test of the relationship between the CEO's financial background and asset financialization in real enterprises," *Statistics & Decisions*, vol. 38, no. 06, pp. 164–168, 2022.

[25] F. Mingyue, "The impact of regional institutional quality on firms' asset structure in China," *Comparative economic and social systems*, vol. 04, pp. 156–165, 2018.

[26] W. Zhibo, "Li Changbong. The impact of asset-light operation on corporate profitability: an empirical study based on the data of Chinese industrial enterprises," *China industrial economics*, vol. 06, pp. 108–121, 2015.

[27] Z. Chengsi, "Zhang Butan. The falling real investment puzzle: a view from financialization," *Economic Research Journal*, vol. 51, no. 12, pp. 32–46, 2016.

[28] Du Yong and Z. Huan, "Chen Jianying. The impact of financialization on future development of real enterprises' core business: promotion or inhibition," *China industrial economics*, vol. 12, pp. 113–131, 2017.

[29] W. Hongjian, Cao yuqiang, Y. Qing, and Z. Yang, "Dose the financialization of non-financial enterprises promote or inhibit corporate innovation," *Nankai Business Review*, vol. 20, no. 01, pp. 155–166, 2017.

[30] Li Xiangchun and S. Yu, "Yao Peng. Combination evaluation on the social benefit of urban public infrastructure: a case study of Tianjin," *Modern Urban Research*, vol. 03, pp. 22–29, 2017.

[31] S. Yichi, *The Financial performance*, Liaoning University, Shenyang, 2011.

[32] Li Xuhui, "The research on the evaluation model and empirical analysis of the level of humanities and social sciences development based on the AHP and entropy methods in economic universities," *Science and technology management research*, vol. 36, no. 20, pp. 53–58, 2016.

[33] L. Liping and J. Yuqing, "Li Jinshegn. Evaluation on enterprise technological innovation capability based on combination weighting method," *Statistics and decision*, vol. 13, pp. 176–179, 2017.

[34] M. Zongguo and L. Cao, "Construction and measurement of manufacturing enterprises high-quality development evaluation system-based on the data of 1881 listed companies from 2015to2018," *Science & Technology Progress and Policy*, vol. 37, no. 17, pp. 126–133, 2020.

[35] S. Zhidong, "Analysis of analytic hierarchy process to build a state-owned enterprises evaluation system," *Auditing Research*, vol. 02, pp. 106–112, 2013.

[36] C. Guotai, "Zhu Zhichuan, Zhang Yuling. The science and technology evaluation model based on entropy and G1 and empirical research of China," *Studies in science of science*, vol. 26, no. 06, pp. 1210–1220, 2008.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4082137, 10 pages
https://doi.org/10.1155/2022/4082137

Research Article

Mechanisms of Agricultural Land Transfer Influence on the Urban Settlement Intention of Rural Floating Population in China

Yu Xie,[1] **Yin Yao**,[1] **Bingbing Zhang**,[1] **Xiongying Chen**,[2] **Xinyu Wang**,[2] **Tsang-Kai Hung**,[3] **and Zijun Wang**[3]

[1]*School of Management, Beijing Union University, Beijing 100101, China*
[2]*Institute of Human Resource Management, Beijing Union University, Beijing 100023, China*
[3]*National Changhua University of Education, Changhua 50007, Taiwan*

Correspondence should be addressed to Xinyu Wang; wxy006@buu.edu.cn

Received 26 May 2022; Revised 26 June 2022; Accepted 29 August 2022; Published 12 September 2022

Academic Editor: Lele Qin

In order to promote the citizenship of China's rural floating population and improve the level of new urbanization, as an important source of property income for rural floating population, the transfer of agricultural land or not has an important impact on whether they choose to return to their hometowns or settle in cities. Based on data from the 2017 China Migrants Dynamic Survey (CMDS), this paper explores the mechanism of the impact of agricultural land transfer on the urban settlement intention of rural floating population by constructing a structural equation modeling and bootstrap test. The results show that agricultural land transfer has a significant positive impact on the urban settlement intention of rural floating population, with occupational prestige and identity recognition playing a part in mediating the effect. Actively promoting the identification and orderly transfer of agricultural land rights, improving the quality of urban employment for rural floating population by strengthening vocational skills training, and accelerating the equalization of urban public services to enhance the identity recognition of rural floating population are important in promoting the orderly and effective integration of rural floating population into cities and their genuine citizenship.

1. Introduction

The China 2022 Government Work Report proposes to promote a new type of urbanization with people as the core and improve the quality of urbanization. The primary task of promoting new-type urbanization is to accelerate the civilization of the agricultural population who transfer from rural areas to urban areas [1]. China's rural floating population generally refers to those rural-to-urban migrants without official transfer of household registration status (Wang et al. 2010 [2], and Huang et al., 2020 [3]), and their urban settlement intention directly affects the development process of China's new-type urbanization level. According to the data of the seventh national census released by the National Bureau of Statistics, the total floating population in China is 375.82 million, among which the rural floating population accounts for about 45%. The influx of a large number of rural floating populations into cities has rapidly advanced the level of urbanization and also changed the urban-rural structure and regional development pattern to a large extent (Xiao et al., 2021) [4]. The rural floating population settling in cities has played an important role in promoting changes in the social structure and accelerating the urbanization process in China [5].

Agricultural land is the most important source of property for rural floating population [6]; its transfer or not has an important impact on whether rural floating population choose to return to their hometowns or settle in cities, after the influx of rural floating population to cities [7]. In order to improve the efficiency of land resources utilization and accelerate the construction of new urbanization, the Chinese government has also taken multiple measures to promote the transfer of agricultural land, as stated in China Central Government's Document No. 1 in 2021 and 2022,

respectively, "to promote the construction of modern agricultural operation systems and encourage the development of various forms of moderate scale operations" and "to carry out a pilot project to standardize the construction of a market for the transfer of rural property rights." The movement of the rural population to cities and nonagricultural industries is an inevitable trend in China's socioeconomic development process and an important fulcrum for urbanization in China (Zhuang 2021 [8]; Li 2022 [9]). In the continuous construction of new urbanization, the research on the relationship between agricultural land transfer and rural population's urban settlement intention has also received more and more attention from scholars. By combing through the relevant literature, it is found that scholars have mainly focused on the impact of rural labor migration on land transfer. He [10] argues that agricultural labor migration is the initial motivation for land transfer. And with the advent of the Lewis turning point, modern factors of production such as capital and technology continue to transfer to the rural areas, Liu and Zhang [11] proposed that the transfer of agricultural land also affects rural labor mobility in reverse, and the higher the degree of agricultural land transfer, the stronger the tendency of citizenship of rural floating population (Zhao et al. 2016 [12]; Du et al., 2018 [13]), and Li et al. [14] measured that for every 1% increase in the degree of agricultural land transfer, the rural population's urban settlement intention increases by 0.777 percentage points accordingly. Furthermore, some scholars have shown that after transferring their agricultural land, rural floating population are more inclined to enter the city to work in nonagricultural industries [15], and their occupational prestige is enhanced after entering nonagricultural industries compared to working in agriculture [16], and at the same time, in the city, rural floating population broaden their horizons and have more opportunities to contact new things and understand new knowledge, and their human capital level can be improved to a certain extent [17], which helps them enter higher-level occupations and promotes occupational prestige; after gaining higher occupational prestige, it also enhances rural floating population's intention to live in the city for a long time and promotes the process of citizenship of rural floating population [18].

Several scholars have shown that agricultural land transfer can contribute to the occupational prestige of rural floating population in different ways. On the one hand, the transfer of agricultural land implies that farmers' ties to the land are minimized for the time that the contract stipulates the transfer [12], which enhances farmers' tendency to nonfarm and promotes their entry into nonfarm jobs [15]. On the other hand, agricultural land transfer can make poor rural household members more inclined to work in cities or enter public administration by promoting their human capital level [19]. At the same time, farmers invest more in human capital to better access nonagricultural jobs and to pursue higher status and income level occupations [18], all of which are conducive to improving rural floating population's occupational prestige. When rural floating population has entered the cities and achieved nonfarm employment as well as urban-rural and sectoral transfers, this does not guarantee the smooth integration of rural floating population into cities [20]. Western studies on immigrant assimilation theory have shown that how to adapt and integrate into the local social environment is the primary problem faced by immigrants after moving in [21]. Identity recognition responds to the degree of immigrants' integration in the place of migration [22]. In the process of social integration of rural floating population, through the continuous interaction with local residents in terms of life and work, rural floating population form their urban identity recognition, which in turn affects their willingness to settle and become citizens in the city [23]. Therefore, after rural floating population transfers their agricultural land out, improving their occupational prestige and enhancing their identity recognition play an important role in promoting their urban settlement intention.

Previous studies have focused more on the impact of agricultural land transfer on the urban settlement intentions of rural floating population, quantifying the extent to which agricultural land transfer affects the urban settlement intentions of rural floating population. According to the push-pull theory, the urban settlement intentions of rural floating population will be influenced not only by the rural push of the land transfer that weakens their attachment to the land but also by the pull effect of the city on their urban settlement [24]. As mentioned earlier, occupational prestige and identity recognition play an important role in attracting rural people to settle in cities and determine the stability of urban settlement and the quality of urban integration. However, the effects of occupational prestige and identity recognition on rural floating population's urban settlement intentions under the agricultural land transfer decision are unclear. It is necessary to clarify the relationship between the agricultural land transfer decision, occupational prestige, identity recognition, and rural floating population's urban settlement intentions and to examine the extent of the effects of occupational prestige and identity recognition. Based on this, this paper selects the data from the 2017 China Migrants Dynamic Survey (CMDS) to explore the impact of agricultural land transfer on rural floating population's urban settlement intention and introduces occupational prestige and identity recognition as mediating variables to analyze the mechanism of the impact of agricultural land transfer on rural floating population's urban settlement intention. The purpose of this study is to provide a reference for promoting the rational transfer of agricultural land, promoting the citizenship of rural floating population, and improving the new urbanization level.

2. Literature Review and Hypothesis Development

2.1. Agricultural Land Transfer and Urban Settlement Intention. To settle in cities, rural floating population associated with land must first have the will to settle in cities, and secondly, they should have some ability to support their urban settlement. Traditionally, the land is the "lifeblood" of farmers, and farmers are tightly linked to it [25]; therefore, this part of the rural floating population has a low intention

to settle in cities. In the context of agricultural land rights, the transfer of agricultural land has reduced the excessive bondage of land to the rural floating population and also eliminated the psychological cost of farmers' land attachment to a certain extent by retaining their land contracting rights [12], which have promoted the tendency of non-agriculturalization of the rural floating population, and has improved farmers' part-time status of "farming in busy times and working in idle times" [26]. Based on the increased leisure time after the agricultural land is transferred out, the rural floating population will choose to move to the city to obtain more economic income and a better living environment [27]; therefore, agricultural land transfer improves the motivation of the rural floating population to move to the city, enhances their willingness to citizenship and urban integration opportunities, and makes the rural floating population more inclined to settle in the city. Based on this, the following hypothesis is proposed.

H1: There is a significant direct positive effect of agricultural land transfer on rural floating population's urban settlement intention.

2.2. The Mediating Role of Occupational Prestige. Occupational prestige is a subjective evaluation of various occupations and is a measure of social prestige (Treiman 1976 [28]; Inkeles and Rossi 1956 [29]). After rural floating population transfers their agricultural land, their connection with the land is weakened; they are "liberated" from the bondage of the land; there is no more agricultural labor; farmers have more free time; and they also reap a certain amount of transfer rent, which to a certain extent will also enhance their tendency to invest in human capital [19]. Their propensity to nonfarm will be enhanced to some extent; in order to obtain higher nonfarm income, they will be more willing to enter nonfarm industries to find jobs [30], and nonagricultural industries generally have higher occupational prestige scores than agriculture-related occupations [16], so entering nonfarm jobs is beneficial to the occupational prestige of rural floating population. Further research found that the transfer of agricultural land prompted farmers to go out to work in cities, and by living in cities and working in secondary and tertiary industries, rural floating population also acquired new knowledge, new ideas, and new concepts, which contributed to the improvement of human capital levels of rural floating population [11]. With an increased level of human capital, they will continue to strive to enter higher-level occupations [31] and obtain higher employment income, which in turn also facilitates their acquisition of higher occupational prestige. Based on this, the following hypothesis is proposed.

H2: There is a significant positive effect of agricultural land transfer on the occupational prestige of rural floating population.

Lu [32] proposed that occupational division can be used as the basis to classify the corresponding social classes using the possession status of organizational, economic, and cultural resources as criteria, and the resources that individuals can master through their own occupations can be expressed in the form of elements of human capital such as skills and knowledge and can be translated into factors that determine the level of occupational prestige, such as dominance, power, income, and so on [33]. According to Xu [34], the criteria that determine the level of occupational prestige are proximity to political authority, job stability, and opportunities for promotion. Regardless of the viewpoint, occupational prestige can, to some extent, reflect the socioeconomic status possessed by an individual [35], and the socioeconomic status of rural floating population in turn affects their urban settlement intention [36]. At the same time, the increase in occupational prestige can also bring certain social reputation to the rural floating population and strengthen their ties with the local area [37], which makes their relationship with the city stronger and has a strengthening effect on their ability and willingness to settle in the city [38]. Based on this, the following hypothesis is proposed in this paper.

H3: There is a significant positive effect of occupational prestige on the rural migrant population's urban settlement intention.

In summary, this paper further infers that there is a mediating role of occupational prestige in the relationship between agricultural land transfer and rural floating population's urban settlement intention. Therefore, this paper proposes the following hypothesis.

H4: Occupational prestige plays a mediating role in the relationship between agricultural land transfer and rural floating population's urban settlement intention.

2.3. The Mediating Role of Identity Recognition. Identity recognition reflects the degree of integration of rural floating population in the city [22] and is the highest level of urban integration of rural floating population [39]. "Push-pull theory" suggests that migration is the result of the interaction of two forces (Lee, 1966 [40]; Cohen and Robinson 1996 [41]), where socioeconomic conditions that are not conducive to the realization of individual values in the outflow location become push forces and those factors that are conducive to the improvement of living conditions and the enhancement of personal growth space in the inflow areas become pull forces [42]. After rural floating population transfer their agricultural land, their personal development space will be limited to a certain extent in rural areas [43], while a better living environment and more employment opportunities in cities will "pull" rural floating population into cities [44]. At the same time, in the past, due to the need to carry out farming work, rural floating population were unable to stay in the city to live and work for a long time, and the degree of urban integration was low. After the transfer of agricultural land, rural floating population can reduce their behavior of pendulum movement between urban and rural areas [12], and the weakening of ties with the countryside increases the possibility of rural floating population working and staying in the city for a long time, which in turn is conducive to promoting rural floating population's integration into cities [45]. In summary, the transfer of agricultural land has contributed to the improvement of their

urban identity recognition. Based on this, the following hypothesis is proposed in this paper.

H5: There is a significant positive effect of agricultural land transfer on the urban identity recognition of rural floating population.

There are differences in the urban settlement intention of rural floating population under recognition of different identities [46], and in the process of urban migration, identity recognition plays an important role in maintaining their psychological security and preventing identity anxiety, and so on. Once they feel rejected by the urban society they live in, rural floating population will develop a "nomadic" identity recognition, develop a sense of marginalization, and fail to integrate into the local society [22]. Only when rural floating population identify with their urban identity and develop a strong sense of emotional attachment and belonging to the local community can they be considered to have achieved urban integration [47]. Related studies have also found that respect and identity recognition can lead to more optimistic emotions and thus more positive integration into the group [48]. The respect and recognition that rural floating population receive in urban life and work determine whether they will develop an emotional attachment and a sense of belonging to the city where they live, which directly affects whether they are willing to truly integrate into the city and affects the willingness of rural floating population to settle in the inflow city. Based on this, the following hypothesis is proposed in this paper.

H6: Identity recognition positively affects rural floating population's urban settlement intention.

In summary, this paper further infers that identity recognition plays a mediating role in agricultural land transfer and urban settlement intention. Therefore, this paper proposes the following hypothesis.

H7: Identity recognition plays a mediating role between agricultural land transfer and rural floating population's urban settlement intention.

Based on the above theoretical analysis and research hypotheses, this paper constructs a model of the influence mechanism of agricultural land transfer on urban settlement intention (Figure 1).

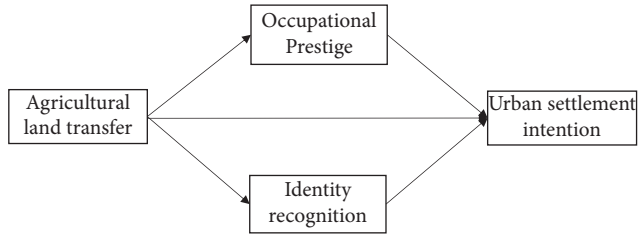


Figure 1: Model of the influence mechanism of agricultural land transfer on urban settlement intention.

3. Research Design

3.1. Data Sources. This paper uses data from the 2017 China Migrants Dynamic Survey (CMDS) organized by the National Health and Wellness Commission, which takes mobile population aged 15 years or older who have lived in the inflow area for more than 1 month and are not registered in their own district (county or city) as the target population, and uses a stratified, multistage, proportional to size (PPS) sampling method to investigate the basic personal characteristics, family members, employment and income and expenditure, social integration, family planning, basic public health, and so on that were investigated in detail with wide coverage and large sample size, which is highly representative. Since the group of interest in this paper is the rural floating population, only the sample of rural household registration is retained. After eliminating the missing values and errors of variables, we finally obtained 50,765 valid samples, which meet the research needs of this paper.

3.2. Variable Measurements. Urban settlement intention. The questionnaire was measured by the questions contained in the "intention to move and stay" section, according to the question "Do you plan to stay in the local area?" The respondents who answered "Yes," "No," and "I do not think about it" were selected and asked, "If you intend to stay in the local area, how long do you expect to stay in the local area?" The respondents who answered "6 ~ 10 years," "more than 10 years," and "settled" were assigned a value of 1 as they had the intention to settle in the city, while those who answered "1 ~ 2 years," "3–5 years," and "not sure" were assigned a value of 0 as they had no intention to settle in the city.

Agricultural land transfer. The questionnaire asked the respondents, "Who is cultivating your contracted land?" The answers were "own farming," "hired farming," "family and friends farming," "subleasing to private individuals," "subleasing to enterprises," "subleasing to village collectives," "abandoning," "planting trees," and "others." Referring to Li et al. [14], subleasing to private individuals, subleasing to enterprises, and subleasing to village collectives with the nature of market transactions are considered agricultural land transfer [14] and assigned a value of 1. The other options are considered as nonagricultural land transfer and assigned a value of 0.

Occupational prestige. Li [16] conducted a nationwide study, which resulted in an occupational prestige scale containing 81 occupations [16]. In this study, the scale measured by Li was used to assign a corresponding occupational prestige score to each rural floating population's occupation as a measure of the variable.

Identity recognition. The degree of identity recognition of rural floating population was measured by the questions included in the "social integration" section of the questionnaire, including the questions "Do you agree with the statement 'I feel I am already a local'?" "Do you agree with the statement 'I feel that the locals are willing to accept me as one of them'?" and so on to measure the degree of identity recognition, and the response options include "do not agree at all," "disagree," "basically agree," and "completely agree" were assigned a score of 1 to 4, respectively, and the average value was obtained by summing up the responses. The higher the score, the higher the degree of identity recognition. The sample definition of main variables and descriptive statistics are shown in Table 1.

Table 1: Definition of main variables and descriptive statistics.

Variable name	Variable type	Mean/percentage	Standard deviation	Description
Urban settlement intention	Categorical variable	Intention to settle in the city = 46.5%; No intention to settle in the city = 53.5%	0.499	1 = Intention to settle in the city 0 = No intention to settle in the city
Agricultural land transfer	Categorical variable	Selected agricultural land transfer = 14.5% Did not select agricultural land transfer = 85.5%	0.352	1 = Selected agricultural land transfer 0 = No choice of agricultural land transfer
Occupational prestige	Continuous variable	39.562	9.962	Range of values (0, 100)
Identity recognition	Continuous variable	3.12	0.404	Range of values [1, 4]

3.3. Research Methods. In this paper, structural equation modeling was used to test the research hypotheses. Unlike using cascade regression to analyze each path individually, structural equation modeling can include all latent and measured variables into the pooled regression model for analysis at one time, and it can also control and reduce the errors caused by measured variables and avoid miscalculation of direct and mediating effects, thus enabling more accurate and unbiased estimation results [49]. In previous studies, the Sobel test is usually used to test the significance of the mediating effect. However, the prerequisite assumption of the Sobel test is that the mediating effects obey a normal distribution, and such an assumption is generally not satisfied in practical studies [50]. Therefore, when the mediating effect does not follow a normal distribution or the distribution cannot be determined, the use of the bias-corrected bootstrap method can effectively reduce the probability of the first type of statistical error (discard error) when compared to other tests such as the Sobel test. The bias-corrected bootstrap method also yields more robust and precise confidence intervals for the mediation effect, which has better statistical validity.

In summary, this paper follows the procedural approach suggested by Preacher and Hayes [51] and MacKinnon et al. [52] to validate the mediating effect and assess the significance level of the magnitude of the mediating effect, based on the validation and estimation procedures proposed by Baron and Kenny [53]. In the first step, only the independent and dependent variables are put into the research model to verify the direct utility between them, and the model will show the path coefficients and whether they have direct utility; in the second step, all variables related to direct and indirect effects are added to the model, and the significance of the path coefficients between the variables is estimated by building a structural equation model; in the third step, using bootstrap resampling technique, the mediating effect is tested for significance and assess their confidence intervals [54].

4. Research Results

4.1. Correlation Analysis. In this study, the correlation analysis of agricultural land transfer, occupational prestige, identity recognition, and urban settlement intention was conducted by SPSS 26. The results of the correlation analysis are shown in Table 2. Occupational prestige, identity recognition, and urban settlement intention were all significantly and positively correlated with agricultural land transfer. Meanwhile, urban settlement intention was significantly and positively correlated with occupational prestige and identity recognition, respectively, while identity recognition was not significantly correlated with occupational prestige. The results of the correlation analysis provided support for the subsequent data analysis.

4.2. Hypothesis Testing. To clarify the relationship between agricultural land transfer, occupational prestige and identity recognition, and urban settlement intention, this paper uses Mplus 8.0 software to test research hypotheses using structural equation modeling. Figure 2 shows the results of the path test analysis of the research model with agricultural land transfer as the independent variable and also shows the direct and indirect effects of agricultural land transfer on rural floating population's urban settlement intention (the figure shows the unstandardized path coefficients, and the values in parentheses are standard errors). First, there is a significant direct positive effect of agricultural land transfer on rural floating population's urban settlement intention ($\beta = 0.070$, $p < 0.01$); second, there is a significant positive effect of agricultural land transfer on occupational prestige ($\beta = 0.891$, $p < 0.001$) and a significant positive effect of occupational prestige on rural floating population's urban settlement intention ($\beta = 0.019$, $p < 0.001$). There is a significant positive effect of agricultural land transfer on the urban identity recognition of rural floating population ($\beta = 0.014$, $p < 0.01$); there is a significant positive effect of identity recognition on the urban settlement intention of rural floating population ($\beta = 1.438$, $p < 0.001$). Thus, hypotheses H1, H2, H3, H5, and H6 were supported by verification.

To further test for mediating effects in the model, bootstrap mediating variable tests were conducted in this paper with 5,000 replicate samples and 95% confidence intervals. The confidence interval of each standardized indirect effect does not contain 0, indicating that each mediating effect is significant. The standardized indirect effect

Table 2: Correlation analysis.

Variables	Agricultural land transfer	Occupational prestige	Identity recognition	Urban settlement intention
Agricultural land transfer	1			
Occupational prestige	0.027***	1		
Identity recognition	0.011**	0.003	1	
Urban settlement intention	0.017***	0.071***	0.272***	1

Note: **Significant correlation at the 5% level and ***significant correlation at the 1% level (the same as below).

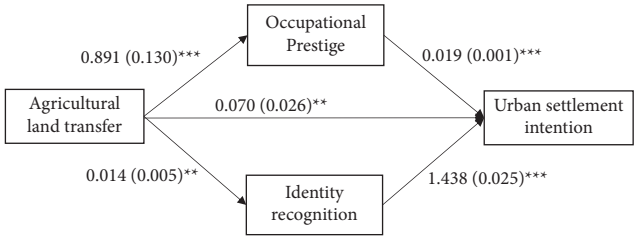


Figure 2: Research model path analysis results.

values, confidence intervals, and relative mediating effects of each mediating variable are shown in Table 3.

The results showed that among the indirect effects of the study model, the mediating effect of occupational prestige between agricultural land transfer and urban settlement intention was significant, with a mediating effect value of 0.017 ($p < 0.001$, 95% confidence interval [0.012, 0.022]); the mediating effect of identity recognition between agricultural land transfer and urban settlement intention was also significant, with a mediating effect value of 0.029 ($p < 0.05$, 95% confidence interval [0.006, 0.034]). Meanwhile, the direct effect of agricultural land transfer on urban settlement intention was significant, with a direct effect value of 0.07 ($p < 0.05$, 95% confidence interval [0.018, 0.122]). Thus, occupational prestige and identity recognition partially mediated the effect between agricultural land transfer and urban settlement intention. Thereby, hypotheses H4 and H7 were supported.

Table 3 also gives the comparison of the two mediating effects of occupational prestige and identity recognition, as well as the direct and indirect effects of agricultural land transfer on urban settlement intention. The results show that the difference between the two mediating effects of occupational prestige and identity recognition is 0.003, with a standard error of 0.677 and a 95% confidence interval containing 0, indicating that there is no significant difference in the magnitude of the two mediating effects. Using the data in Table 3, it can be calculated that the total effect of agricultural land transfer on urban settlement intention is 0.107, the direct effect is 0.070, the indirect effect is 0.037, and the proportion of the indirect effect to the total effect is 34.6%, that is, the mediating effect accounts for 34.6% of the total effect and the direct effect accounts for 65.4% of the total effect in the overall model.

5. Discussion

Summing up the above results, it can be seen that the agricultural land transfer behavior of rural floating population has a significant positive effect on their urban settlement intentions, which is consistent with the findings of Zhao et al. [12], Du et al. [13], and Li et al. [14]. From the perspective of the realistic growth environment and living conditions of the rural floating population, the rural floating population grows up in rural areas and has a certain gap with urban residents in terms of the living environment, infrastructure, and local economic level. After rural floating population transfer their agricultural land out, their own ties to the most important source of property income they own in the countryside are weakened (Li et al. [14]; Fei [25]), and in pursuit of a better living environment and higher income levels, they will tend to enter the cities for engaging in nonagricultural jobs and then live and work in the city for a long time. Nowadays, the new generation of rural migrant workers has gradually become the main body of the rural floating population and the main force of China's new type urbanization construction [55], and in the survey sample of this paper, most of the rural floating population who are willing to settle in cities were born after 1980, and the age distribution is mostly concentrated between 20 and 40 years old, belonging to the new generation of rural floating population, who have the characteristics of young people's openness, optimism, and self-confidence and pay attention to the realization of self-worth [55]. Compared to the older generation of rural floating population, they have a higher propensity to invest in human capital, are more confident in their abilities, and are more accepting of changes in their lives [56], but also due to their general lack of farming experience and land attachment (Corsi and Salvioni, 2017) [57], they are more inclined to transfer their agricultural land to reap certain transfer rents to better support themselves to live and work in the city and have a higher urban settlement intention.

In addition to the direct effect, agricultural land transfer also has an indirect positive effect on urban settlement intentions through two mediating variables: occupational prestige and identity recognition. It has been shown that expected earnings in the city determine the urban settlement decisions of floating population [58] and that the occupation in which an individual works largely determines his or her income level. The proportion of people who would like to settle in the city is significantly higher among the sample who have stayed in the city for more than seven years than other groups. Longer stays in cities lead to higher human capital among rural floating population [59], and the advantages of higher human capital are directly manifested in the ability of rural floating population to enter higher-level occupations, promote their own occupational prestige, and earn higher incomes. The rural floating population who stay

Table 3: Results of the bootstrap test analysis for the significance of the mediation effect.

Path/effect	Bootstrap analysis test results (unstandardized)		Significance (two-tailed P-value)	95% Confidence interval (bootstrap with bias correction)
	Estimated value	Standard error		
C (total effect)	0.107	0.027	0.001	0.054, 0.163
C' (direct effect)	0.070	0.026	0.008	0.018, 0.122
$a1 \times b1$ (mediating effect of occupational prestige)	0.017	0.003	0.001	0.012, 0.022
$a2 \times b2$ (mediating effect of identity recognition)	0.020	0.007	0.005	0.006, 0.034
$a1 \times b1 + a2 \times b2$ (total indirect effect)	0.037	0.008	0.001	0.022, 0.052
$a1 \times b1 - a2 \times b2$ (comparison of indirect effects)	−0.003	0.008	0.677	−0.018, 0.012

longer in the city gain advantages in terms of occupational prestige and economic income, enabling them to meet the material conditions for settling in the city, and also increasing their satisfaction and happiness with urban life. Thus, rural floating population with high occupational prestige will have a stronger urban settlement intention. The marital status of the rural floating population in the sample shows that there are more married people, and the urban settlement intention of this rural floating population is stronger, as verified by other scholars in their studies [60]. The family size of the rural floating population in the sample shows that those who choose to settle in the city tend to have a family size of three to four members, accounting for 34.2% of the total sample. In order to improve the education level of the next generation, most rural floating population choose to migrate in a family-oriented manner, bringing their children to the city together to enjoy the educational resources of the city [61]. As rural floating population live in the city for a longer period of time, they also become more accustomed to the urban lifestyle, and at the same time, their children grow up in the urban environment, the family as a whole has a high degree of urban identity and a low willingness to return to their hometown, so influenced by family decisions, this part of the rural floating population is more inclined to settle in the city. In addition, most of the new generation of rural floating population also want to work in more "decent" jobs in the city and thus gain a higher occupational prestige; therefore, the new generation of rural floating population has a low willingness to return to their hometown and stronger urban settlement intention.

6. Conclusions

Improving the urban settlement intention of the rural floating population is important for promoting a new type of urbanization with people as the core in China. Based on this, this paper uses data from the 2017 China Migrants Dynamic Survey, selects rural floating population as the research object, analyzes the mechanism of the effect of agricultural land transfer on rural floating population's urban settlement intention by combing through the relevant literature, constructs a research hypothesis model, and conducts an empirical test. The results show that first, there is a significant direct positive effect of agricultural land transfer on the urban settlement intention of rural floating population. This result indicates that the higher the degree of agricultural land transfer, the stronger the urban settlement intention of rural floating population. Secondly, in addition to the direct effect, agricultural land transfer also has an indirect positive effect on urban settlement intention through two mediating variables: occupational prestige and identity recognition. Specifically, there are two indirect effects of agricultural land transfer on rural floating population's urban settlement intention: first, it has an indirect positive effect on rural floating population's urban settlement intention by increasing their occupational prestige; the second is through increasing their urban identity recognition, which has an indirect positive effect on their urban settlement intention; and third, the direct effect of agricultural land transfer on rural floating population's urban settlement intention is significantly larger than the indirect effect.

The research findings of this paper are that first, it is necessary to further implement the confirmation of agricultural land rights and the issuance of land contract management certificates to ensure that land ownership is clear. The grassroots government should strengthen the dissemination of knowledge on agricultural land transfer policies to guide the rural floating population to form reasonable expectations and at the same time strengthen the capacity building of arbitration of agricultural land transfer disputes to dispel the rural floating population's concerns about agricultural land transfer, thereby promoting the orderly transfer of agricultural land. Second, increase employment support for key groups among the rural floating population, carry out vocational skills upgrading actions according to the career development needs of the rural floating population, improve the lifelong vocational skills training system, and promote the upgrading of the human capital level of the rural floating population so that they can enter higher-level occupations and improve the quality of their urban employment. Third, accelerate the equalization of public services in towns and cities and realize the extension of public services to the rural floating populations. By increasing the financial budget for rural floating population to use public resources in urban communities, we should give them the opportunity to fully participate in various activities in urban communities, strengthen the communication and understanding between rural floating population and urban residents, increase rural floating population's sense of belonging to the city, and help them truly realize citizenship.

The research limitations of this paper are reflected in the following aspects: first, the new generation of rural floating

population accounts for the majority of the sample with urban settlement intentions. In the future, we should classify the rural floating population by type and carefully analyze the factors affecting the willingness of different types of rural floating population to settle in cities. Second, in the CMDS questionnaire, the options for the urban settlement intention question included "not sure, I do not think about it," and 26.5% of the rural floating population chose this option, and in the process of data analysis, the sample of answering "not sure, I do not think about it" is usually classified as those who have no intention to settle in the city. However, from a practical point of view, this group of people who answer "not sure, I do not think about it" may be the part of the rural floating population who are more confused about their future life and lack planning and are also the group that is easily ignored by various social policies. From the perspective of attracting labor and talent to cities, future studies clarifying the future urban settlement intentions of this group may play a role in promoting the construction of new urbanization.

Data Availability

This paper uses data from the 2017 China Migrants Dynamic Survey (CMDS) organized by the National Health and Wellness Commission. The data used to support the findings of this study are not directly available to the public but are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest with respect to the publication of this paper.

Acknowledgments

This paper was supported by the major project of the National Social Science Foundation of China (no. 19ZDA150) and the Beijing Union University Research Project (no. XP202009).

References

[1] National Development and Reform Commission, "Key tasks of new urbanization and urban-rural integration in 2022," 2022, https://www.gov.cn/zhengce/zhengceku/2022-03/22/content_5680416.htm.

[2] J. W. Wang, Z. T. Cui, H. W. Cui et al., "Quality of life associated with perceived stigma and discrimination among the floating population in Shanghai, China: a qualitative study," *Health Promotion International*, vol. 25, pp. 394–402, 2010.

[3] Y. Huang, W. L. Liu, Y. Zhuo, and X. Y. Sun, "Social insurance participation and urban settlement intentions of China's floating population," *Population, Space and Place*, vol. 26, no. 8, p. e2366, 2020.

[4] L. Q. Xiao, Q. Z. Deng, Y. Q. Lin, and Y. L. Mao, "Research on coordinated development between cultivated land protection and construction land intensive use under the background of new-style urbanization," *Chinese Journal of Agricultural Resources and Regional Planning*, vol. 42, no. 9, pp. 62–71, 2021.

[5] Q. C. Song and Y. T. Gan, "Study on the employment status of working-age migrant population and its influencing factors," *The Social Science Journal*, vol. 4, pp. 63–72, 2021.

[6] G. Z. Li, Y. L. Zhang, and Y. Y. Yi, "The influence of welfare compensation on farmers' willingness of transferring the land into capital," *Journal of Southwest University (Social Sciences Edition)*, vol. 48, no. 3, pp. 88–99, 2022.

[7] D. Y. Zhuang, "Empirical research on new generation of migrant workers' preference of long-term residing in medium and small-sized cities," *Journal of Northwest Forestry University*, vol. 16, no. 4, pp. 96–100, 2016.

[8] X. Q. Ye, "China's rural areas toward 2035: vision, challenges and strategies," *Journal of Management World*, vol. 37, no. 4, pp. 98–112, 2021.

[9] J. S. Li, "Rural revitalization and human modernization: a study based on comparative history," *Dong Yue Tribune*, vol. 43, no. 3, pp. 16–23+191, 2022.

[10] Z. H. He, "Migration of farmers' circulation of farm lands and the efficiency of land allocation," *Fudan Journal (Social Sciences)*, vol. 4, pp. 95–103, 2006.

[11] X. Y. Liu and L. X. Zhang, "Analysis of the relationship between the stability of rural land property rights and labor transfer," *China Rural Economy*, vol. 2, pp. 29–39, 2008.

[12] Z. Zhao, X. G. Zheng, and D. M. Li, "Land transfer, non-agricultural employment and tendency of urbanization: evidence from agricultural transfer population in Sichuan," *Journal of Nanjing Agricultural University*, vol. 16, no. 4, pp. 90–99+158, 2016.

[13] W. Du, J. K. Niu, and L. Che, "The willingness of agriculture population's citizenization: the double influence of the family livelihood resilience and land policy," *Journal of Public Management*, vol. 15, no. 3, pp. 66–77+157, 2018.

[14] Y. H. Li, N. N. Liu, and X. Q. Li, "Farmland circulation, housing choice and peasant-workers' citizenization," *Economic Geography*, vol. 39, no. 11, pp. 165–174, 2019.

[15] Y. X. Dang, W. Z. Zhang, L. Chen, and D. S. Zhan, "The influence of living environment satisfaction on migrants' settlement intention," *Northwest Population Journal*, vol. 42, no. 5, pp. 105–114, 2021.

[16] C. L. Li, "Prestige stratification in the contemporary China: occupational prestige measures and socio-economic index," *Sociology Study*, vol. 2, pp. 74–102+244, 2005.

[17] F. S. Zeng and Y. L. Xia, "Research on agricultural land transfer and new farmer's cultivation: an empirical analysis based on polynomial distribution lag model," *Agricultural Technology Economics*, vol. 6, pp. 14–21, 2014.

[18] X. T. Jin and S. Zhou, "What is the significance of developmental cultural consumption of new generation migrant workers: a study based on the influence of citizenship intention on occupational prestige," *Social Science Front*, vol. 4, pp. 189–196, 2017.

[19] J. K. Zhou, W. B. Wang, M. Y. Gong, and Z. X. Huang, "Land transfers, occupational stratification and poverty reduction," *Economic Research Journal*, vol. 55, no. 6, pp. 155–171, 2020.

[20] G. S. Zhang and Z. Y. Tian, "China's rural labor mobility in the 40 years of reform and opening-up: changes, contributions and prospects," *Issues in Agricultural Economy*, vol. 7, pp. 23–35, 2018.

[21] R. D. Alba and V. Nee, "Rethinking assimilation theory for a new era of immigration," *International Migration Review*, vol. 31, no. 4, p. 826, 1997.

[22] X. Q. Ai, X. X. Cheng, and G. Z. Li, "Research on the influence mechanism of social discrimination on migrant workers'

willingness to settle down: identity-based mediating effect," *Population and Development*, vol. 27, no. 1, pp. 73–85, 2021.

[23] X. J. Zhang, "Group exclusion and partial acceptance-an empirical analysis of intergroup relations between citizens and migrant workers," *Social Sciences in Guangxi*, vol. 5, pp. 175–178, 2008.

[24] H. Y. Gu, Y. K. Ling, T. Y. Shen, and L. D. Yang, "How does rural homestead influence the hukou transfer intention of rural-urban migrants in China?" *Habitat International*, vol. 105, p. 102267, 2020.

[25] X. T. Fei, *Rural China*, Shanghai People's Publishing House, Shanghai, 1988.

[26] X. H. Ma and H. Z. Cui, "Establishing a land transfer system to promote the large-scale operation of regional agricultural production," *Journal of Management World*, vol. 11, pp. 63–77, 2002.

[27] C. C. Fan, "Settlement intention and split households: findings from a survey of migrants in Beijing's urban villages," *China Review*, vol. 11, no. 2, pp. 11–42, 2011.

[28] D. J. Treiman, "A standard occupational prestige scale for use with historical data," *Journal of Interdisciplinary History*, vol. 7, no. 2, p. 283, 1976.

[29] A. Inkeles and P. H. Rossi, "National comparisons of occupational prestige," *American Journal of Sociology*, vol. 61, no. 4, pp. 329–339, 1956.

[30] L. Zhang and L. Tao, "Barriers to the acquisition of urban hukou in Chinese cities," *Environment and Planning A*, vol. 44, no. 12, pp. 2883–2900, 2012.

[31] Z. S. Yue, S. Z. Li, M. W. Feldman, and H. F. Du, "Floating Choices: a generational perspective on intentions of rural–urban migrants in China," *Environment and Planning A: Economy and Space*, vol. 42, no. 3, pp. 545–562, 2010.

[32] X. Y. Lu, *Social Mobility in Contemporary China*, Social Science Literature Press, Beijing, 2004.

[33] N. Lin, *Social Capital: A Theory of Social Structure and Action*, Cambridge University Press, England, 2002.

[34] X. X. Xu, "The change of social structure in China from the perspective of career evaluation and career choice," *Sociology Study*, vol. 3, pp. 67–85, 2000.

[35] C. E. Bose, *Jobs and Gender: A Study of Occupational Prestige*, Praeger Publishers, NY, USA, 1985.

[36] S. Q. Zheng, F. J. Long, C. C. Fan, and Y. Z. Gu, "Urban villages in China: a 2008 survey of migrant settlements in Beijing," *Eurasian Geography and Economics*, vol. 50, no. 4, pp. 425–446, 2009.

[37] P. L. Zhu and Z. B. Yang, "Multi-dimensional analysis on the influence factors of migrant workers' sense of belonging," *Journal of South China Agricultural University (Social Science Edition)*, vol. 18, no. 1, pp. 44–53, 2019.

[38] S. Haug, "Migration networks and migration decision-Making," *Journal of Ethnic and Migration Studies*, vol. 34, no. 4, pp. 585–605, 2008.

[39] J. H. Yang, "From segregation, choice of integration to integration: theoretical considerations on social integration of migrant population," *Population Research*, vol. 33, no. 1, pp. 17–29, 2009.

[40] E. S. Lee, "A theory of migration," *Demography*, vol. 3, no. 1, pp. 47–57, 1966.

[41] R. Cohen and V. Robinson, "Theories of migration," *Population*, vol. 52, no. 1, p. 249, 1997.

[42] Y. Yang and Y. Q. Zhen, "An analysis of the identity transformation of new generation migrant workers based on push-pull theory," *China Youth Study*, vol. 8, pp. 26–30, 2012.

[43] F. Li, H. Feng, and X. Q. Ai, "The research on endowment of land resources and the willingness of migrant workers to return home under the background of rural revitalization," *Population & Economics*, vol. 6, pp. 35–47, 2020.

[44] H. B. Ruan, "Impact of social conditions and policy support on urban integration of migrant workers: empirical analysis based on push-pull theory," *Journal of Agro-Forestry Economics and Management*, vol. 20, no. 5, pp. 588–597, 2021.

[45] J. L. Hu, D. Li, and Q. F. Li, "Non-agricultural employment, migrant workers' willingness to settle in the city and urbanization location selection: a study based on micro survey data," *Journal of Agro-Forestry Economics and Management*, vol. 18, no. 5, pp. 598–606, 2019.

[46] X. Huang, Y. Liu, D. S. Xue, Z. G. Li, and Z. L. Shi, "The effects of social ties on rural-urban migrants' intention to settle in cities in China," *Cities*, vol. 83, pp. 203–212, 2018.

[47] C. G. Wang, "The relationship between social identity and urban-rural integration of the new generation of rural migrants," *Sociology Study*, vol. 3, pp. 63–76, 2001.

[48] W. Y. Gan, "An empirical study of the identity, emotional commitment and turnover intention of the new generation migrant workers from the rural areas in the perspective of the organizational support," *Journal of Management*, vol. 31, no. 2, pp. 36–49, 2018.

[49] G. W. Cheung and R. S. Lau, "Testing mediation and Suppression effects of latent variables: Bootstrapping with structural equation models," *Organizational Research Methods*, vol. 11, no. 2, pp. 296–325, 2008.

[50] D. P. Mackinnon, C. M. Lockwood, J. M. Hoffman, S. G. West, and V. Sheets, "A comparison of methods to test the mediation and other intervening variable effects," *Psychological Methods*, vol. 8, no. 1, pp. 1–35, 2002.

[51] K. J. Preacher and A. F. Hayes, "Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models," *Behavior Research Methods*, vol. 40, no. 3, pp. 879–891, 2008.

[52] D. P. Mackinnon, C. M. Lockwood, and J. Williams, "Confidence Limits for the indirect effect: distribution of the product and resampling methods," *Multivariate Behavioral Research*, vol. 39, no. 1, pp. 99–128, 2004.

[53] R. M. Baron and D. A. Kenny, "The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations," *Journal of Personality and Social Psychology*, vol. 51, no. 6, pp. 1173–1182, 1986.

[54] R. S. Lau and G. W. Cheung, "Estimating and comparing specific mediation effects in complex latent variable models," *Organizational Research Methods*, vol. 15, no. 1, pp. 3–16, 2012.

[55] L. Zhao, S. Y. Liu, and W. Zhang, "New trends in internal migration in China: Profiles of the New-generation migrants," *China and World Economy*, vol. 26, no. 1, pp. 18–41, 2018.

[56] Y. Liu, Z. G. Li, and W. Breitung, "The social networks of new-generation migrants in China's urbanized villages: a case study of Guangzhou," *Habitat International*, vol. 36, no. 1, pp. 192–200, 2012.

[57] A. Corsi and C. Salvioni, "Once part-timer Always part-timer? Causes for Persistence in Off-farm work state of farmers," *Bio-Based and Applied Economics Journal*, vol. 6, no. 2, pp. 159–182, 2017.

[58] M. P. Todaro, "A model of labor migration and urban unemployment in less developed countries," *The American Economic Review*, vol. 59, no. 1, pp. 138–148, 1969.

[59] W. R. Qian and B. Z. Li, "The effects of initial intention achievement and perceived fairness on migrant workers' willingness to stay in cities and their intergenerational differences--Based on research data from 16 cities in Yangtze River Delta," *Journal of Management World*, vol. 9, pp. 89–101, 2013.

[60] R. J. Zhao, H. Zhou, and C. C. N. Peng, "A study on the temporal variation of migrants' settlement intention: based on the China migrants dynamic survey (2010-2017)," *Population and Development*, vol. 27, no. 6, pp. 22–35, 2021.

[61] J. Chen and W. Wang, "Economic incentives and settlement intentions of rural migrants: evidence from China," *Journal of Urban Affairs*, vol. 41, no. 3, pp. 372–389, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6151667, 14 pages
https://doi.org/10.1155/2022/6151667

Research Article

The Different Effects of Firm Resources on Firm Performance under Volatility: An Examination Using Big Data

Xuelian Piao [1] **and MyeongCheol Choi** [2]

[1] *College of Business, Kwangwoon University, Seoul, Republic of Korea*
[2] *Depart of Business, Gachon University, Seongnam, Republic of Korea*

Correspondence should be addressed to MyeongCheol Choi; oz760921@gachon.ac.kr

Received 17 June 2022; Accepted 12 August 2022; Published 7 September 2022

Academic Editor: Lele Qin

According to the resource-based view, research and development (R&D) and advertising are critical resources firms use to improve their performance. This study aims to clarify the different effects of R&D and advertising on firm performance using distinct criteria—firm value and firm profitability. It also verifies whether the effects of R&D and advertising apply in a volatile environment. We run panel data regression models with a big data sample of manufacturing firms publicly listed on the Korea Composite Stock Price Index over an extended period of 27 years. We find that R&D has more positive effects on firm value than advertising, while advertising has more positive effects on firm profitability than R&D; these relationships are consistent even when volatility is considered. This suggests that firms should mix and match their investments between R&D and advertising resources for improved effectiveness and efficiency, and these resources should be accumulated and exploited consistently regardless of environmental dynamics.

1. Introduction

The resource-based view (RBV) indicates that firms develop and exploit their own resources to generate and sustain a competitive advantage [1]. Barney [1] introduced four empirical indicators for these resources: they are 'valuable, rare, inimitable, and nonsubstitutable.' Two key resources, research and development (R&D) and advertising, satisfy the characteristics of resources that generate a sustained competitive advantage [2–5]. As a source of innovation, R&D activities can lead a firm to develop new products for customers or upgrade existing products, while advertising activities enhance a firm's marketing communications, create brand recognition, and build reputation [3]. Therefore, these two resources have been recognized as key resources that allow firms to differentiate and improve firm performance. How do these two resources differ? What are the different roles R&D and advertising play in firm performance?

Although previous studies have compared R&D and advertising, they primarily use one criterion for firm performance and try to clarify the differences between the two resources in terms of their level of intensity in various industries (e.g., [3, 4]). This study uses different firm performance criteria—firm profitability and firm value—and compares the different effects on firm performance. It further investigates whether these resources maintain their effects in highly volatile environments. When faced with economic fluctuations and volatility, some firms treat R&D and advertising investments as aspects that can be postponed or reduced to address short-term liquidity. This study also examines whether it is appropriate for firms to slash R&D and advertising budgets in an unexpected environment. In today's era of uncertainty, research on such issues is urgently needed, and it is possible to provide useful tips for firm survival. Thus, we perform an empirical analysis to reexamine the role R&D and advertising resources play in firm performance, while considering environmental volatility.

The RBV is a foundational and seminal theory that is widely disseminated in management science, and it is intertwined with three management research streams: the

traditional strategy perspective, the organizational economics paradigm, and industrial organizational research [6]. Accordingly, the RBV has contributed significantly to building foundations for various new follow-up theories, such as the organizational capability and dynamic capability views [7]. A few studies have conducted in-depth evaluations of the RBV, pointing out that it needs further development (e.g., [7, 8]). Priem and Butter [7] insist that the RBV needs to address black-box issues such as the processes through which resources are transformed into capabilities, how these resources improve firm performance, how various resources interact inside firms, and so on. Under the RBV, R&D and advertising are recognized as the proper resources for firms to promote for a sustainable competitive advantage. Thus, the idea that R&D and advertising generally enhance firm performance has garnered widespread support (see [7–11]). However, research is lacking on how the roles of R&D and advertising differ with respect to firm performance. This study investigates the underlying RBV processes through an in-depth analysis of the nature of a firm. We disclose two dimensions of firm performance and investigate the different roles R&D and advertising resources play in these dimensions. Furthermore, this study includes environmental volatility to examine whether it shifts the impacts of the resources. Therefore, it synthesizes the RBV with related theories such as the organizational and dynamic capability views.

South Korea has a market economy that ranked 12th worldwide in 2019 in terms of nominal gross domestic product (GDP). Despite being one of the major G-20 economies, it lacks natural resources and has a rather small domestic consumption market; thus, South Korea promotes an export-oriented policy. Currently, the country is highly dependent on trade, with the highest export-to-GDP ratio among the G-20 countries. Due to its export-oriented and open economic structure, South Korea experiences substantial economic volatility influenced by the global economic cycle. Two of the world's most devastating financial crises hit its economy hard: the country came close to a national bankruptcy because of the 1997 Asian financial crisis and experienced a sharp decline in international trade during the 2008 global financial crisis. Therefore, the Korean context provides an appropriate research setting for investigating the effects of key resources in the context of substantial volatility.

This study contributes to the strategic management literature and further develops the RBV, as it reexamines the RBV and particularly investigates its underlying processes in depth. We restrict the examined resources to R&D and advertising to simplify the research model, avoid interference from too many resources, and investigate their dynamic effects on firm performance. We especially contribute to discovering the contrasting effects of R&D and advertising on firm performance when it is classified into two dimensions: firm value and firm profitability. Our results imply that R&D and advertising in substance have a mutually dependent relationship in improving overall firm performance. We also reflect environmental volatility as an important factor in this analysis and observe how the effects of R&D and advertising are affected by volatility. Finally, we use a large dataset of manufacturing firms that are publicly listed on the Korea Composite Stock Price Index (KOSPI) over an extensive period from 1993 to 2019. We believe that the findings from our empirical analysis are generalizable and adequately reflect environmental dynamism.

The next section reviews and analyses the RBV and other related theories. In particular, we investigate the nature of firms and lay the foundation for developing our hypotheses. The relevant hypotheses are formulated by closely following the reviewed theories. We then describe the dataset and statistical methods used to test the hypotheses. Our interpretation of the empirical results leads to discussions of the study's theoretical contributions and practical implications. Finally, we discuss the study limitations and provide directions for future research.

2. Theory and Hypotheses

2.1. Resource-Based View. Seminal works on the RBV literature include Wernerfelt [12] and Barney [1]. Upon analysing firms' diversification strategies from the perspective of resources, Wernerfelt [12] insists that firms should pay attention to their own resources, while many scholars at that time asserted that firm management should focus on products or external opportunities and threats. Barney [1] provides a more detailed resource-based perspective at the business level. He maintains that organizational resources that satisfy four attributes—(1) valuable, (2) rare, (3) difficult to imitate, and (4) nonsubstitutable—can create a sustained competitive advantage [1]. Such resources are mainly intangible, including R&D and marketing resources, rather than tangible resources like buildings and machines.

Wernerfelt [12] and Barney [1] laid the foundation for many RBV studies [13–15], and the development of RBV research relates to three major management research streams: strategy, organizational economics, and industrial organization [6]. To gain an in-depth understanding of the RBV, we review the interrelationships among these fields of study. First, the RBV is useful in explaining firm performance, an area of considerable focus in the strategic management field, thus making it an important theory in strategic management. Firms with heterogeneous resources make distinctive strategic choices and create different economic rents, ultimately leading to sustained competitive advantages in their industries [1, 15].

The RBV is also closely associated with the organizational economics paradigm [16]. The theories from these two research fields share the same background of the neoclassical theory of the firm [6]. The fields both found that the neoclassical theory of the firm has limitations, as it neglects the following points: transaction costs, bounded rationality, technological uncertainty, organizational learning, and price as a signal of quality [6]. Studies of the RBV and the organizational economics paradigm have tried to overcome these limitations. The RBV is fundamentally linked to the organizational economics paradigm, as both emphasize 'firm-specific' and 'distinctive competencies' based on resources [16].

The RBV also relates to industrial organization research. While industrial organization research places importance on firms' external market environments and industry structures [17, 18], the RBV focuses on firms' internal aspects and resources. However, these two streams both involve product or resource constraint issues [12], and both pursue the same fundamental goal of rent generation.

The RBV is a cornerstone in the field of management; it has influenced various studies and is closely interrelated with other mainstream management fields. To make the RBV even more useful in strategic management research, acknowledging rigorous critiques can help overcome its limitations. Our study aims to contribute to further developing the RBV in this sense. The RBV contends that firms can attain a competitive edge from resources that are heterogeneous, scarce, and difficult to replicate [1]. Such arguments draw criticism of the RBV in that it does not pay much attention to the process or dynamism influenced by environmental factors [19]. Firms cannot be isolated from external factors, all of which affect their internal factors. As such, the RBV needs to address the process black box, that is, the question of how, for example, resources generate sustainable competitive advantages apart from the effect of heterogeneity, how resources interact with other resources, and how resources respond to external environments [7]. This recognition brings attention to the paradigm of organizational capability and the dynamic capability view.

The organizational capability view departs from knowledge-based resources, insisting that such resources are developed into capabilities that do not remain stationary inside firms [20, 21]. Rather, this view emphasizes the dynamism and interactive process between internal and external factors that turn resources into capabilities. The organizational capability view is consistent with the dynamic capability view. The seminal work by Teece et al. [22] points out that dynamic capability focuses on adjusting to the external environment by integrating, building, and reconfiguring the firm's internal resources. Thus, dynamic capability is said to be developed within the stream of the RBV. Meanwhile, other scholars contend that the dynamic capability view belongs to the evolutionary economic stream, especially reflecting the Schumpeterian "capability building" theory. However, these capabilities, after all, come from strategically using, integrating, and reconfiguring resources; thus, some studies of the RBV share the terms "resource" and "capability." Regarding resources, this study also embraces the concept that resources are developed into capabilities through integration, reconfiguration, and so on and monitors how the effects of resources interact with environmental volatility.

2.2. Firm Performance. Firm performance is an important topic and goal in management science. Accordingly, various management scholars have studied the relationship between their fields of expertise and firm performance. In particular, strategic management research focuses on firm performance, so the related research topics mainly consist of rent-seeking behaviours [23]. Well-known related literature includes Chandler's diversification strategy [24], Porter's competition strategy [25], and Pearce et al.'s corporate strategic plan [26]. These studies have all conducted in-depth research on the relationship between various strategies and firm performance. Nevertheless, why is the topic of firm performance important? What is the nature of firm performance? Here, we disclose the hidden dimensions of firm performance.

Firm performance, by nature, is related to firm survival. Firms that sustain and survive should satisfy value > price > cost [27].

Fundamentally, firms produce products, sell these products to customers, and receive the price for their survival. To be successful in competition, firms should not only satisfy their customers, but also gain sufficient rewards. Meanwhile, customers buy products only when they perceive that the value of the offered products is higher than the price they pay for the products [28]. As shown in the above inequalities, this logic is reflected on the first inequality. If customers do not perceive the value that the products deserve, no matter how much effort firms put into making the products, they may lose their customers. Thus, this determines the effectiveness of firms according to how firms realize the first inequality [29].

On the producers' side, firms can survive only when the price of products is higher than the cost of the products, and this logic is reflected on the second inequality. Thus, the necessary condition for firms' survival is to increase the price or decrease the cost of production. Firms will be shunned by their customers if product prices become exorbitant because the cost increases due to inefficiencies. Thus, whether firms perform well for the second inequality depends on their efficiency [30]. Furthermore, as each firm has limited resources, efficiency is the solution to the problem of resource limitation to improve or maintain firm performance.

Overall, firms must simultaneously achieve both the inequalities; otherwise, they cannot survive, especially in the longer term. Thus, to improve firm performance to achieve sustainability or survive, firm management should consider these two dimensions simultaneously. First, firms should increase the difference between value and price (V-P) as much as possible. This represents firm value and symbolizes firm effectiveness [25]. Second, firms should increase the difference between price and cost (P-C) as much as possible, which represents firm profitability and symbolizes firm efficiency [31].

In this study, we investigate the relationship between resources and firm performance; thus, our focus is on observing how resources influence the two dimensions or categories of firm performance. Only when resources have positive effects on both the value and profitability of a firm do such resources conform to the RBV. However, we expect different effects on value or profits depending on the type of resource. In this study, we restrict our investigation to R&D and advertising resources to simplify the research model and framework.

2.3. R&D and Advertising Resources. R&D and advertising are the key resources implicated in the RBV. However, firms

must spend money to accumulate R&D and advertising resources, and current accounting rules for such expenses mean that they have an immediate negative impact on financial performance. Accordingly, firm management is prompted to cut R&D or advertising investments under adverse conditions.

Many studies have found that R&D and advertising resources, as intangible resources, contribute to firm performance. However, some studies are biased towards the finance perspective when analysing R&D and advertising effects [3–5]. Our study addresses this limitation by performing an in-depth analysis of the effects of these resources in conjunction with strategic management theories. The features of intangible resources include tacitness (hard to codify) and immobility (not easily traded) because of imperfect market factors. Hence, intangible resources satisfy the characteristics of 'valuable, rare, not easily imitable, and nonsubstitutable,' [1] and accordingly create a competitive advantage. R&D and advertising resources are typical critical intangible resources, as advocated by the RBV [32, 33].

Firm resources can be sorted into three categories: physical, human, and organizational [1]. Organizational resources refer to the capability to organize and coordinate internal resources to produce the desired results. A firm's objective is to maximize revenue with constrained resources and reinforced competitiveness. This requires a large input of organizational resources. For manufacturing firms, organizational resources help produce attractive products that sell at acceptable prices in the right places and help publicize the products through promotion. R&D and advertising affiliated with organizational resources display these critical roles in such processes.

R&D resources, as intangible resources, can be defined as a firm's ability to generate new technology or products/services and improve existing technology or products/services to attain certain goals [32]. Thus, these capabilities are also presented as high-quality technological processes or innovations. R&D's objective is, after all, to satisfy customers' infinite needs, especially their shifting needs, over time. Even when R&D brings about innovative technology or products/services that customers do not expect, it adds value for them as these items resolve their unexpected difficulties or bring them joy. Thus, R&D realizes firms' effectiveness, which represents the first inequality in the equation highlighted earlier. Several studies have found a significantly positive relationship between R&D resources and firm performance. For example, Chan et al. [9] have reported that R&D increases stock returns. Lev and Sougiannis [10] have shown that R&D increases market value, while Kotabe [11] has shown that R&D improves profitability. Admitting that it is within the same context of firm performance improvement, this study conjectures that R&D is biased towards improving firm value, which is closely associated with customers' perceived value.

Advertising is firms' second most important organizational resource. Advertising resources can be defined as the capability or process of integrating and designing a firm's related knowledge, skills, and resources to lead a strong orientation towards markets, consumers, and competitive demands [34]. Market-oriented advertising can enhance firm performance [35–37]. Advertising allows firms to develop brands for their products and services and form market barriers against rival firms. Advertising realizes product differentiation, which leads to price differentiation for firms; accordingly, it improves efficiency to overcome resource limitations. Advertising sets out the firm's communication strategy to create brand equity by promoting ideas, goods, or services. The targeted result is to ensure that consumers willingly pay the price that firms deserve. Even if firms develop more innovative and wonderful products through R&D resources, they cannot add price premiums and expand their target market without exploiting advertising resources.

Therefore, we hypothesize that R&D (advertising), as a resource, has a greater impact on firm value (firm profitability) than advertising (R&D):

(i) H1 : compared with advertising resources, R&D resources have a more positive impact on firm value

(ii) H2 : compared with R&D resources, advertising resources have a more positive impact on firm profitability

2.4. Environmental Volatility. Environmental volatility refers to the external environment's instability and turbulence. It comes from economic change, political events, and/or changes in the industry structure, which lead to changes in customers' preferences, technological uncertainty, and industrial competition structure/strength [38]. Thus, it can increase firm unpredictability and cause a substantial number of products to fall into disuse or lead to the inability to procure certain materials, leaving an unresolved gap in supply and demand. When confronting such environmental fluctuations and volatility, firms should quickly adjust or reconfigure their value chain; however, many firms fail to adapt to such environmental changes and suffer serious damage [39]. Meanwhile, some firms successfully overcome such difficulties using their own resources or capabilities. Therefore, the question arises as to whether a completely new resource or capability is needed to overcome environmental volatility or whether the existing resources or capabilities are sufficient in the face of such environmental changes. The critics of the RBV argue that it does not provide a good explanation of the effects resources have on firms in a fluctuating environment due to its rather static approach [22, 40]. This study aims to contribute to developing the RBV to overcome such limitations.

In situations of environmental stability vis-à-vis environmental volatility, resources seem to have a more positive impact on firm performance. Some studies insist that environmental change/volatility has a detrimental effect on firm performance [39, 41], while others argue that it strengthens the positive relationship between resources and firm performance [40, 42]. When an environmental change happens, the balance between supply and demand will be disturbed by technological uncertainty or changes in consumer tastes. Although these environmental changes generally have adverse impacts on firm performance, when

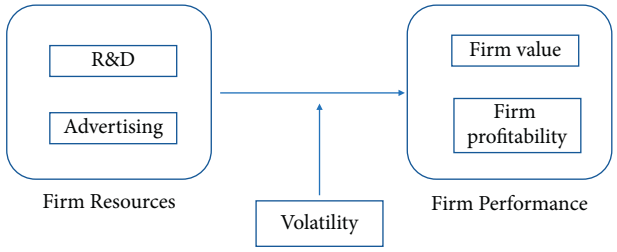


Figure 1: Relationships among the relevant factors in this research.

firms correctly predict an environmental change and prepare new products or services at the appropriate time, they can overcome such crises. They may even improve firm performance with an adequate price offered to the right customers. Some critical resources such as R&D and advertising may help firms relish these challenges and even reverse a downward trend.

While the business environment is full of fluctuations, firms are concerned that as consumers reduce or delay purchases, the firms will be unable to achieve their expected sales or profits even if they invest considerable money in R&D and advertising [43]. However, the opposite view is that, even in a greatly fluctuating environment, resources are valuable and helpful [42]. It is argued that firms can produce differentiated products to satisfy consumers' specific needs and implement active communication with consumers through R&D and advertising resources, even in a volatile environment, leading to a sustainable increase in firm value and profitability. Therefore, we suggest conservatively that economic volatility does not decrease the effects of R&D and advertising resources on each dimension of firm performance:

(i) H3 : the impact of R&D resources on firm value is not reduced in a volatile environment

(ii) H4 : the impact of advertising resources on firm profitability is not reduced in a volatile environment

This study investigates the outward relationship between firm resources and firm performance, while we dig into the inside details of the constructs of firm resources and firm performance. We select R&D and advertising, which are two of the critical firm resources, and firm profitability and firm value, which are two distinct firm performance criteria. The first and second hypotheses depict the dynamic relationships of these factors. In addition, we add volatility to the relationships as proposed in the third and fourth hypotheses. Figure 1 illustrates a general outline of the relationships among the relevant factors in our research.

3. Data and Methodology

3.1. Data Collection. The data were obtained from the KisValue Database of the Korea NICE Holdings Company. From this database, we construct a data sample that includes manufacturing firms publicly listed on the KOSPI for the period 1993–2019, making it appropriate for panel data analysis. The sample consists of 447 firms, comprising 8,071 firm-year observations. The reason this study limits the research data to manufacturing firms publicly listed on the KOSPI is that only manufacturing firms make relatively even investments in R&D and advertising [6, 11], and only KOSPI firms provide market value data, which is needed to calculate firm value.

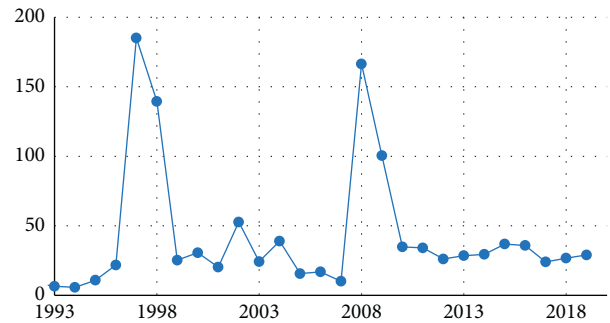


Figure 2: Volatility trend of the exchange rates from 1993 to 2019.

3.2. Variables and Measurements. The independent variables are R&D and advertising resources, which are measured as the intensity of such resources for the firm's sales. R&D (advertising) intensity is defined as the ratio of R&D (advertising) expenditure to a firm's total net sales. To control for factors that may affect firm performance, we select the following firm-level control variables: firm size, age, and export-related variables. Firm size indicates a firm's workload, which can affect its performance [44]. Firm size can be measured by two variables; one is the logarithm of a firm's number of employees, and the other is the logarithm of firm assets. In previous empirical studies, the effects of firm size on firm performance have been found to be both positive and negative, since they may depend on the different cases. Firm age points to a firm's experience level and generally has positive effects on firm performance. Firm age is measured by the length of a firm's existence (in years) since it was established to the time of observation.

As South Korea has an export-oriented economy, its firms generally have export sales and expenditures. As export-related variables may also impact firm performance, we control for the export ratio and overseas sales expenditure. A firm's export ratio is measured as its export sales divided by its total net sales. When a firm's export ratio increases, it means the firm's business scope may have expanded to more foreign markets. Consequently, the export ratio may have a negative relationship with firm performance because an expanded business scope indicates an increased workload and higher coordination costs, which may harm firm performance [45]. We also control for overseas sales expenditure, measured by the ratio of overseas sales expenditure to the firm's total net sales, and expect the same negative sign as with the export ratio.

Each year's economic volatility is calculated as the standard deviation of the year's daily exchange rates between the Korean won and the U.S. dollar, which follows the measurement used in previous studies [46, 47]. The variance in the daily exchange rates can reflect economic volatility, especially in relation to the international economy. Figure 2

shows the trend of the exchange rate volatility, which is very high during both the 1997 and 2008 financial crises—two of the world's most devastating financial crises in history. When we include the exchange rate volatility, we also control for the yearly mean exchange rate in the relevant year.

The dependent variables in this study represent two categories of firm performance: firm value and firm profitability. Firm value (firm profitability) is measured using Tobin's Q (return on assets [ROA]). Tobin's Q captures firm value, measured by the ratio of the market value of all assets owned by a firm to the replacement value of book assets [48]. A higher Tobin's Q means higher firm value. As a common measurement for firm profitability, ROA reflects a firm's profitability relative to its total assets and thus refers to the degree to which a firm manages its assets efficiently to generate earnings [49, 50].

3.3. Data Analysis Method. Equations (1)–(9) are the regression models used in this study.

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 \text{Asset}_{i,t} + \alpha_4 Emp_{i,t} + \alpha_5 \text{Age}_{i,t} + \alpha_6 Expratio_{i,t} + \alpha_7 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (1)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 \text{Asset}_{i,t} + \alpha_4 Emp_{i,t} + \alpha_5 \text{Age}_{i,t} + \alpha_6 Expratio_{i,t} + \alpha_7 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (2)$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 Ex_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (3)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 Ex_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (4)$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times \text{Vol}_t + \alpha_4 \text{Vol}_t + \alpha_5 Ex_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (5)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 AD_{i,t} \times Vol_t + \alpha_4 Vol_t + \alpha_5 Ex_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (6)$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 Ex_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (7)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 Ex_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (8)$$

Note: $Q_{i,t}$ is Tobin's Q of firm i in period t; $P_{i,t}$ is the ROA of firm i in period t; $RD_{i,t}$ is the R&D intensity of firm i in period t; $AD_{i,t}$ is the advertising intensity of firm i in period t; $\text{Asset}_{i,t}$ is the natural logarithm of assets of firm i in period t; $\text{Emp}_{i,t}$ is the logarithm of number of employees of firm i in period t; $\text{Age}_{i,t}$ is the length of existence of firm i in period t; $\text{Expratio}_{i,t}$ is the export ratio of firm i in period t; $\text{OverseasExp}_{i,t}$ is the overseas sales expenditure of firm i in period t; Vol_t is the volatility of exchange rate during period t; Ex_t is the exchange rate during period t; $\alpha_1 \sim \alpha_{11}$ is the coefficient of each variable, and α_0 is constant; $\varepsilon_{i,t}$ is the error term.

Equation (1) shows the effects of R&D and advertising resources on Tobin's Q, without considering environmental volatility. Equation (2) shows the effects of the two resources on ROA, also without considering environmental volatility. Equation (3) captures the effects of R&D and advertising resources on Tobin's Q while controlling for the environment-related variables, and (4) captures the effects of the two resources on ROA while controlling for the environment-related variables. Equations (5) and (6) add the interaction between volatility and R&D/advertising resources to the previous corresponding models and show how these effects change. Equations (7) and (8) include both the interaction of volatility and R&D and the interaction of volatility and advertising to capture how the effects of the main resources shift along with the hierarchical regression models. All eight models control for firm size, firm age, and firm export-related variables. The subscript letter i refers to the firm number, and t refers to the observation year. Additionally, $\varepsilon_{i,t}$ denotes each equation's error term, which is assumed to follow a normal distribution. Based on these models, we run panel analytic hierarchical regressions. The variance inflation factor (VIF) values derived from the VIF test are much less than 10, confirming that there is no multicollinearity problem in these regressions, thereby guaranteeing the reliability of the empirical analysis to a certain degree.

4. Results

4.1. Main Results. The descriptive statistics of the variables used in the regressions are shown in Table 1, and Table 2 shows the correlation coefficients of the explanatory and dependent variables. Tables 3 and 4 show the results of the panel analytic hierarchical regressions for the eight models above. In Tables 3 and 4, the overall R^2 increases gradually from Models 1 to 8 as the explanatory variables are added to the regression models one at a time. This means that as the fitted variables are added, the explanatory power increases.

Table 3 presents the regression results with Tobin's Q as the dependent variable. In Model 1, the coefficient of R&D intensity is 7.512, which is positive and significant at the 1% level, while the coefficient of advertising is 0.256 and not significant.

Table 1: Descriptive statistics.

	Tobin's Q	ROA	R&D	Advertising	Asset	Employee	Age	Export ratio	Overseas expenditure	Volatility	Exchange rate
Mean	1.074	0.050	0.015	0.017	26.232	6.203	33.168	0.277	0.002	42.980	1,088.287
Standard deviation	0.655	0.070	0.108	0.025	1.525	1.381	16.966	0.292	0.005	45.016	150.394

Table 2: Correlation matrix.

	Tobin's q (ROA)	R&D	Advertising	Asset	Employee	Age	Export ratio	Overseas expenditure	Volatility	Exchange rate
Tobin's Q (ROA)	1(1)									
R&D	0.292 *** (-0.038 ***)	1								
Advertising	0.031 (0.109 ***)	0.044 **	1							
Asset	0.051 *** (0.012)	0.034 ***	−0.219 ***	1						
Employee	0.105 *** (0.152 ***)	0.049 ***	−0.126 ***	0.726 ***	1					
Age	−0.076 *** (-0.148 ***)	−0.016	0.110 ***	0.142 ***	−0.003	1				
Export ratio	−0.045 *** (-0.093 ***)	−0.011	−0.312 ***	0.146 ***	0.047 ***	-0.075 ***	1			
Overseas expenditure	0.088 *** (0.033)	0.200 ***	0.040	0.193 ***	0.234 ***	0.132 ***	−0.032	1		
Volatility	−0.071 *** (−0.006)	−0.010	0.032	−0.003	−0.003	−0.015	0.028 **	0.036	1	
Exchange rate	−0.063 *** (-0.086 ***)	0.019 *	−0.025	0.131 ***	0.011	0.092 ***	0.058 ***	0.082 ***	0.301 ***	1

Note. The symbols ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Regression results for the dependent variable-Tobin's Q.

Dependent variable: Tobin's Q(t)	Model (1)	Model (3)	Model (5)	Model (7)
R&D(t)	7.512 ***	7.617 ***	9.384 ***	9.596 ***
Advertising(t)	0.256	0.302	0.641	0.0169
R&D(t) × Volatility(t)			−0.048 *	−0.055 *
Advertising(t) × Volatility(t)				0.012
Volatility(t)		−0.000	0.000	−0.000
Exchange rate(t)		−0.000 *	−0.000	−0.000
Asset(t)	0.001	0.006	0.005	0.005
Employee(t)	0.011	0.008	0.008	0.008
Age(t)	−0.004 ***	−0.004 ***	−0.004 ***	−0.004 ***
Export ratio(t)	−0.233 ***	−0.216 **	−0.214 **	−0.210 **
Overseas expenditure(t)	2.257	2.726	3.048	3.066
Constant	1.097 **	1.169 ***	1.165 **	1.180 ***
N	597	597	597	597
Overall R^2	0.165	0.171	0.175	0.176

Note. The symbols ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Therefore, hypothesis 1, that R&D resources have a more positive impact on firm value than advertising resources, is supported. Model 3 adds the control variables—exchange rate volatility and the yearly mean exchange rate—to Model 1; the results show that the coefficient of R&D intensity does not lose its positive significance, and the coefficient of advertising intensity remains insignificant. Model 5 adds the interaction term of volatility and R&D to Model 3, showing that the coefficient of R&D intensity maintains its positive significance, and the coefficient of the interaction term of volatility and R&D is negative (−0.048) and significant at the 10% level. However, this coefficient's magnitude is very small; thus, it nearly loses its economic significance. Model 7 inserts the interaction term of advertising intensity and volatility, and its results are consistent with those of Model 5. Therefore, volatility does not influence the effects of R&D on firm value. These results support hypothesis 3.

Table 4 presents the regression results with ROA as the dependent variable. In Model 2, the coefficient of advertising intensity is 0.956, which is positive and significant at the 1% level. The magnitude of the advertising coefficient is rather small, and our data sample of manufacturing firms provides a reason. Previous research has found that the advertising effect is relatively small in manufacturing firms compared with nonmanufacturing firms [4]. The coefficient of R&D intensity is -0.142, which is negative and insignificant. Thus, hypothesis 2, that advertising resources have a more positive impact on firm profitability than R&D resources, is supported. Model 4

Table 4: Regression results for the dependent variable-ROA.

Dependent variable: ROA(t)	Model (2)	Model (4)	Model (6)	Model (8)
R&D(t)	−0.142	−0.129	−0.131	0.091
Advertising(t)	0.956 ***	0.957 ***	0.925 ***	0.874 ***
R&D(t) × Volatility(t)				−0.006
Advertising(t) × Volatility(t)			0.001	0.003
Volatility(t)		−0.000	−0.000	−8.16e-06
Exchange rate(t)		−0.000	−0.000	−0.000
Asset(t)	0.001	0.002	0.002	0.002
Employee(t)	0.007 ***	0.007 ***	0.007 ***	0.007 ***
Age(t)	−0.001 ***	−0.001 ***	−0.001 ***	−0.001 ***
Export ratio(t)	−0.023 *	−0.021 *	−0.021 *	−0.020 *
Overseas expenditure(t)	−0.287	−0.246	−0.248	−0.214
Constant	0.001	0.006	0.007	0.008
N	634	634	634	634
Overall R^2	0.106	0.108	0.108	0.111

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Regression results for the dependent variable-Tobin's Q (one-year lag).

Dependent variable: Tobin's Q(t)	Model (1)	Model (3)	Model (5)	Model (7)
R&D(t-1)	10.610 ***	10.756 ***	11.887 ***	11.630 ***
Advertising(t-1)	0.825	0.745	0.958	1.533
R&D(t-1) × Volatility(t-1)			−0.030	−0.022
Advertising(t-1) × Volatility(t-1)				−0.015
Volatility(t-1)		0.000	0.001	0.001
Exchange rate(t-1)		−0.000	−0.000	−0.000
Asset(t-1)	−0.014	−0.011	-0.011	−0.010
Employee(t-1)	0.030 *	0.028	0.028	0.028
Age(t-1)	−0.005 ***	−0.004 ***	−0.005 ***	−0.004 ***
Export ratio(t-1)	−0.004 ***	−0.003 ***	−0.004 ***	−0.003 ***
Overseas expenditure(t-1)	0.464	0.520	0.710	0.685
Constant	1.321 ***	1.345 ***	1.340 ***	1.322 ***
N	583	583	583	583
Overall R^2	0.257	0.258	0.260	0.260

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

adds the control variables—exchange rate volatility and the yearly mean exchange rate—to Model 2. The coefficient of advertising intensity remains positive and significant, and the coefficient of R&D intensity remains negative and insignificant. Model 6 adds the interaction term of volatility and advertising, and the results show that the coefficient of advertising intensity maintains a positive sign and significance, while the coefficient of the interaction term of volatility and advertising is 0.001 and not significant. Model 8 inserts the interaction term of R&D intensity and volatility, and its results are consistent with those of Model 6. This means that the volatility factor does not influence the effects of advertising on firm profitability. Thus, the results support hypothesis 4.

These results are achieved under the premise that all substantially important firm-level variables are controlled. The signs of these control variables are generally in line with the estimations, but firm age always has negative and significant coefficients, despite their small magnitude. This implies that, in South Korea, firms can achieve better performance and adapt to a dynamically changing environment more easily when firms are younger. The coefficient of the export ratio has a significantly negative sign, as assumed.

4.2. Robustness Tests. We conducted several robustness checks to ensure the reliability of our empirical results. First, we implemented a one-year lag for the independent and control variables, as it may take a certain amount of time for firms to see the effects of R&D and advertising resources for exploration or exploitation on firm performance. Tables 5 and 6 show the one-year lagged regression results, which correspond well with the results in Tables 3 and 4, providing further evidence to support the respective hypotheses. Particularly noteworthy is the result that the coefficient of the interaction term of R&D and volatility lost significance in this robustness test; thus, hypothesis 3 that the effects of R&D resources on firm value are not impacted by a volatile environment is more strongly supported.

As a second robustness test, we use an alternative measurement for volatility; we calculate the annual standard deviation of the daily KOSPI 200. The KOSPI 200 is an index tracking 200 large firms that trade on the Korea Exchange, representing the state of the stock market and South Korea's economy. Thus, the measurement using the KOSPI 200 better reflects the volatility of the Korean domestic economy compared to that of the exchange rate. The KOSPI 200 data in this study cover 2003 to 2016, which is a relatively short timeframe.

Table 6: Regression results for the dependent variable-ROA (one-year lag).

Dependent variable: ROA(t)	Model (2)	Model (4)	Model (6)	Model (8)
R&D(t-1)	0.046	0.023	0.033	0.135
Advertising(t-1)	0.802 ***	0.814 ***	0.936 ***	0.913 ***
R&D(t-1) × Volatility(t-1)				−0.003
Advertising(t-1) × Volatility(t-1)			−0.003	−0.002
Volatility(t-1)		−0.000	−3.68e-06	0.000
Exchange rate(t-1)		0.000	0.000	0.000
Asset(t-1)	−0.002	−0.002	−0.002	−0.002
Employee(t-1)	0.008 ***	0.009 ***	0.009 ***	0.009 ***
Age(t-1)	−0.001 ***	−0.001 ***	−0.001 ***	−0.001 ***
Export ratio(t-1)	−0.000 **	−0.000 **	−0.000 **	−0.000 **
Overseas expenditure(t-1)	0.353	0.348	0.353	0.368
Constant	0.072	0.068	0.065	0.065
N	612	612	612	612
Overall R^2	0.123	0.125	0.127	0.128

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

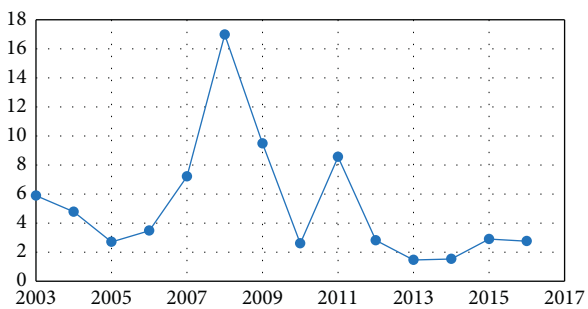


Figure 3: Volatility trend of the KOSPI 200 from 2003 to 2016.

Figure 3 shows the KOSPI 200's volatility trend, revealing that the volatility in 2008 is very high, similar to the exchange rate volatility trend. However, we cannot observe the status in 1997 due to limited data. When we include the KOSPI 200 volatility, we also control for the yearly mean of the KOSPI 200 index. For this robustness test, we run the following regression models of equations (9)–(14), replacing the exchange rate volatility with the KOSPI 200 volatility. Tables 7 and 8 report the regression results and show that the main effects are consistent with those in Tables 5 and 6, as the signs and significances are maintained; thus, all the hypotheses are supported.

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 Kospi_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (9)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 Kospi_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (10)$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 Vol_t + \alpha_5 Kospi_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (11)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 AD_{i,t} \times Vol_t + \alpha_4 Vol_t + \alpha_5 Kospi_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (12)$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 Kospi_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \quad (13)$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 \text{Kospi}_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}. \quad (14)$$

Note: Vol_t is the volatility of the KOSPI 200 in period t; Kosp_t is the mean of the KOSPI 200 in period t.

As a third robustness test, we use another alternative measurement for volatility by calculating the standard deviation of the annual corporate bond daily market interest rate. Previous research has reviewed use of this measurement as the volatility of the domestic economy [51]. In this study, the corporate bond market interest rate data cover the period 1995–2020, and the trend during the period is presented in Figure 4. The volatility in 1997 and 1998 is very high, which corresponds to that of the exchange rate volatility. However, the volatility in 2008 is not as high as the exchange rate volatility. This may be because South Korea's domestic economy did not sustain much damage from the 2008 financial crisis. When we include the corporate bond market interest rate volatility variable, we also control for the yearly mean of the corporate bond market interest rate. Tables 9 and 10 repeat the regressions used in Equations (15)–(20) shown below, replacing the KOSPI 200

Table 7: Regression results for the dependent variable-Tobin's Q (KOSPI 200 volatility).

Dependent variable: Tobin's Q(t)	Model (9)	Model (11)	Model (13)
R&D(t)	5.465 ***	7.368 ***	7.371 ***
Advertising(t)	6.237 **	6.970***	6.959*
R&D(t) × Volatility(t)		-0.534	-0.535
Advertising(t) × Volatility(t)			0.002
Volatility(t)	0.005	0.015	0.015
KOSPI 200(t)	−0.013	−0.013	−0.013
Asset(t)	0.043	0.037	0.043
Employee(t)	0.021	0.019	0.019
Age(t)	−0.007 ***	−0.007 ***	−0.007 ***
Export ratio(t)	−0.313	−0.290 *	−0.290*
Overseas expenditure(t)	−5.242	−4.375	−4.375
Constant	0.406	0.357	0.357
N	255	255	255
Overall R^2	0.217	0.221	0.221

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

Table 8: Regression results for the dependent variable-ROA (KOSPI 200 volatility).

Dependent variable: ROA(t)	Model (10)	Model (12)	Model (14)
R&D(t)	−0.086	−0.085	0.116
Advertising(t)	0.998 ***	1.088 ***	0.984 *
R&D(t) × volatility(t)			−0.057
Advertising(t) × volatility(t)		0.013	0.013
Volatility(t)	−0.004 *	−0.004 *	−0.004 *
KOSPI 200(t)	0.003 ***	0.003 ***	0.003 ***
Asset(t)	0.013 ***	0.013 ***	0.013 ***
Employee(t)	−0.001	−0.002	−0.002
Age(t)	−0.001 ***	−0.001 ***	−0.001 ***
Export ratio(t)	−0.059 ***	-0.059 ***	−0.057 ***
Overseas expenditure(t)	0.292	0.331	0.388
Constant	−0.296 ***	−0.296 ***	−0.300 ***
N	268	268	268
Overall R^2	0.258	0.258	0.262

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

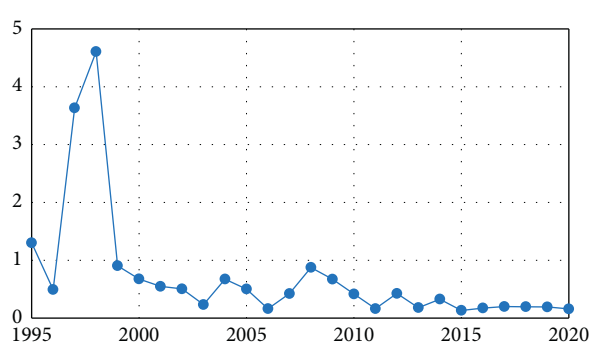


Figure 4: Volatility trend of market interest rates from 1995 to 2020.

volatility with the corporate bond market interest rate volatility. The results in Tables 9 and 10 exhibit the same pattern as in the previous tables, indicating that our main results are robust to these replacements or changes.

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 \text{Int}_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \tag{15}$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 Vol_t + \alpha_4 \text{Int}_t + \alpha_5 \text{Asset}_{i,t} + \alpha_6 Emp_{i,t} + \alpha_7 \text{Age}_{i,t} + \alpha_8 Expratio_{i,t} + \alpha_9 \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \tag{16}$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 Vol_t + \alpha_5 \text{Int}_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,} + \varepsilon_{i,t}, \tag{17}$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 AD_{i,t} \times Vol_t + \alpha_4 Vol_t + \alpha_5 \text{Int}_t + \alpha_6 \text{Asset}_{i,t} + \alpha_7 Emp_{i,t} + \alpha_8 \text{Age}_{i,t} + \alpha_9 Expratio_{i,t} + \alpha_{10} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \tag{18}$$

$$Q_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 \text{Int}_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}, \tag{19}$$

$$P_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 AD_{i,t} + \alpha_3 RD_{i,t} \times Vol_t + \alpha_4 AD_{i,t} \times Vol_t + \alpha_5 Vol_t + \alpha_6 \text{Int}_t + \alpha_7 \text{Asset}_{i,t} + \alpha_8 Emp_{i,t} + \alpha_9 \text{Age}_{i,t} + \alpha_{10} Expratio_{i,t} + \alpha_{11} \text{OverseasExp}_{i,t} + \varepsilon_{i,t}. \tag{20}$$

Table 9: Regression results for the dependent variable-Tobin's Q (interest rate volatility).

Dependent variable: Tobin's Q(t)	Model (15)	Model (17)	Model (19)
R&D(t)	6.584 ***	8.115 ***	7.862 ***
Advertising(t)	1.387	1.824	3.678**
R&D(t) × volatility(t)		−3.551 **	−2.843 **
Advertising(t) × volatility(t)			−2.387 **
Volatility(t)	0.034	0.063 **	0.087 **
Interest rate(t)	−0.027 **	−0.026 ***	−0.027 ***
Asset(t)	−0.002	0.001	0.006
Employee(t)	0.018	0.017	0.014
Age(t)	−0.004 ***	−0.004 ***	−0.004 ***
Export ratio(t)	−0.195 **	−0.185 **	−0.208 **
Overseas expenditure(t)	0.613	0.335	0.102
Constant	1.318 **	1.210 **	1.086 **
N	529	529	529
Overall R^2	0.192	0.202	0.208

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

Table 10: Regression results for the dependent variable-ROA (interest rate volatility).

Dependent variable: ROA(t)	Model (16)	Model (18)	Model (20)
R&D(t)	−0.150	−0.148	−0.143
Advertising(t)	0.907 ***	1.019 ***	1.019 ***
R&D(t) × volatility(t)			−0.010
Advertising(t) × volatility(t)		−0.137	−0.135
Volatility(t)	−0.005	−0.003	−0.003
Interest rate(t)	0.001	0.001	0.001
Asset(t)	0.005	0.005	0.005
Employee(t)	0.005 *	0.005 *	0.005 *
Age(t)	−0.001 ***	−0.001 ***	−0.001 ***
Export ratio(t)	−0.032 **	−0.034 **	−0.034 **
Overseas expenditure(t)	−0.259	−0.277	−0.277
Constant	−0.086	−0.095	−0.095
N	556	556	556
Overall R^2	0.121	0.122	0.122

Note. The symbols ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

Note: Vol_t is the volatility of market interest rate in period t; Int_t is the mean of market interest rate in period t.

5. Conclusions and Implications

The RBV has been developed as an influential theoretical lens in the management field [6]. Although the importance of resources for firm performance is generally recognized by academia, debate continues regarding the types of resources that aid in firm performance, how resources contribute to firm performance, and whether the effects of these resources are sustained in a volatile environment. Our findings address these debates and provide some solutions.

First, using a sample of Korean KOSPI manufacturing firms, this study provides additional evidence that critical intangible resources such as R&D and advertising positively affect firm performance. However, when firm performance is broken down into firm value and firm profitability, there is an obvious contrast between the effects of R&D and advertising. R&D resources have a larger effect on firm value than advertising resources. Meanwhile, advertising resources have a larger effect on firm profitability than R&D resources. Firm value and firm profitability represent two different dimensions of or criteria for firm performance. Firm value primarily represents consumers' appreciation and the effectiveness of firm operations. R&D resources contribute more towards satisfying and improving value for consumers, thus helping maximize effectiveness. By contrast, firm profitability is more concerned with a firm's intrinsic side, which is associated with efficiency. Advertising resources play an important role in creating price premiums or increasing sales to enhance efficiency. In such mechanisms, R&D and advertising resources contribute to firm performance. This study adopts accounting data to measure firm performance, which is a more objective performance measurement than survey data. According to preceding studies, the relationship between resources and firm performance is stronger when subjective performance indicators are used [42]. Therefore, this study's results provide more conservative estimates for hypotheses testing, as it uses objective performance measurements. Previous research also finds that panel data analysis reports much weaker resource effects than cross-sectional data analysis [42]. Thus, the results of this study, which uses panel data, indicate that the effects of the two resources on firm performance are significant and sustained.

Second, the finding that R&D affects firm value more than advertising does and that advertising has a greater impact on firm profitability than R&D does indicates the relatedness and mutual dependence of these two resources. A firm not only pays attention to firm value, but also simultaneously manages firm profitability, since a proper balance between effectiveness and efficiency is at the heart of a firm's sustainability. This interrelationship implies that a good combination of R&D and advertising resources may amplify the independent effect of either R&D or advertising on firm performance [52]. With R&D resources, firms develop more innovative and differentiated products, while with advertising resources, firms promote these new products to exploit and create a market. Thus, firms can improve their performance through the synergy of R&D and advertising, creating a vital competitive edge that is not easily visible in average firms.

Third, our findings confirm that the effects of R&D and advertising resources are not diminished in volatile environments. Although our study does not find that environmental volatility has significantly negative effect on firm performance, previous research [39] has found that changing environments harm firm performance. Accordingly, there is concern that resource effects on firm performance are reduced or lost in an adverse environment. By contrast, this study finds that the effects of R&D and advertising resources on firm performance are maintained in a volatile environment. Some earlier studies on the effects of resources do not consider environmental dynamism or use a single and stable environmental setting (e.g., [53–55]). To overcome these earlier limitations, this study incorporates environmental volatility in the regressions. The results show that the effects of R&D and advertising resources remain constant in any environment. Some recent literature has found that environmental fluctuations strengthen the relationship between dynamic capability and firm performance [42]; however, in our study, environmental factors do not positively moderate the relationship between R&D/advertising resources and firm performance. Thus, we infer that R&D and advertising resources may be considered "ordinary capabilities," serving as cornerstones of firm operations, rather than "dynamic capabilities" [40].

Finally, the effects of some of the control variables used in this study also have implications. The effects of firm age and the export ratio remain negative and significant in all regressions, including robustness tests, although the magnitudes of their coefficients are so small that they almost lose economic significance. However, we infer from the consistent results that firm age may have a negative effect on firm performance under conditions of environmental volatility. This means that a firm with a longer history may have difficulty adapting to environmental changes because of organizational inertia, and the effects of experience are not as helpful in such a dynamic environment [37]. The fact that the export ratio also has a negative effect on firm performance indicates that, under conditions of environmental volatility, a higher export ratio is not good for firm performance because export sales may cause more uncertainty and problems than domestic sales [46].

Regarding its practical implications, this study presents strategic guidelines for firms aiming to improve firm performance. First, managers should clearly distinguish between firm value and firm profitability when considering firm performance. They should sort out which resources play major roles in improving each criterion of firm performance. R&D resources contribute more to firm value, while advertising resources contribute more to firm profitability. Firm value represents effectiveness, while firm profitability represents efficiency. Thus, for firm sustainability, managers should analyse which is lacking, effectiveness or efficiency. If effectiveness (efficiency) is more urgent for the firm, within the range of these two resources, managers should invest more in R&D (advertising) resources. The inseparable relationship between effectiveness and efficiency for firm performance highlights that R&D and advertising resources are closely related to each other. Therefore, management should consider R&D and advertising resources jointly in decision-making because the combination of the two resources may create great synergy, especially for manufacturing firms. This finding also warns that firms cannot achieve the expected return if they invest disproportionately in these two resources.

Next, the support for the hypotheses that environmental volatility does not lessen the impact of R&D and advertising on each criterion of firm performance more strongly underscores the importance of R&D and advertising resources for firms. When faced with economic fluctuations and volatility, firms mistakenly believe R&D and advertising investment are things that can be postponed or reduced to address short-term liquidity. It is a misguided strategy to reduce the budget for R&D and advertising to recover from a negative environment. Firms should accumulate and exploit these two resources consistently, regardless of environmental dynamics, to sustain their competitive advantage.

Finally, the effects of firm age and the export ratio in our empirical analysis can also provide practical implications for firm officials. Firm age may have negative effects on firm performance, especially under conditions of environmental volatility; therefore, firms with a longer history should care more about adapting to environmental change. They should overcome organizational inertia, which impedes innovation and creativity, and stimulate passion for challenging new things. The negative effects of the export ratio highlight the domestic market's importance, especially under conditions of environmental volatility. Firms are aggressive in opening up overseas markets, but they must remember that sales in the domestic market are fundamental for firm performance, especially in the presence of environmental uncertainty. Thus, firms should secure a certain amount of domestic sales regardless of the circumstances, including cases in which the overseas market shows explosive growth.

We acknowledge that this study has some limitations and suggest further research to overcome these limitations. First, future research can provide additional evidence by examining this topic in the context of other countries to improve reliability in terms of generalizing the study's implications. Second, this study focuses on R&D and advertising resources to explain the impact of firm resources on firm performance; future research can investigate other critical resources, such as human capital management, knowledge management, strategic decision-making, and cooperation. Third, although this study's estimation using financial performance measures provides a more conservative estimation of the resource-performance relationship, future research that implements surveys can yield new insights through a process-oriented approach. Such studies may investigate a more detailed mechanism through which resources work for firm performance. Fourth, we restricted environmental volatility to economic volatility, although we measure economic volatility using three different indexes, including robustness tests. Future research can expand the concept of volatility to other dimensions, such as political uncertainty and industrial turbulence. These types of volatility may require firms to use other resources to overcome them and adjust.

Notwithstanding these limitations, we believe that this study has both theoretical and practical contributions.

Specifically, it reaffirms the RBV and shows the importance of R&D and advertising resources. More importantly, we investigate how R&D and advertising resources contribute differently to firm performance by separating firm performance into firm value and firm profitability. As firms benefit from the simultaneous realization of effectiveness and efficiency, the effects of R&D and advertising are inseparable, and they are interrelated in achieving firm sustainability. Furthermore, the effects of R&D and advertising do not disappear in a volatile environment. The robustness of our results suggests that R&D and advertising resources are reliable sources of success, and firms should not curtail investments in these resources when they are confronted with an adverse environment. This study reaffirms that firm heterogeneity comes from heterogeneous resources.

Data Availability

The data used to support the findings of this study were supplied by KISVALUE under license and so cannot be made freely available. Requests for access to these data should be made to KISVALUE, https://www.kisvalue.com/web/index.jsp.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was conducted under Kwangwoon University's 2020 Research Grant. This work was supported by the Gachon University Research Fund of 2020 (GCU-202002660001).

References

[1] J. B. Barney, "Firm resources and sustained competitive advantage," *Journal of Management*, vol. 17, no. 1, pp. 99–120, 1991.

[2] K. Efrat and A. Shoham, "Born global firms: the differences between their short- and long-term performance drivers," *Journal of World Business*, vol. 47, no. 4, pp. 675–685, 2012.

[3] T. L. Andras and S. S. Srinivasan, "Advertising intensity and R&D intensity: differences across industries and their impact on firm's performance," *International Journal of Business and Economics*, vol. 2, no. 2, pp. 81–90, 2003.

[4] Y. K. Ho, H. T. Keh, and J. M. Ong, "The effects of R&D and advertising on firm value: an examination of manufacturing and nonmanufacturing firms," *IEEE Transactions on Engineering Management*, vol. 52, no. 1, pp. 3–14, 2005.

[5] K. W. Chauvin and M. Hirschey, "Advertising, R&D expenditures and the market value of the firm," *Financial Management*, vol. 22, no. 4, pp. 128–140, 1993.

[6] J. T. Mahoney and J. R. Pandian, "The resource-based view within the conversation of strategic management," *Strategic Management Journal*, vol. 13, no. 5, pp. 363–380, 1992.

[7] R. L. Priem and J. E. Butler, "Is the resource-based 'View' a useful perspective for strategic management research?" *Academy of Management Review*, vol. 26, no. 1, pp. 22–40, 2001.

[8] D. G. Sirmon, M. A. Hitt, and R. D. Ireland, "Managing firm resources in dynamic environments to create value: looking inside the black box," *Academy of Management Review*, vol. 32, no. 1, pp. 273–292, 2007.

[9] L. K. C. Chan, J. Lakonishok, and T. Sougiannis, "The stock market valuation of research and development expenditures," *The Journal of Finance*, vol. 56, no. 6, pp. 2431–2456, 2001.

[10] B. Lev and T. Sougiannis, "The capitalization, amortization, and value-relevance of R&D," *Journal of Accounting and Economics*, vol. 21, no. 1, pp. 107–138, 1996.

[11] M. Kotabe, "The relationship between offshore sourcing and innovativeness of U.S. Multinational firms: an empirical investigation," *Journal of International Business Studies*, vol. 21, no. 4, pp. 623–638, 1990.

[12] B. Wernerfelt, "A resource-based view of the firm," *Strategic Management Journal*, vol. 5, no. 2, pp. 171–180, 1984.

[13] B. Wernerfelt, "The resource-based view of the firm: ten years after," *Strategic Management Journal*, vol. 16, no. 3, pp. 171–174, 1995.

[14] J. B. Barney, "Looking inside for competitive advantage," *Academy of Management Perspectives*, vol. 9, no. 4, pp. 49–61, 1995.

[15] M. A. Peteraf, "The cornerstones of competitive advantage: a resource-based view," *Strategic Management Journal*, vol. 14, no. 3, pp. 179–191, 1993.

[16] J. B. Barney and W. Ouchi, *Organizational Economics: Toward a New Paradigm for Studying and Understanding Organizations*, Jossey-Bass, Hoboken, New Jersey, 1986.

[17] A. Phillips and R. E. Stevenson, "The historical development of industrial organization," *History of Political Economy*, vol. 6, no. 3, pp. 324–342, 1974.

[18] M. E. Porter, "The contributions of industrial organization to strategic management," *Academy of Management Review*, vol. 6, no. 4, pp. 609–620, 1981.

[19] G. A. Knight and S. T. Cavusgil, "Innovation, organizational capabilities, and the born-global firm," *Journal of International Business Studies*, vol. 35, no. 2, pp. 124–141, 2004.

[20] B. Kogut and U. Zander, "Knowledge of the firm, combinative capabilities, and the replication of technology," *Organization Science*, vol. 3, no. 3, pp. 383–397, 1992.

[21] B. Kogut and U. Zander, "What firms do? Coordination, identity, and learning," *Organization Science*, vol. 7, no. 5, pp. 502–518, 1996.

[22] D. J. Teece, G. Pisano, and A. Shuen, "Dynamic capabilities and strategic management," *Strategic Management Journal*, CO, vol. 18, no. 7, pp. 509–533, 1997.

[23] E. H. Bowman, "Epistemology, corporate strategy, and academe," *Sloan Management Review*, vol. 15, no. 2, pp. 35–50, 1974.

[24] A. D. Chandler, *Strategy and Structure: Chapters in the History of the Industrial Enterprise*, M.I.T. Press, Cambridge, MA, USA, 1962.

[25] M. E. Porter, *Competitive Strategy*, Free Press, New York, NY, USA, 1980.

[26] T. C. Powell, "Research notes and communications strategic planning as competitive advantage," *Strategic Management Journal*, vol. 13, no. 7, pp. 551–558, 1992.

[27] R. W. Hilton, M. W. C. Maher, and F. H. C. Selto, *Cost Management: Strategies for Business Decisions*, McGraw-Hill, New York, NY, USA, 2000.

[28] B. T. Khoa, L. T. Huynh, and M. H. Nguyen, "The relationship between perceived value and peer engagement in sharing

economy: a case study of ridesharing services," *Journal of System and Management Sciences*, vol. 10, no. 4, pp. 149–172, 2020.

[29] R. L. Priem, "A consumer perspective on value creation," *Academy of Management Review*, vol. 32, no. 1, pp. 219–235, 2007.

[30] E. J. Blocher, K. H. Chen, and T. W. Li, *Cost Management: A Strategic Emphasis*, McGraw Hill International, New York, NY, USA, 2002.

[31] J. Bain, *Barriers to New Competition: Their Character and Consequences in Manufacturing Industries*, Harvard University Press, Cambridge, MA, USA, 1956.

[32] M. Kotabe, S. S. Srinivasan, and P. S. Aulakh, "Multinationality and firm performance: the moderating role of R&D and marketing capabilities," *Journal of International Business Studies*, vol. 33, no. 1, pp. 79–97, 2002.

[33] H. S. Seo and Y. Kim, "Intangible assets investment and firms' performance: evidence from small and medium-sized enterprises in Korea," *Journal of Business Economics and Management*, vol. 21, no. 2, pp. 421–445, 2020.

[34] J. Weerawardena, G. S. Mort, P. W. Liesch, and G. Knight, "Conceptualizing accelerated internationalization in the born global firm: a dynamic capabilities perspective," *Journal of World Business*, vol. 42, no. 3, pp. 294–306, 2007.

[35] G. J. Hooley, G. E. Greenley, J. W. Cadogan, and J. Fahy, "The performance impact of marketing resources," *Journal of Business Research*, vol. 58, no. 1, pp. 18–27, 2005.

[36] J. C. Narver and S. F. Slater, "The effect of a market orientation on business profitability," *Journal of Marketing*, vol. 54, no. 4, pp. 20–35, 1990.

[37] D. Kelly and T. L. Amburgey, "Organizational inertia and momentum: a dynamic model of strategic change," *Academy of Management Journal*, vol. 34, no. 3, pp. 591–612, 1991.

[38] B. Kogut and N. Kulatilaka, "Operating flexibility, global manufacturing, and the option value of a multinational network," *Management Science*, vol. 40, no. 1, pp. 123–139, 1994.

[39] S. H. Lee and M. Makhija, "The effect of domestic uncertainty on the real options value of international investments," *Journal of International Business Studies*, vol. 40, no. 3, pp. 405–420, 2009.

[40] S. G. Winter, "Understanding dynamic capabilities," *Strategic Management Journal*, vol. 24, no. 10, pp. 991–995, 2003.

[41] P. Rivoli and E. Salorio, "Foreign direct investment and investment under uncertainty," *Journal of International Business Studies*, vol. 27, no. 2, pp. 335–357, 1996.

[42] A. Karna, A. Richter, and E. Riesenkampff, "Revisiting the role of the environment in the capabilities-financial performance relationship: a meta-analysis," *Strategic Management Journal*, vol. 37, no. 6, pp. 1154–1173, 2016.

[43] F. K. Reilly, A. F. McGann, and R. A. Marquardt, "Advertising decision and stockholders' wealth," *Journal of Advertising Research*, vol. 17, no. 4, pp. 49–56, 1977.

[44] X. Piao and J. J. Moon, "When does knowledge similarity help foreign firms improve performance?" *Asian Business & Management*, vol. 18, no. 4, pp. 301–323, 2019.

[45] P. S. Aulakh, M. Kotabe, and H. Teegen, "Export strategies and performance of firms from emerging economies: evidence from Brazil, Chile, and Mexico," *Academy of Management Journal*, vol. 43, no. 3, pp. 342–361, 2000.

[46] T. Kwak, "Changes in real exchange rate and business fluctuations: a comparative study of Korea and Japan," *International Area Studies Review*, vol. 3, no. 3, pp. 309–330, 2009.

[47] B. N. Iyke and S. Y. Ho, "Consumption and exchange rate uncertainty: evidence from selected Asian countries," *The World Economy*, vol. 43, no. 9, pp. 2437–2462, 2020.

[48] K. H. Chung and S. W. Pruitt, "A simple approximation of Tobin's q," *Financial Management*, vol. 23, no. 3, pp. 70–74, 1994.

[49] T. Khanna and K. Palepu, "Is group affiliation profitable in emerging markets? An analysis of diversified Indian business groups," *The Journal of Finance*, vol. 55, no. 2, pp. 867–891, 2000.

[50] J. M. Lim and S. C. Lee, "Relationship between characteristics of board of directors and excess cash holdings," *World Journal of Accounting, Finance and Engineering*, vol. 2, no. 1, pp. 31–36, 2018.

[51] J. Y. An, H. S. Lee, and H. C. Ju, "Volatility by the level of interest rate and RBC," *Journal of the Korean Data and Information Science Society*, vol. 25, no. 6, pp. 1507–1520, 2014.

[52] C. L. Peng, A. P. Wei, M. L. Chen, and W. T. Huang, "Synergy between R&D and advertising on shareholder value: does firm size matter?" *Canadian Journal of Administrative Sciences - Revue Canadienne des Sciences de l Administration*, vol. 35, no. 1, pp. 47–64, 2018.

[53] A. Z. Acar and C. Zehir, "The harmonized effects of generic strategies and business capabilities on business performance," *Journal of Business Economics and Management*, vol. 11, no. 4, pp. 689–711, 2010.

[54] O. Chatain, "Value creation, competition, and performance in buyer-supplier relationships," *Strategic Management Journal*, vol. 32, no. 1, pp. 76–102, 2011.

[55] M. Q. Collins and E. Galbraith, "A study on advertising strategy based on the impact of a business reputation on the market," *International Journal of Smart Business and Technology*, vol. 9, no. 2, pp. 107–118, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6807145, 9 pages
https://doi.org/10.1155/2022/6807145

Research Article

Research on How External Environment Influences Digitalization of Cultural Enterprises

Hao Ji,[1] **Yu Pang**,[2] **Lingling Suo**,[1] **and Tongtong Wang**[1]

[1]*Business College, Beijing Union University, Beijing, China*
[2]*Management College, Beijing Union University, Beijing, China*

Correspondence should be addressed to Hao Ji; hao.ji@buu.edu.cn

Received 13 July 2022; Accepted 23 July 2022; Published 6 September 2022

Academic Editor: Lele Qin

Digitalization is critical to the growth of cultural industry today. However, existing research has not explained the mechanism by which the external environment affects the digitalization of cultural enterprises. Based on structural equation modeling, we tested the model empirically using data from 295 cultural enterprises in Beijing. The results show that two external environmental variables, the market pressure and the government's supportive policies, have a positive impact on the adoption of digitalization in cultural enterprises through technical and organizational factors. The research conclusion explains how the external environment influences digitalization in cultural enterprises. Technological factors of digitalization capability and digitalization compatibility and organizational factors of perceived benefits play a mediating role between the external environment and the digitalization of cultural enterprises. Based on these conclusions, we finally put forward a series of countermeasures to enhance the digitalization of cultural enterprises.

1. Introduction

With the development of the digital economy, a new generation of digital technologies represented by big data, artificial intelligence, Internet of things, cloud computing, blockchain, etc., has radiated to many industries in the cultural industry, expanding the boundaries of the cultural industry and extending the cultural industry chain. New products and new formats of the digital cultural industry emerge in an endless stream. Taking China as an example, according to the data from the National Bureau of Statistics of China, among the cultural and related industries above designated size, the 16 industry subcategories with obvious characteristics of the new digital culture format have achieved an operating income of 3,962.3 billion yuan in 2021, which was an increase of 18.9% over the previous year, also an average increase of 20.5% for the two years.

In recent years, scholars have conducted various research projects on the motivations of enterprise digitalization, but the research objects are mostly concentrated in manufacturing, construction, and large- and medium-sized enterprises. Since these companies usually have more social and technological resources, they have more advantages in the face of digital transformation. However, existing studies have neglected the digital motivation of traditional cultural industries. The cultural industry is an important pillar industry of the national economy. Under the influence of COVID-19 and fierce external competition, the survival crisis and the development challenges they face are more prominent. It is urgent to survive and develop through digital construction. Therefore, it is necessary to explore the factors influencing the adoption of digital technology in cultural enterprises in the background of digital transformation.

Secondly, a number of studies have discussed the factors that influence the adoption of digital technologies by companies based on technology adoption theory. However, most of the above studies focus on technology and enterprise level, ignoring the role of the external environment. In view of this, this paper will construct and test how external environmental factors affect the adoption of digital technology by cultural enterprises empirically based on the TOE framework.

This paper hopes to provide both theoretical and practical contributions. Theoretically, it provides arguments for how external environmental factors affect the adoption of digital technology and complements and improves existing research. In practice, by explaining the influencing factors and influence paths of enterprises in the cultural industry adopting digital technology, it provides a reference for the ways in which enterprises in the cultural industry adopt digital technology. It also enlightens the macro-support policies for the digital transformation of the cultural industry.

2. Theoretical Basis and Model Hypothesis

2.1. Theoretical Background and Hypothesis. Technology adoption theory has always been the focus of scholars at home and abroad, mainly used to explain or predict the influencing factors of individuals or organizations adopting new information technologies. The technology acceptance model (TAM), first proposed by Davis [1], uses rational behavior theory to explore the factors that affect individuals' acceptance of information systems. The TAM model proposes that the easiness and usability of perception determine attitudes and behavioral intentions to accept information technology together.

The unified theory of acceptance and use of technology (UTAUT) proposed by Venkatesh et al. [2] explains the organization's acceptance of new technology at the enterprise level. Venkatesh et al. [2] believed that expected performance, expected workload, social influence, promotion conditions, hedonic motivation, price value, and habits all affect the organization's behavioral intentions, and its behavioral intentions will further affect user behavior. This theory was subsequently extended to research on consumer acceptance and use of the mobile Internet.

Based on the TAM and UTAUT models, Tornatzky and Fleischer [3] proposed a technology-organization-environment theoretical model (TOE) by introducing macro-dimensional variables. The TOE model explores and explains the reasons why enterprises adopt new technologies by considering the factors of technology, enterprise, and external environment at the same time. Among them, technical factors are related to the internal and external technologies and alternative potential technologies of enterprises; enterprise factors refer to the characteristics of enterprises, such as the size and resources of enterprises; external environmental factors include market factors, competitors, and regulatory environment. In the background of digital transformation, the external environment can make cultural enterprises fully aware that digital technology can affect the competitiveness of cultural enterprises, which in turn affects the strategic decision of cultural enterprises whether to adopt digital technology.

The TOE framework includes three levels—technology, organization, and environment—and is highly systematic. At the same time, for the adoption of different technologies, the TOE model allows the specific components of the technical dimension, the organizational dimension, and the environmental dimension to be different, so the final decisive factors are different according to the actual situation. The TOE model examines the advantages within the organization, outside the organization and technology, and has good operability and clear structure. Therefore, the model has been widely supported and applied in the research of enterprise technology adoption.

Based on the TOE theory and referring to the research of Lv et al. [4], this paper will analyze the impact of the external environment on the adoption of digital technology by cultural enterprises.

2.2. Adoption of Digital Technology in the Cultural Industry. In view of the important role of digital technology in enterprise development, many scholars have studied the direct factors of enterprise digital technology adoption from the perspective of technology and enterprises. A review of the existing literature shows that most of the research focuses on manufacturing, construction, and small- and medium-sized enterprises. Few research studies focus on the factors of digital technology adoption in the cultural industry. And most research studies only verify the direct impact of technology and business factors on the adoption of digital technology, ignoring the impact of external environments such as government policies and competitive pressures. Therefore, the paper will introduce external environmental factors on the basis of existing research and construct a hierarchical model in which the external environment affects the adoption of digital technology in the cultural industry through the mediation of technical and environmental factors.

2.2.1. Environment Level. Most scholars believe that government policies, especially those about tax cuts, low-interest loans, or intellectual property regulations, can enhance competitive advantage and boost corporate performance. The formation and development of the digital cultural industry benefit from the promotion of government policies. With the advent of the digital age, governments around the world have successively issued a series of policies to promote the development of the digital cultural industry. Taking China as an example, in 2019, the General Office of the State Council of China issued "Opinions on Further Stimulating the Potential of Cultural and Tourism Consumption." The document calls for promoting the integration of culture, tourism, and modern technology and developing a new generation of immersive experiential culture and tourism consumption content based on technologies such as 5 G, ultra-high definition, augmented reality, virtual reality, and artificial intelligence. The "Opinions of the Ministry of Culture and Tourism on Promoting the High-Quality Development of the Digital Cultural Industry" issued by the Ministry of Culture and Tourism of China in 2020 pointed out that the deep integration of the cultural industry with the digital economy and the real economy should be promoted, and it was clearly proposed to implement the digitalization strategy of the cultural industry and promote the high-quality development of the digital cultural industry. In

2020, 13 departments including the National Development and Reform Commission, the Central Cyberspace Administration of China, and the Ministry of Industry and Information Technology issued "Opinions on Supporting the Healthy Development of New Business Formats and New Models, Activating the Consumer Market and Driving Employment Expansion," which proposes that relying on the national data sharing and open platform system, new business forms and new models that support online and offline integration should be regarded as important breakthroughs in economic transformation and promotion of reform and innovation. The document also proposes to support the development of 15 new formats and models, including a series of new formats and models related to the cultural industry, such as online education, industrial platform development, and digital transformation of traditional enterprises. In 2021, the Fourteenth Five-Year Plan for the National Economic and Social Development of the People's Republic of China and the Outline of the Vision for 2035 clearly stated that it is necessary to implement the digitalization strategy of the cultural industry and accelerate the development of new cultural enterprises, cultural formats, and cultural consumption models. In terms of specific policies, in addition to financial and market support, it also actively promotes various cultural industry associations to hold competitions, exhibitions, seminars, training, international exchanges, and other activities. In addition to the national unified policy promotion, each region also has its own regional support policies. Taking Haidian District, Beijing's support policy for the e-sports industry as an example, the government promotes game research and development and content creation, gathers game companies and e-sports clubs, supports the construction of e-sports venues and the holding of events, and supports the development of game e-sports exchange activities. At the same time, the government also strengthens talent support, optimizes the business environment, and provides a series of subsidies and incentive policies in these areas. Haidian District Government especially supports innovative entities to build a common technology platform for game development, an open source and open innovation platform, a public technology service platform, and a game engine research and development platform. According to the innovation and investment amount, a maximum of 10 million yuan of financial subsidies will be given. Therefore, this paper proposes the following hypotheses:

H1a: Government policy has a positive influence on the digital ability of cultural enterprises.

H1b: Government policy has a positive influence on the digital compatibility of cultural enterprises.

H1c: Government policy has a positive influence on cultural enterprises' perceived gains from digital technologies.

From the market perspective, the digital transformation of traditional cultural industries and the expansion of digital platform businesses are more due to concerns about their own survival crisis and market competition. Affected by COVID-19, the traditional cultural industry has been severely impacted. Taking China as an example, it is facing difficulties such as the complete suspension of cultural tourism, the cancellation of the nighttime economy, the closure of offline entertainment, and the low ebb of cultural investment and financing. On the other hand, competitive pressure forces companies to adopt new technologies to maintain their competitive advantage. Competitive pressure refers to the degree of pressure that cultural enterprises feel from commercial competitors. Several empirical studies have shown that, when the number of competitors adopting new technologies increases, companies perceive competitive pressures and quickly turn technology adoption ideas into strategic needs. Therefore, to maintain their competitiveness in the cultural industry, cultural enterprises will increasingly adopt digital strategies to facilitate interaction with other organizations and users. Taking the film and television industry as an example, the established large-scale cultural media groups are building their own digital audiovisual platforms. For example, Disney Group launched Disney+ at the end of 2019. Comcast's NBCUniversal launched Peacock in April 2020. WarnerMedia launched the HBO Max digital video service platform in May. Based on the above literature, the following hypotheses are proposed:

H2a: Survival and competitive pressures have a positive influence on the digital ability of cultural enterprises.

H2b: Survival and competitive pressures have a positive influence on the digital compatibility of cultural enterprises.

H2c: Survival and competitive pressures have a positive influence on cultural firms' perceived gains from digital technologies.

2.2.2. Technical Level. Digital competence refers to the ability of cultural enterprises to understand, use, and exploit digital technologies. In the context of digital transformation, technological capabilities, especially digital technology capabilities, greatly affect whether companies adopt and use digital technology. Digital compatibility refers to the degree to which digital technologies are compatible with the existing, previous practices, and current needs of cultural enterprises using digital technologies. The digital technologies adopted by cultural enterprises must be compatible with their existing technological resources or strategic strategies. Otherwise, enterprises may choose to abandon the adoption of digital technologies for fear of the negative impact of technological incompatibility. Accordingly, the following hypotheses are proposed:

H3: Digital ability has a positive influence on the adoption of digital technologies by cultural enterprises.

H4: Digital compatibility has a positive influence on the adoption of digital technologies by cultural enterprises.

2.2.3. Enterprise Level. In the background of digital technology, perceived benefit refers to the degree to which cultural enterprises believe that digital technology can bring effective benefits to the enterprise. The fundamental reason why cultural enterprises have perceived gain is that the unique nature of digital technology can make cultural enterprises believe that digital technology can bring innovation and competitive advantage to their products or services. Combining digital technology with product or service innovation can not only help cultural enterprises to expand their market share but also ensure that cultural enterprises can survive and continue to grow for maximum benefit. At the same time, the continuous integration of digital technology and the real economy has also brought the ecological development trend of multidimensional symbiosis and sharing to the cultural industry. Combined with digital communication methods, various emerging cultural industry activities can be carried out, such as digital exhibitions of cultural relics, digital cultural tourism, and online live broadcasts, to realize the development, preservation, and appreciation of cultural and creative resources. Considering the possible benefits that cultural enterprises may bring when they embrace or use digital technologies, we propose the following hypotheses:

> H5: Perceived gain from digital technologies has a positive influence on the adoption of digital technologies in cultural enterprises.

Therefore, the research model of this paper is established, as shown in Figure 1.

3. Research Method

3.1. Investigation Process and Sample Characteristics. We got the data by distributing questionnaires to cultural industry practitioners. There are two sample sources. The first one was a random survey of cultural enterprises in Beijing's cultural and creative industry clusters including Zhongguancun Creative Industry Pilot Base, Shijingshan Beijing Digital Entertainment Industry Demonstration Base, Daxing National New Media Industry Base, etc. A total of 194 valid paper questionnaires were obtained after excluding items with missing answers and those with obvious regularity in answering. The second one was to send online questionnaires to practitioners in the cultural industry by e-mail, and a total of 101 valid questionnaires were recovered.

To avoid false inferences, the paper and electronic questionnaires were tested for homogeneity before the data were combined. The chi-square value showed that the two groups of questionnaires were not different in major respects and could be combined, resulting in a total of 295 questionnaire samples. The interviewed companies came from the culture and art industry, the press and publication industry, the radio, television, and film industry, the advertising and exhibition industry, the art trading industry, and the multimedia industry.

3.2. Scale Design. Our questionnaire was designed on the basis of a literature review. Based on the scales used in the existing research, each item is evaluated and modified one by one to adapt to the specific environment of digital technology in China. The questionnaire scale of the study is based on the existing mature scale design. In addition to demographic indicators, it includes government policies, survival and competitive pressures, digital ability, digital compatibility, perceived gains, and digital technology adoption behaviors. The items to measure government policy are from Lai et al. [5], to measure survival and competition pressure are from Low et al. [6], to measure digital ability are from Zhu and Kraemer [7], to measure digital compatibility are from Zhu et al. [8], to measure perceived gain are from Lai et al. [5], and the items to measure digital technology adoption behavior are from Gangwar [9].

After completing the preliminary design of the questionnaire, we discussed with relevant scholars. We also conducted field visits in cultural and creative industries gathering areas and revised the initial questionnaire according to the opinions of the respondents. At the same time, to ensure the applicability of the questionnaire to Chinese cultural industry practitioners, 50 samples were selected for the pretest of the scale to ensure that the semantics of each item are unambiguous, properly arranged, and discriminative. The 50 pre-samples were divided into low group and high group with 27% and 73% as quantiles. After the independent sample t-test, the subjects with significant difference in mean, that is, with discriminating power, were retained. All scales were scored using a Likert 7-point scale, with "1" to "7" representing "strongly disagree" to "strongly agree."

3.3. Research Tools. We used structural equation modeling (SEM) in this paper and utilized the software SPSS22 and Amos24.0 for data analysis and model validation.

4. Research Results

The study followed a two-step analysis of structural equations, confirmatory factor analysis to measure the validity of the model construction, and path analysis and significance analysis of the structural model. We also examined the mediation effect to understand the mechanism of action of the model.

4.1. Confirmatory Factor Analysis. Confirmatory factor analysis is an important step in performing structural equation analysis. Before proceeding with the structural equation path analysis, it should be determined whether the measured items can correctly reflect the research aspect. We tested the validity of the scales of government policy, survival and competition pressure, digital competence, digital compatibility, perceived gain, and digital technology adoption through confirmatory factors.

Firstly, we tested the convergent validity of the scale. Convergent validity means that items with the same latent trait fall on the same factor dimension, and the measured

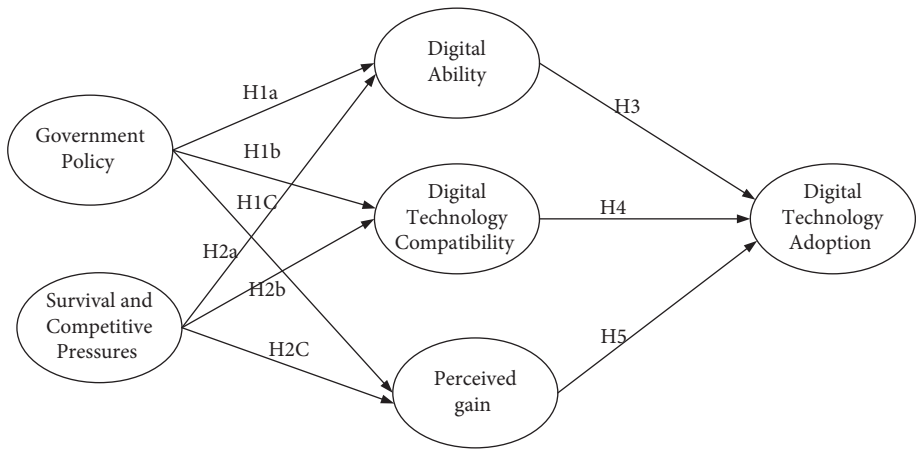


Figure 1: Research model and hypotheses.

Table 1: Reliability and convergent validity.

Construct	Items	Factor loading	CR	AVE
Government policy (GP)	GP1	0.908	0.889	0.728
	GP2	0.881		
	GP3	0.763		
Survival and competitive pressures (SCP)	SCP1	0.808	0.842	0.572
	SCP2	0.786		
	SCP3	0.684		
	SCP4	0.741		
Digital ability (DA)	DA1	0.676	0.749	0.499
	DA2	0.700		
	DA3	0.741		
Digital compatibility (DC)	DC1	0.767	0.848	0.584
	DC2	0.768		
	DC3	0.850		
	DC4	0.660		
Perceived gain (PG)	PG1	0.868	0.900	0.751
	PG2	0.952		
	PG3	0.770		
Digital technology adoption (DTA)	DTA1	0.754	0.893	0.737
	DTA2	0.935		
	DTA3	0.877		

values of the items are highly correlated. Fornell and Larcker [10] pointed out that the criteria for good convergent validity are factor loading greater than 0.5; combination reliability (CR) greater than 0.6; and average variance extracted (AVE) greater than 0.5. The test results are shown in Table 1. The standardized loadings of all items in the scale are above 0.5 and are significant; CR is greater than 0.8, and the AVE is greater than 0.5. This indicates that the scale has good convergent validity.

Secondly, we tested the discriminant validity between facets to detect that the underlying traits represented by each facet were significantly different from those of other facets. We adopted the method of Hair et al. [11]. In this study, the correlation coefficient between the facets of the measurement model was set to 1. If rejected, there is discriminant validity between the dimensions. Specifically, this study compared a restricted model, restricting the correlation coefficient between facets to 1, with an unrestricted model. We then compared the difference in the chi-square values of the two models and divided the difference between the chi-square values of the restricted and unrestricted models by the difference in the degrees of freedom of the two. If the difference of the chi-square value is larger and reaches a significant level, the difference of the chi-square value is 7.879; when $p = 0.001$, it indicates that there is a significant difference between the two models, and the discriminant validity is higher. The discriminant validity analysis results are shown in Table 2. The differences in chi-square values were significant, indicating that there was good discriminant validity among the dimensions.

Table 2: Discriminant validity.

Constructs constrained	χ^2	Degrees of freedom	χ^2 difference
Default model	247.171	155	—
(GP, SCP)	296.341	156	49.17***
(GP, DA)	271.955	156	24.784***
(GP, DC)	291.801	156	44.63***
(GP, PA)	293.893	156	46.722***
(GP, DTA)	304.778	156	57.607***
(SCP, DA)	274.653	156	27.482***
(SCP, DC)	296.341	156	49.17***
(SCP, PA)	288.796	156	41.625***
(SCP, DTA)	301.441	156	54.27***

* p-value <0.05; ** p-value <0.01; and *** p-value <0.001.

4.2. Goodness-of-Fit of the Structural Model. The degree of fitness is measured by the degree of consistency between the theoretical hypothesis model estimated by the model and the actual data of the sample. The better the fitness is, the closer the expected covariance matrix is to the sample matrix. A good fitness index is a necessary condition for structural equation analysis. The compatibility index values of this paper are shown in Table 3. It can be seen that except for the RMSEA index, the other fitness index values all meet the ideal standard required by SEM analysis, and the RMSEA index is still within the acceptable critical value (≤0.1), indicating that the fitness of this model is acceptable.

Table 3: Goodness-of-fit of the structural model.

Statistical check	Goodness-of-fit criteria	Structural model
χ^2/df	≤5	1.595
CFI	≥0.92	0.973
NFI	≥0.90	0.931
IFI	≥0.90	0.973
TLI	≥0.90	0.967
PGFI	≥0.50	0.680
PCFI	≥0.50	0.794
PNFI	≥0.50	0.759
SRMR	≤0.08	0.048
RMSEA	≤0.08	0.045

4.3. Path Coefficients for Structural Equation Models. The model fitting results are shown in Figure 2, and the standardized path coefficients and hypothesis verification results are shown in Table 4. Except for H1c, the p values of the other hypotheses of the path coefficients are all significant and supported. It shows that government policies have a positive impact on the improvement of digital ability and digital compatibility of enterprises, and the survival and competition pressure of the market will improve the digital ability and digital compatibility of enterprises and will make enterprises perceive benefits. Furthermore, the improvement of corporate digital ability and digital compatibility, as well as corporate perception benefits, will push cultural companies to further adopt digital technologies. However, H1c has not been supported.

4.4. The Mediating Effect of Digital Ability, Digital Technology Compatibility, and Perceived Gain. To understand the combined impact of government policies and survival and competitive pressures from the market on digital technology adoption, further analysis of mediation effects is required. The external environment has an impact on the adoption of digital technologies through technological and corporate factors. On the one hand, the external environment prompts cultural enterprises to have sufficient digital ability, and the digital technology adopted should be compatible with the current business or future development direction of cultural enterprises. This is a technically necessary condition for cultural enterprises to adopt new technologies. On the other hand, the pressure of the external environment will further prompt enterprises to perceive the benefits brought by digital technology. External environmental factors need to be driven by the internal interests of the enterprise to reflect its impact on the adoption of digital technology in cultural enterprises. We used the Sobel, Aroian, and Goodman tests. When the z value is greater than 2, the mediating effect is significant.

Formulas for the tests provided here were drawn from the studies of MacKinnon et al. [12] and from MacKinnon et al. [13]:

Sobel test equation:

$$z - \text{value} = \frac{a * b}{SQRT\,(b2 * sa2 + a2 * sb2)}. \quad (1)$$

Aroian test equation:

$$z - \text{value} = \frac{a * b}{SQRT\,(b2 * sa2 + a2 * sb2 + sa2 * sb2)}. \quad (2)$$

Goodman test equation:

$$z - \text{value} = \frac{a * b}{SQRT\,(b2 * sa2 + a2 * sb2 - sa2 * sb2)}. \quad (3)$$

The Sobel, Aroian, and Goodman tests in Table 5 demonstrate that digital ability, digital technology compatibility, and perceived gain play a mediating role in the external environment and digital technology adoption in cultural enterprises.

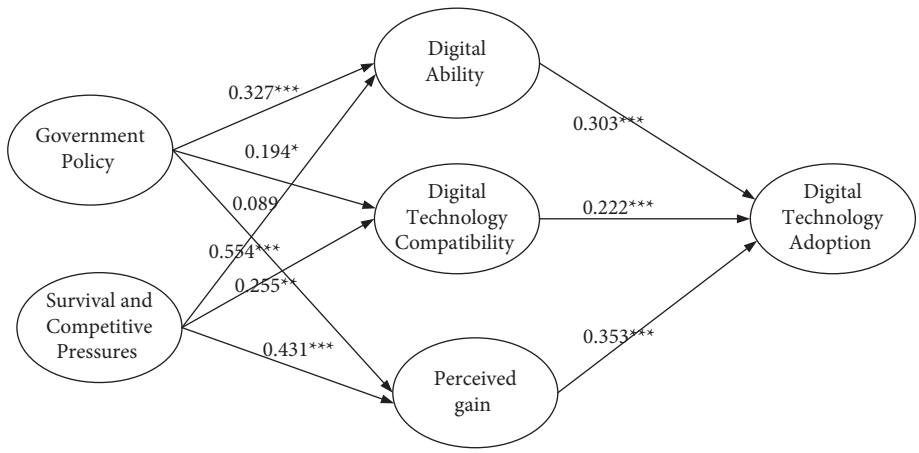


Figure 2: Standardized solution of structural modeling analysis. * p-value <0.05; ** p-value <0.01; and *** p-value <0.001.

Table 4: Path coefficients and testing results of hypotheses.

Path	Hypothesis	Standardized path coefficient	T value	p value	Result
GP⟶DA	H1a	0.327	3.637	***	Supported
GP⟶DC	H1b	0.194	2.233	*(0.026)	Supported
GP⟶PG	H1c	0.089	1.095	0.274	Unsupported
SCP⟶DA	H2a	0.554	5.529	***	Supported
SCP⟶DC	H2b	0.255	2.75	**(0.006)	Supported
SCP⟶PG	H2c	0.431	4.98	***	Supported
DA⟶DTA	H3	0.303	4.394	***	Supported
DC⟶DTA	H4	0.222	3.691	***	Supported
PG⟶DTA	H5	0.353	5.58	***	Supported

* p-value <0.05; ** p-value <0.01; and *** p-value <0.001.

Table 5: Mediating effect test.

Equation	Relationship	Unstandardized regression weights	Standard error	Sobel test	Aroian test	Goodman test
GP⟶DA⟶DTA	GP⟶DA	0.265	0.073	2.79	2.75	2.84
	DA⟶DTA	0.319	0.073			
GP⟶DC⟶DTA	GP⟶DC	0.231	0.090	2.10	2.05	2.15
	DC⟶DTA	0.183	0.050			
SCP⟶DA⟶DTA	SCP⟶DA	0.515	0.093	3.43	3.40	3.47
	DA⟶DTA	0.319	0.073			
SCP⟶DC⟶DTA	SCP⟶DC	0.303	0.110	2.20	2.15	2.26
	DC⟶DTA	0.183	0.050			
SCP⟶PG⟶DTA	SCP⟶PG	0.524	0.105	3.72	3.68	3.75
	PG⟶DTA	0.284	0.051			

5. Conclusion

5.1. Research Conclusion. Our study confirms that government policies have a positive impact on cultural enterprises' digital ability and compatibility. This conclusion implies that government policies can improve the digital capabilities and compatibility of cultural enterprises. In addition, the findings suggest that survival and competitive pressures can also contribute to a firm's digital capabilities and compatibility and perceived gain of digitalization. Facing the increasingly fierce market competition and living environment of digital transformation, cultural enterprises must consider how to use digital capabilities and compatibility to maintain their competitive position in the market and ensure their long-term development. Furthermore, the findings show that digital ability, digital compatibility, and perceived gain further have a positive impact on digital technology adoption in cultural enterprises. And they play an intermediary role in promoting the digitalization of cultural enterprises in the external environment. Clearly, this suggests that technological and organizational factors play a significant role in enterprise digital technology adoption.

5.2. Suggestions. Our results show that the TOE model holds in the background of digital technology adoption in cultural enterprises. The external environment, including markets and policies, will positively influence the adoption of digital technologies by cultural enterprises through mediating the role of digital capabilities, digital compatibility, and perceived benefits. Therefore, to improve the adoption of digital technology in cultural enterprises, in addition to the continuous construction of the market environment and policy environment, it is also necessary to cultivate enterprises' digital capabilities and digital compatibility and improve enterprises' perceived benefits of digital technology. Enterprises should also have a strong ability to apply data technology and self-motivation. Specifically, promoting the digitalization of cultural enterprises can be carried out from the following four aspects.

5.2.1. Strengthening Policy Support for the Technical Capabilities of Cultural Enterprises. The study finds that government support promotes the digitalization of cultural enterprises through the enhancement of enterprise digital ability and compatibility. Therefore, in addition to tax incentives, financial support, and government subsidies, the support policies should also focus on cultivating the technical capabilities of enterprises and improving the digital compatibility. In terms of specific operations, first of all, the government should speed up the construction of infrastructure and improve the all-round, high-performance supply and service capabilities of the network system. In the information age, online production, online consumption, and online services have become the norm. The construction of new infrastructure has become an indispensable condition in the supply chain, production chain, and value chain of enterprises. The digital cultural industry requires high-quality network infrastructure. Second, we continue to strengthen the construction of digital public platforms. The digital cultural industry requires the organic integration of different formats and industries. The interconnection and resource sharing between different formats and industries requires the use of digital public platforms such as SaaS platforms and industrial Internet to open up the entire chain of production, consumption, service, and corporate decision-making for enterprises to form industrial intelligence clusters.

5.2.2. Cultivate a More Complete and Fair Market Survival and Competition Environment. The corporate market environment is an important factor in promoting the digitalization of cultural enterprises. Therefore, the government should also pay attention to the market construction of the cultural industry. (1) It is necessary to strengthen the top-level design of relevant regulations in the field of digital culture and establish a market supervision system that is different from the traditional cultural industry, to promote the healthy and orderly development of the digital culture market. (2) It is necessary to gradually improve the legislative work in the field of digital cultural industry and strengthen the legislation and protection of digital content copyright; and according to the continuous extension and expansion of the connotation of the digital cultural industry, timely adjust and improve the existing laws and regulations on the digital cultural industry and gradually establish a legal system covering the field of the digital cultural industry. (3) It is necessary to follow the laws of the market, break industry monopoly and barriers, and give private enterprises, small- and medium-sized enterprises, and digital new media opportunities for free development and fair participation in cultural market competition.

5.2.3. Enhance the Digital Application Capabilities of Cultural Enterprises. Digital ability and digital compatibility play a driving role in promoting the application of digital technology in cultural enterprises in the external environment. However, in our survey, many respondents simply understood digital upgrading as using digital technology as an auxiliary means, instead of using data as an important factor of production, failing to capture the digital dividends of precision marketing and production. In fact, technological change brings standard services as well as the possibility of standardizing customized services. The development model with data as the core production factor can realize the effective connection between producers and consumers. The digital cultural industry with creativity as the core is at the cusp of high-quality integration of the digital economy and the real economy and has great potential for development. Therefore, it is necessary to change the understanding that digital technology only plays an auxiliary role in enterprises, further enhance the digital capabilities and digital technology compatibility capabilities of cultural enterprises, and pay attention to the important role of cultural cross-border integration.

5.2.4. Enhancing the Profitability of Digital Technology Utilization in Cultural Enterprises. Perceived benefits play a mediating role in the promotion of market conditions for the adoption of digital technologies by cultural enterprises. Improving the profitability of digitalization also has important implications for the adoption of digital technologies in cultural enterprises. In terms of scale, China's digital creative industry ranks second in the world, but the overall development quality needs to be improved. From the perspective of revenue, the average operating revenue of China's digital industry in 2019 was $46.87 billion, accounting for only 31.3% of that in the United States. The important reason is that China lacks core competitiveness in the world's digital economy industrial chain. In terms of content innovation, it is not as good as Sony, Netflix, and other companies. In terms of software platform development, it is difficult to shake the position of Google (Android), Microsoft (Windows), and Apple (ios). There are also issues such as chips that need to be tackled in the manufacture of digital creative technology equipment. Therefore, China's digital creative industry is big but not strong. The growth of the profitability of the digital creative industry requires various explorations and efforts, such as strengthening the cultivation of innovative talents in the cultural industry.

Data Availability

The data sets used and/or analyzed during the current study can be obtained from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This research was funded by the Institute of Beijing Studies (BJXJD-KT2022-YB07).

References

[1] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS Quarterly*, vol. 13, no. 3, pp. 319–340, 1989.

[2] V. Venkatesh, M. G. Morris, and G. B. Davis, "User acceptance of information technology: toward a unified view," *MIS Quarterly*, vol. 27, no. 3, pp. 425–478, 2003.

[3] L. Tornatzky and M. Fleischer, *The Process of Technology Innovation*, Lexington, MA, 1990.

[4] F. Lv, Y. Zhu, and K. Robert, "Research on the impact of external environment on the adoption of digital technology by small and medium-sized enterprises," *Science Research*, vol. 39, no. 12, p. 9, 2021.

[5] Y. Lai, H. Sun, and J. Ren, "Understanding the determinants of big data analytics (BDA) adoption in logistics and supply chain management: an empirical investigation," *International Journal of Logistics Management*, vol. 29, pp. 676–703, 2018.

[6] C. Low, Y. Chen, and M. Wu, "Understanding the Determinants of Cloud Computing adoption," *Industrial management & data systems*, vol. 111, pp. 1006–1023, 2011.

[7] K. Zhu and K. L. Kraemer, "E-Commerce metrics for net-enhanced organizations: assessing the value of e-commerce to firm performance in the manufacturing sector," *Information Systems Research*, vol. 13, no. 3, pp. 275–295, 2002.

[8] K. Zhu, K. Kraemer, and S. Xu, "Electronic business adoption by European firms: a cross-country assessment of the facilitators and inhibitors," *European Journal of Information Systems*, vol. 12, no. 4, pp. 251–268, 2003.

[9] H. Gangwar, "Understanding the determinants of big data adoption in India: an analysis of the manufacturing and services sectors," *Information Resources Management Journal*, vol. 31, no. 4, pp. 1–22, 2018.

[10] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.

[11] J. F. Hair, R. E. Anderson, B. J. Babin, and W. C. Black, *Multivariate Data Analysis: A Global Perspective*, Pearson, Upper Saddle River, NJ, 2010.

[12] D. P. MacKinnon, R. A. Scribner, and J. H. Dwyer, "Alcohol outlet density and motor vehicle crashes in Los Angeles County cities," *Journal of Studies on Alcohol*, vol. 55, no. 4, pp. 447–453, 1994.

[13] D. P. MacKinnon, G. Warsi, and J. H. Dwyer, "A simulation study of mediated effect measures," *Multivariate Behavioral Research*, vol. 30, no. 1, pp. 41–62, 1995.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5144874, 8 pages
https://doi.org/10.1155/2022/5144874

Research Article

Influencing Factors and Simulation Modeling of Tourist Environmental Protection Behavior under the Background of OSG Platform

Lixia Wang[1,2] and Weiyu Fu[3,4]

[1]*School of Economics and Management, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*
[2]*School of Business Administration, Henan Polytechnic University, Jiaozuo, Henan 454003, China*
[3]*School of Computer Science and Technology, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*
[4]*Jiangsu Vocational College of Finance and Economics, Huaian, Jiangsu 223003, China*

Correspondence should be addressed to Weiyu Fu; lb18170001@cumt.edu.cn

Received 6 April 2022; Revised 17 June 2022; Accepted 20 June 2022; Published 1 September 2022

Academic Editor: Lele Qin

Due to the continuous socio-economic progress, tourism has flourished. In addition, the improvement of people's living standards and constant changes in social awareness and concepts has also made tourism a normal part of daily life. In the past few years, there has been a boom in overseas travel, and tourism has become a rigid demand. This study proposes a new method and model that enables researchers to conduct in-depth analysis and discussion on the influencing factors of tourists' environmental protection behavior. Additionally, OSG platform can be used for simulation and modeling. This study uses OSG platform to conduct a simulation experiment on tourists' environmental protection behavior. The results of the experiment indicate that tourists' environmental protection behavior is related to six factors, including tourist characteristic factors, tourists' environmental attitude factors, tourists' emotional factors towards scenic spots, tourists' habit factors, social factors, and promotion conditions. At the same time, these factors have some validity. The experimental results involving tourists' environmental protection behavior can provide more targeted methods and guidance for the development of tourism and also enable tourism to develop more comprehensively and perfectly.

1. Introduction

With the constant advancement of the social economy, the tourism industry continues to thrive. The living standards of the people have improved. As their social consciousness and ideas are constantly changing, travel and tourism have become the normality of their daily life. In the past few years, there has even been an upsurge in overseas travel, and tourism has become a rigid demand [1, 2]. However, what follows is the emergence of new troubles and issues, such as the problem of littering in the scenic spots and uncivilized behaviors that are detrimental to environmental protection and destroy the historical sites and facilities in the scenic areas [3, 4]. Therefore, analyzing the factors that may affect tourists' environmental behavior, then instilling in them the correct concept of environmental protection, and continuously improving their behavioral habits so that it becomes a conscious behavior of citizens are the urgent challenges and key points to be solved [5].

Environmental protection behaviors are also referred to as environment-friendly low-carbon behaviors and environmental protection behaviors in our country. At present, the studies of environmental awareness carried out by the experts in the industry are mainly concentrated on the demographic factors such as age, education level, and birth environment of citizens, as well as subjective environmental and ecological education, environmental attitudes, environmental awareness, and other factors, or research

regarding the influence on tourist behaviors from the perspective of tourist motivation [6]. Hence, the intervention to environmental protection behaviors mainly focuses on publicity, punishment, and other solutions at present. However, little attention has been paid to the influence of traditional Chinese culture and the mechanism of rewards and punishments on environmental protection behaviors.

The literature research on the influencing factors of tourists' environmental protection behavior mainly focuses on the investigation of environmental protection awareness, environmental protection behavior, and the relationship between some single or several factors and tourists' environmental protection behavior. Scholars have investigated the demographic factors such as tourists' age and education level, and there are not many achievements in systematically studying the influencing factors of tourists' environmental protection behavior. Huangxueli et al. explored and analyzed the leading factors affecting tourists' low-carbon tourism life behavior, while Zhaoliming et al. conducted empirical research on the influencing factors of public low-carbon tourism behavior. The existing literature mainly studies from the perspective of tourists' psychological awareness and emotion. The intervention policy on tourists' behavior focuses on publicity and education, ignoring the empirical research on the impact of Chinese traditional cultural factors, incentive policies, and punitive policies on tourists' environmental protection behavior. To a certain extent, the existing literature lacks in-depth research on the mechanism of various influencing factors on tourists' environmental protection behavior. Therefore, this study makes an in-depth and systematic study on the internal and external influencing factors of tourists' environmental protection behavior through grounded theoretical methods, constructs a theoretical model of the influencing factors of tourists' environmental protection behavior, discusses the action mechanism of internal factors and the governance mechanism of external factors, and explores effective intervention mechanisms, so as to put forward policy suggestions for effectively guiding tourists' environmental protection behavior. These will ultimately help to promote the formation and maintenance of Chinese tourists' environmental behavior habits and have important theoretical value and practical guiding significance for reducing environmental pollution, building an ecological and low-carbon society, and promoting people-oriented social and economic healthy and sustainable development.

In this study, a quantitative analysis of factors that may influence environmental protection is carried out first. In addition, 3D simulation modeling is performed based on the OSG platform so as to guide the environmental protection behaviors in tourists, and effective policy recommendations are put forward.

2. Methods and Model Constructions

2.1. Data Analysis. The main factors that affect tourists' environmental behavior are six factors: tourists' attitude, tourists' characteristics, social environment, tourists' emotion, promotional conditions, and habits. Moreover, the influence mechanism and path of the above six factors on tourists' environmental protection behavior are also different. Tourist characteristic factors are the internal causes of tourists' environmental protection behavior. Different attribute characteristics make tourists show different environmental protection attitudes, which directly affect the production of environmental protection behavior. Through the interview, it is found that the consistency between psychological awareness and environmental protection behavior is obvious, but some punitive measures will arouse people's rebellious psychology and produce nonenvironmental behavior. According to sociological principles, social factors determine both psychological awareness and behavioral motivation. Therefore, many scholars regard social factors as the prefactor of behavior and take this as the premise to explore the direct effect of social environmental factors on tourists' environmental protection behavior, as well as its guiding effect on tourists' environmental protection behavior through psychological factors.

Based on the existing theories, the commonly used questionnaire survey method is adopted in this study to select interviewees, carry out interviews, and acquire and collect the corresponding data so as to obtain the most realistic and relevant data accordingly. The design of the questions to be asked in the interview is shown in Figure 1. It should be noted that before the questionnaire survey is carried out, it is necessary to explain the connotation of some environmental protection behaviors to the tourists so as to ensure that the tourists can have a thorough and in-depth understanding of the questionnaire, followed by proper exchange and communication of their ideas.

Based on the concept of the algorithm, the business entity should first make the judgments as follows:

(1) Whether the investment of the enterprise in environmental protection technology in the previous cycle was increased or decreased

(2) Whether the profit of the enterprise was increased or decreased in the last cycle

According to the results of the questionnaire survey regarding the two issues designed, a certain probability adjustment is made to the investment, in which the tourists are involved, as listed in Table 1.

When they accept the concept of environmental protection and become aware of the influence of their behaviors, tourists have experienced a process of learning, understanding, and acceptance. In accordance with their subjective awareness and surrounding environment, some targeted technical changes and adjustments are made to the subjective awareness of tourists accordingly. When the probability of investment in the corresponding environmental protection is adjusted, a random number is given randomly (the range of its value is [0, 1]), and the environmental awareness judgment on the tourist is carried out according to random numbers mentioned above, as shown in equation (1):

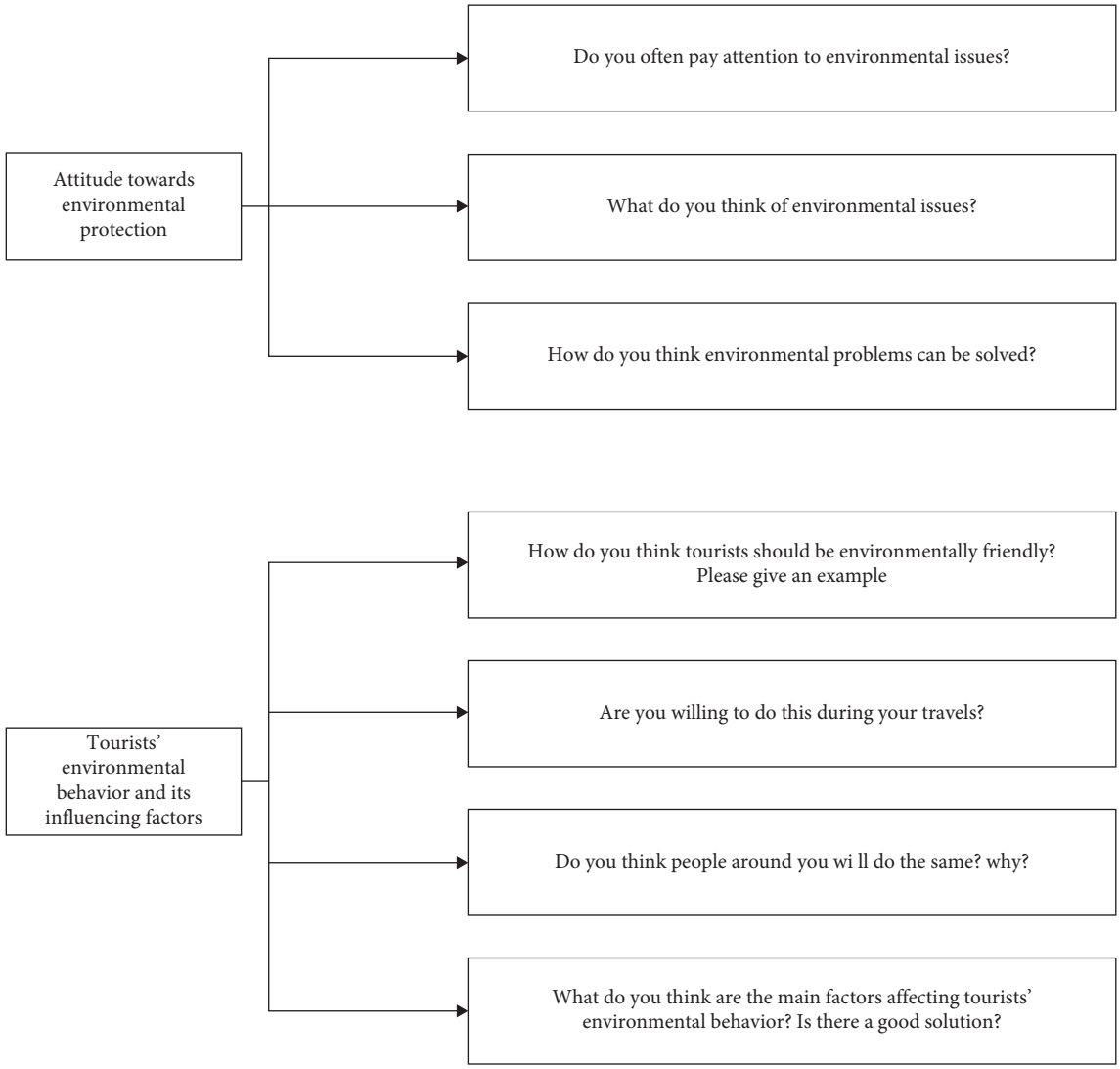


Figure 1: Questions to be asked in the interview.

Table 1: Process of probability adjustment for the willingness to invest in environmental protection technology.

Investment in environmental protection technology	Changes in profit	Changes in probability
Decrease	Increase	$(p^d + \omega, p^i - \omega/2, p^c - \omega/2)$
	Decrease (including remaining unchanged)	$(p^d - \omega, p^i + \omega/2, p^c + \omega/2)$
Increase	Increase	$(p^d - \omega/2, p^i + \omega, p^c - \omega/2)$
	Decrease (including remaining unchanged)	$(p^d + \omega/2, p^i - \omega, p^c + \omega/2)$
Remain unchanged	Increase	$(p^d - \omega/2, p^i - \omega, p^c + \omega/2)$
	Decrease (including remaining unchanged)	$(p^d + \omega/2, p^i + \omega, p^c - \omega/2)$

$$\text{techlnvest} = \begin{cases} \text{techlnvest}(t-1) - \Delta I_1\left(0 \le r < p^d\right), \\ \text{techlnvest}(t-1) + \Delta I_1\left(p^d \le r < p^i + p^r\right), \\ \text{techlnvest}(t-1)\left(\left(p^i + p^r\right) \le r < 1\right). \end{cases} \tag{1}$$

In response to the uncivilized and noncompliance of tourists with the relevant environmental protection stipulations and requirements, local governments should issue the corresponding laws and regulations or administrative measures to restrain and punish the violation behaviors so as to achieve the purpose of addressing three issues with one initiative. At the same time, based on the theory of public opinion, local governments should rely on the public to criticize the illegal and nonconforming behaviors of tourists. For example, in Nanjing's Xuanwu Lake, tourists illegally and privately picked the precious double lotus flower. In serious cases, it can also provide the corresponding means of

supervision and reporting. The specific process is shown in Figure 2.

As shown in Figure 2, it is first necessary to determine the capability of tourists. Through the establishment of the corresponding model, the subjective constraints are explored and used to discuss the relationship between input and output and represent it with a quantitative function [7–10], as shown in the following equation:

$$Q(T) = T(t)L^{\alpha}K^{\beta}. \tag{2}$$

In the above equation, $Q(t)$ stands for the actual output quantity invested by tourists in the period t; $T(t)$ stands for the technical level of tourists, environmental protection awareness, and so on; L stands for the labor force input by the corresponding environmental protection enterprises and training institutions for the purpose of cultivating environmental protection awareness; K stands for the investment capital theory of environmental protection enterprises; α and β are constants. $T(t)$ is obtained as follows:

$$T(t) = \frac{B - \text{techlnvest}(t)}{1 + B - \text{techlnvest}(t)}. \tag{3}$$

For the purpose of further simplifying the model, the input cost of the enterprise in environmental protection is simulated based on equation (4), in which C_1 and C_2 are constants:

$$\text{productCost} = C_1 \cdot Q(t) + C_2 \cdot L. \tag{4}$$

2.2. Coding Category. Through the collection, preprocessing, classification, and sorting of the data acquired, the samples are divided into two parts: samples for analysis and samples for the test [11–14]. The samples for analysis are used for the simulation of results, and the samples for the test are used to test the effectiveness of the method proposed in this study. With respect to the premise of analysis, it is necessary to encode the data effectively, which is carried out mainly in three aspects: open coding, spindle coding, and data analysis.

The first step is open coding. The so-called open coding refers to the whole process, in which the concept of questionnaire survey and data acquisition is used to represent the corresponding data [15–17]. In this study, it is first necessary to sort out, consolidate, and classify the behaviors of tourists that are subject to the influence of environmental factors and identify whether they are subjective factors or not, their level of education, the family, social environment, and whether their behaviors are simply imitation of others or induced by other factors. The analysis of the real responses in the questionnaires is carried out through combining word by word and consolidating the information effectively so as to extract the coding elements and obtain the preliminary result to be further analyzed. Through further optimization, analysis, and screening of the data results, the sets of processed data are formed accordingly, and these data sets are further namely abstractly to form data sets after open coding.

On the basis of open coding, further in-depth analysis is carried out in this study on the influencing factors, and 25 indexes are extracted accordingly. These indexes can be divided into 6 major categories, and the bar graphs of some indexes are shown in Figure 3.

After the analysis of the samples is completed, the verified samples are selected to carry out practical verification of the experimental method based on the theory to determine the effectiveness and feasibility of the proposed method and the reliability of the samples. The results of the verification suggest that the influencing factors are relatively fixed and highly correlated. Hence, the relevant indexes selected in this study can be used to carry out environmental protection evaluation appropriately and effectively.

3. Development of a Prototype System for the Simulation of Traffic Flow

3.1. System Design. On the basis of data analysis, the existing 3D software research foundation is combined [18–20]. In this study, a relatively mature OSG platform is selected to establish the model and construct the platform for simulation of the traffic flow in the scenic area. From the perspective of business process analysis, the system mainly includes data loading, data analysis, and data visualization, such as 3D simulation and modeling of the road network in a scenic area, which can be used to carry out microscopic simulation of the traffic flow on the roads in the scenic area. It should be noted that as the roads in the scenic area are dynamic, data processing, 3D visualization, and other features are provided. The software framework of the microscopic simulation prototype system for road traffic in the scenic area is shown in Figure 4.

(1) The microscopic framework for the traffic in the scenic areas is designed, simulated, and implemented in practice. Through the combination of big data, intelligent transportation, computer simulation, and VR/AR technology, 3D simulation modeling is carried out based on the microscopic traffic in the scenic area. At the same time, on the basis of data modeling, a model system for the microscopic simulation of traffic flow in the scenic areas is established. It adopts an open framework and is characterized by the operation across the platforms, extensible, portable, and other features. Users of the platform can add or delete the corresponding simulation models and analysis modules based on the location and traffic features of the scenic area. Meanwhile, the platform can also be used as auxiliary support for the government transportation department, and it can assist in intelligent traffic analysis and be used for road evacuation in scenic areas.

(2) *Analysis of the Parking of Scooters in an Environment with Full Coverage.* Combined with the features of the scenic area, the relevant international theories are combined to customize the related models and indexes based on the scenic roads, real-time traffic, and other aspects. At the same time, the relevant models can be fused into the microscopic simulation model of the scenic area. It should be noted that all factors

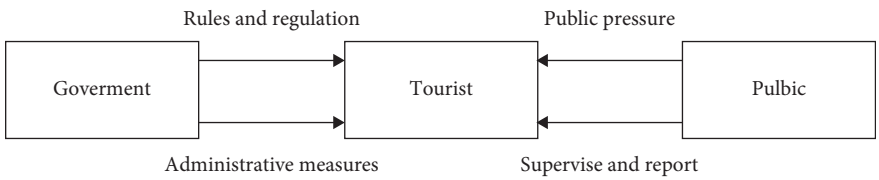


Figure 2: Interaction between the government, the public, and the tourists.

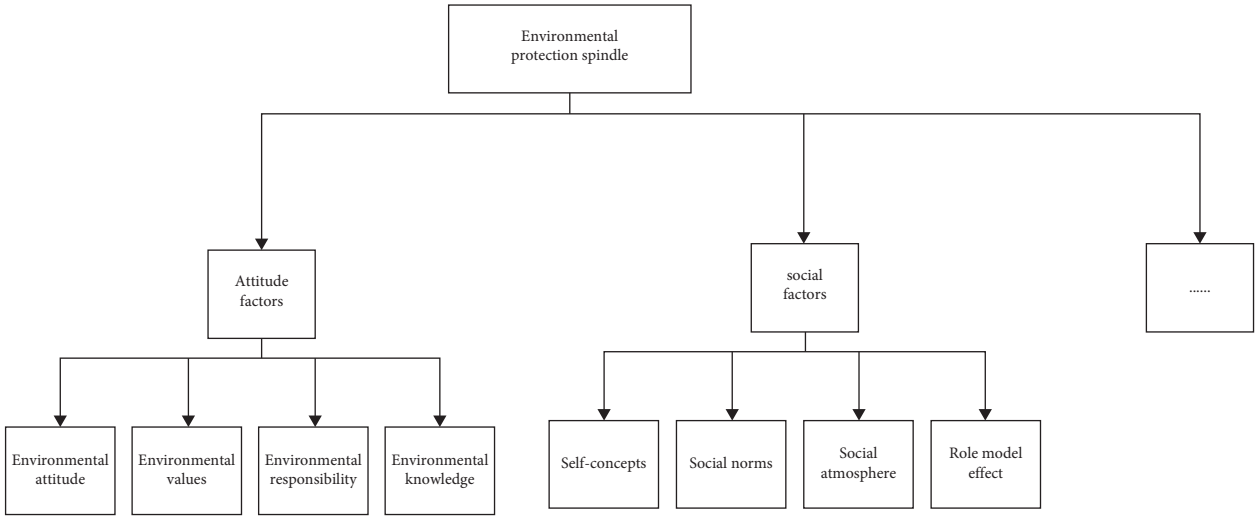


Figure 3: Theoretical model of factors that may influence the environmental protection behavior of tourist.

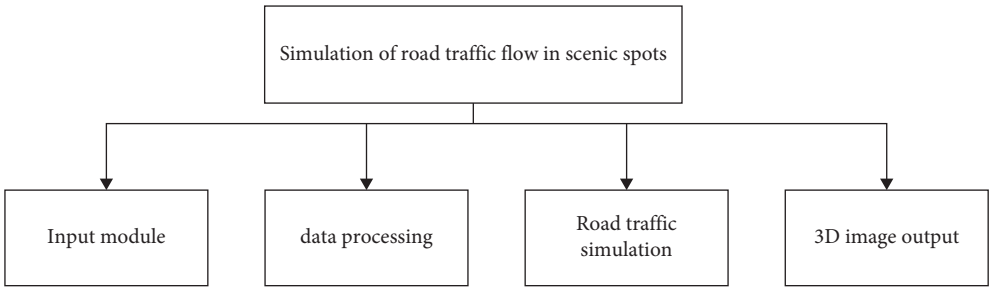


Figure 4: Software framework of the prototype system.

such as the number of tourists in the scenic spot, the emissions of scooters in the scenic area, the relative proportion of vehicle models, and the delays in parking can have a certain influence on the total emissions of pollutants from vehicles in the scenic area [21].

(3) *Management Analysis of Dynamic Resources*. In the microscopic 3D traffic simulation model for the scenic area, it is necessary to allocate resources to each vehicle in the scenic area and clarify their status at each moment in real time until the corresponding vehicles are no longer within the scope of the scenic area. If the configuration of dynamic resources is not optimized, 3D simulation will continue to occupy more and more computer resources, which can lead to a slower and slower running speed of the computer. Hence, it is necessary to optimize the configuration of dynamic resources to achieve sustained optimization of the dynamic resources, save the computation resources, and ensure the speed of 3D operation. In the practical process of 3D simulation, the vehicles are located in the scenic area, where the platform can allocate resources to the vehicles accordingly [22–25]. When the vehicles have left the scenic area, the system will release the corresponding computer resources at once.

In the practical modeling process of 3D data, high-definition and 3D object models are generated quickly based on the mature OSG platform. Subsequently, the corresponding textures are attached to establish the corresponding model for 3D data. On this basis, LOD analysis,

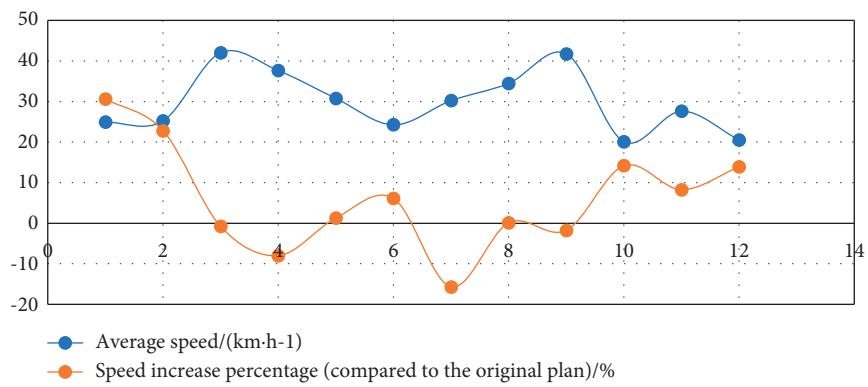


Figure 5: Traffic conditions at the intersection of the scenic spot during peak hours upon the change in the timing of the signal lights.

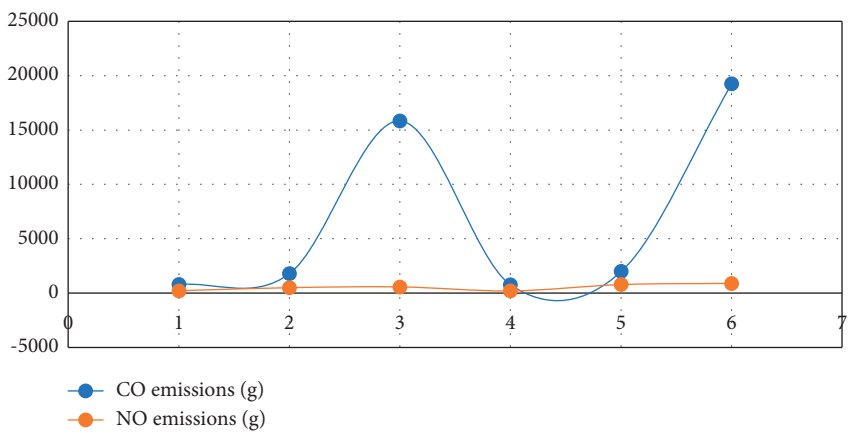


Figure 6: Comparison of vehicle emissions under different scenarios.

texture mapping, and other corresponding technologies are implemented by using the system to meet the requirements of 3D visualization. In the process of model establishment and utilization, online modeling of the 3D scene is carried out based on the corresponding open interface [26].

3.2. Simulation Application. After the 3D data are modeled, the road blockage and real-time vehicle operation during the holiday peak period of the scenic spot are simulated based on the developed microscopic simulation model for the traffic flow of the scenic spots and the corresponding pollutant emissions caused by motor vehicles at the intersection can be obtained at the same time.

The current status is analyzed through the simulation. In the east-west direction and the straight direction of the scenic spot, the speed of the vehicle flow is relatively slow, which is even less than 20 km/h. The possible reason is that there are excessive signal indications on the existing roads in the scenic spots, the corresponding interval of green light is relatively short, and there are relatively few roads. Under these conditions, congestion may occur in the scenic areas during peak periods of holidays and festivals. For the purpose of addressing this issue, combined with further communication with the signal lights and traffic control department, the corresponding interval is adjusted, and the data after the adjustment are simulated and calculated again. The effect after the adjustment is shown in Figure 5. From the results thus obtained, it can be observed that the congestion in the scenic areas during holidays and festivals has been dramatically improved [27]. However, as the duration of the green light in other directions has been extended, the driving speed of vehicles may be influenced to some extent.

The comparison of vehicle emissions under different scenarios when the simulation runs for 1000 s is shown in Figure 6. From the figure, it can be observed that (1) with the overall increase in vehicle speed, the traffic capacity of the intersection is increased, so is the total value of vehicle emissions. However, the average emissions per vehicle are slightly reduced. (2) Whether it is CO or NOx, small vehicles have the highest contribution to the total emissions, and the possible reason is that small vehicles often account for the largest proportion of vehicles running in the road network [28].

4. Conclusion

The constant advancement of the social economy has driven the continuous improvement of people's awareness of travel. In this study, the environmental protection behaviors are classified and sorted out based on the existing studies. The factors that may influence the environmental protection

behaviors of tourists are constructed, and the corresponding model is established for the analysis from 6 major factors, such as the subjective awareness of the tourists, the external environment, the habitual awareness, and the conditions. Finally, the OSG platform is used to construct the corresponding simulation model test. The results of the practice indicate that the proposed method has a certain level of effectiveness and can provide more targeted decision-making support for government departments. Based on the influencing factor model and conclusion analysis of tourists' environmental protection behavior, in order to effectively guide tourists to implement environmental protection behavior, relevant departments should consider multiple ways and means to publicize environmental protection when formulating policies and enhance people's psychological awareness of environmental responsibility and environmental protection (including tourism environmental protection). On the basis of traditional methods, we will continue to innovate the ways and contents of environmental education, such as WeChat, microblog, micro film, etc., expand the forms and contents of environmental education, advocate rationality and comfort, and enhance tourists' awareness of environmental protection, so as to promote the transformation of their environmental behavior.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The study was supported by Young Backbone Teachers Support Program of Henan Polytechnic University, China (Grant No. 2019XQG-13), by Soft Science Project of Henan Province in 2022 (Grant No. 222400410174), by Innovation Team of Philosophy and Social Sciences of Henan Polytechnic University, China (Grant No. CXTD2020-2), and by Program for Science and Technology Innovation Talents in Universities of Henan Province (No. 2021-CX-042).

References

[1] J. Huan, "Influencing factors Responsible tourism litter management the theory of planned behavior Zero Litter Initiative," *Science of the Total Environment*, vol. 657, no. 3, pp. 1127–1137, 2018.

[2] H. Hu, J. Zhang, C. Wang, Y. Peng, and C. Guang, "What influences tourists' intention to participate in the Zero Litter Initiative in mountainous tourism areas: a case study of Huangshan National Park, China," *Science of the Total Environment*, vol. 657, no. 20, pp. 1127–1137, 2019.

[3] Y. Liu, L. Xie, Y. Ma, Y. Liao, K. Xue, and J. Jin, "Studies on ultrasonic disintegration kinetics of SEBS in PP melts and the influencing factors," *Journal of Applied Polymer Science*, vol. 134, no. 5, pp. 56–63, 2016.

[4] L. Zhang, J. An, M. Liu et al., "Spatiotemporal variations and influencing factors of PM2.5 concentrations in Beijing, China," *Environmental Pollution*, vol. 262, no. 4, p. 114276, 2020.

[5] J. Akter, M. Reza, and M. Ahmed, "Application of passive energy savings strategies for optimization of building energy performance: a case study," *Journal of System and Management Sciences*, vol. 8, no. 3, pp. 52–66, 2018.

[6] O. I. Macovei, "Applying the theory of planned behavior in predicting proenvironmental behaviour: the case of energy conservation," *Human Reproduction*, vol. 54, no. 6, pp. 701–716, 2015.

[7] Z. Li, G. Zhang, X. Yu, Q. Liu, and X. C. Zhang, "Phosphorus loss and its estimation in a small watershed of the Yimeng mountainous area, China," *Environmental Earth Sciences*, vol. 73, no. 3, pp. 1205–1216, 2015.

[8] A. J. Blomberg, L. Li, J. D. Schwartz, and A. Brent, "Exposures to paper beta radiation in greater Massachusetts and factors influencing their spatial and temporal variability," *Environmental Science and Technology*, vol. 4, no. 2, pp. 203–210, 2020.

[9] P. Meincke, L. Asmer, L. Geike, and H. Wiarda, "Concepts for cargo ground handling of unmanned cargo aircrafts and their influence on the supply chain," *Journal of System and Management Sciences*, vol. 8, no. 3, pp. 26–51, 2018.

[10] A. Graa, "The impact of environmental factors on impulse buying behavior using the mehrabian and russell's framework," *Chemistry - A European Journal*, vol. 21, no. 17, pp. 6501–6510, 2015.

[11] K. M. Tramonte, R. C. L. Figueira, A. P. Majer et al., "Geochemical behavior, environmental availability, and reconstruction of historical trends of Cu, Pb and Zn in sediment cores of the Cananeia-Iguape coastal system, Southeastern Brazil," *Marine Pollution Bulletin*, vol. 127, no. 2, pp. 1–9, 2018.

[12] W. Hu, "An improved flower pollination algorithm for optimization of intelligent logistics distribution center," *Advances in Production Engineering & Management*, vol. 14, no. 2, pp. 177–188, 2019.

[13] L. R. Mehrkam, N. J. Hall, C. Haitz, and C. D. L. Wynne, "The influence of breed and environmental factors on social and solitary play in dogs (*Canis lupus* familiaris)," *Learning & Behavior*, vol. 45, no. 4, pp. 367–377, 2017.

[14] C. Zhang, Y. Xue, H. Zhao et al., "Prevalence and related influencing factors of depressive symptoms among empty-nest elderly in Shanxi, China," *Journal of Affective Disorders*, vol. 245, no. 4, pp. 750–756, 2019.

[15] H. Liu, X. Yi, J. Bi, P. Wang, D. Liu, and Z. Zhou, "The enantioselective environmental behavior and toxicological effects of pyriproxyfen in soil," *Journal of Hazardous Materials*, vol. 365, no. 5, pp. 97–106, 2019.

[16] D. Grguraš, M. Kern, and F. Pušavec, "Cutting performance of solid ceramic and carbide end milling tools in machining of nickel based alloy Inconel 718 and stainless steel 316L," *Advances in Production Engineering & Management*, vol. 14, no. 1, pp. 27–38, 2019.

[17] S. P. Glaholt, M. L. Kennedy, E. Turner, J. K. Colbourne, and J. R. Shaw, "Thermal variation and factors influencing vertical migration behavior in Daphnia populations," *Journal of Thermal Biology*, vol. 60, no. 3, pp. 70–78, 2016.

[18] D. E. Ausband, S. B. Bassing, and M. S. Mitchell, "Environmental and social factors influencing wolf (*Canis lupus*) howling behavior," *Ethology*, vol. 126, no. 9, pp. 890–899, 2020.

[19] B. Cao, Y. Liang, S. Yoshida, and R. Guan, "Facial expression decoding based on Fmri brain signal," *International Journal of Computers, Communications & Control*, vol. 14, no. 4, pp. 475–488, 2019.

[20] F. Han and J. Li, "Assessing impacts and determinants of China's environmental protection tax on improving air quality at provincial level based on Bayesian statistics," *Journal of Environmental Management*, vol. 271, no. 3, pp. 111017–111117, 2020.

[21] L. Luo and Y. Shi, "Study on the influencing factors of farmers' purchase behavior of organic fertilizers based on logistic model," *Current Journal of Applied Science and Technology*, vol. 9, no. 6, pp. 1127–1137, 2020.

[22] J. Xiao, "Spatial variations and influencing factors of river networks in river basins of China," *International Journal of Environmental Research and Public Health*, vol. 18, no. 5, pp. 1127–1137, 2021.

[23] F. Bahja, C. Cobanoglu, K. Berezina, and C. Lusby, "Tourism review factors influencing cruise vacations: the impact of online reviews and environmental friendliness article information: for authors factors influencing cruise vacations," *The Impact of Online Reviews and Environmental Friendliness*, vol. 3, no. 4, pp. 56–63, 2019.

[24] M. Zhang, G. Tang, and Y. Zhang, "Factors influencing mobile search engine users' continuance behavior under the context of service harm crisis event," *International Journal of Mobile Human Computer Interaction*, vol. 10, no. 3, pp. 30–48, 2018.

[25] Y. Xuan, "Influencing factors of aquatic environmental quality and research on measures for aquatic ecological environment protection," *Environment and Development*, vol. 5, no. 6, pp. 701–716, 2018.

[26] H. Liu, J. Shang, and D. Wang, "A study on the consistency and influencing factors of China's provincial energy saving and environmental protection," *Resources Science*, vol. 4, no. 3, pp. 17–19, 2018.

[27] L. Xiao-Hui, Y. Zhang, J. Wang, and S. Sun, "Analysis of influencing factors and mechanism of willingness to pay for environmental protection in livestock and poultry farms based on ism empirical analysis-based on 383 questionnaires in shandong province," *Resource Development & Market*, vol. 6, no. 3, pp. 203–210, 2019.

[28] L. Wenming, C. Yin, C. Luo, X. Wang, T. Zhang, and J. Wang, "Analysis on the relation between tourist moral disengagement and civilized tourism behavior under virtual environment: a case study of Xihong city," *Journal of Central South University of Forestry & Technology(Social Sciences)*, vol. 4, no. 3, pp. 26–51, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5606280, 13 pages
https://doi.org/10.1155/2022/5606280

Research Article

Application of Artificial Intelligence Technology in Martial Arts Education Governance

Weiwu Ye,[1] Shihong Li,[1] Shuaibing Liu,[2] and Yuan Zhou[3]

[1]*College of National Traditional Sports, Harbin Sport University, Harbin 150008, China*
[2]*College of Martial Arts and Arts, Nanjing Sport Institute, Nanjing 210014, China*
[3]*Public Course Department, Hubei Institute of Fine Arts, Wuhan 430205, China*

Correspondence should be addressed to Yuan Zhou; zhouyuan@hifa.edu.cn

Received 21 May 2022; Revised 26 June 2022; Accepted 15 July 2022; Published 29 August 2022

Academic Editor: Lele Qin

Martial arts education has a relatively comprehensive educational function. Compared with other educational methods, it has some unique features. When martial arts education carries out moral education, it not only attaches importance to the teaching of moral norms but also requires martial arts practitioners to practice moral norms, so martial arts education is more practical in improving moral literacy. In fact, the role of martial arts education is far from just playing its role in strengthening the body. This kind of prejudice of mindset conceals the diversity characteristics of martial arts education. This paper proposes to apply artificial intelligence technology in martial arts education governance, which uses the target tracking algorithm based on deep learning to track and analyze the movement of martial arts practitioners. At the same time, this paper uses the pose estimation algorithm of coordinate regression to predict the key points of the human body from the global perspective of the human body and then locates the key points of the human body from the features. It greatly simplifies the prediction of key points and solves the problem of nonstandard movements of students in martial arts education. The experimental analysis part includes the results and analysis of the impact of AI-based flipped classroom teaching on students' martial arts learning and the comparison and analysis of students' martial arts learning in the two classes after the experiment. The analysis results show that the P values of the four aspects of learning interest, active participation attitude, independent exploration ability, and analysis and problem-solving ability of the two classes are all less than 0.01, indicating that there is a significant difference.

1. Introduction

Many studies have shown that there are still many problems in martial arts education in various aspects. For example, martial arts education is not valued in modern society, facing the useless place of mass martial arts education, and the educational value of martial arts has not been fully explored in today's society. Many previous studies have paid attention to the realization of the value of martial arts education, and many great ideas and methods have been put forward. However, there is no effective solution to the governance of martial arts education. According to the development law of martial arts, the martial arts project should be transformed in a centralized manner to reflect the characteristics of its own projects, so that martial arts can better reflect the national characteristics. It combines tradition and fashion better. The charm of martial arts is that it not only has a smooth body but also has more handsome movements than aerobics, which people from other countries cannot resist. It is necessary to understand how to realize the educational value of martial arts. As an educational program, martial arts have similarities and differences with other educational programs. The application of artificial intelligence technology in martial arts education governance makes modern people like martial arts and to readily accept martial arts education. It needs the majority of martial arts educators to learn from the development law of other projects and to explore the law of martial arts education implementation.

Martial arts education is becoming more and more important all over the world. Sangjin aimed to develop a preschool exercise program utilizing basic mixed martial arts (MMA) techniques to improve the athletic ability of

preschool children. He also validated the effect of the program on their athletic ability, development, and body composition by applying the program to the preschool curriculum [1]. In order to study the importance of physical activity to physical health, Wolfgang research shows that martial arts shed light on the benefits of sports to the public. He also explored the huge but untapped potential of physical activity tailored for public health [2]. To evaluate the use of martial arts (MA) programs in secondary physical education (PE) settings, Rotunda found that MA teaching has the potential to produce physical and psychosocial benefits for both adult and adolescent participants. He seldom implemented systematic programs in schools [3]. Ujuagu et al. aimed to evaluate the pedagogy of junior high school martial arts physical education curriculum and effective self-defense programs and techniques. Using a survey research design, the researchers found that the techniques used in practical teaching are difficult for teachers to implement, and practical ones are usually not taught [4]. At present, martial arts education is involved in the physical education courses of universities, but there are not many courses in primary and secondary schools and high schools, so it still needs greater efforts to incorporate martial arts into education. Akehurst's qualitative case explored part of the extracurricular sports program of taekwondo, measuring the benefits of student learning, health, and well-being. Studies have shown that traditional taekwondo can promote self-regulation in education [5]. In the process of martial arts teaching, the education and inheritance of culture in martial arts teaching is the insufficiency. Wang analyzed and learned the content of martial arts teaching in primary and secondary schools. Through a comprehensive understanding of the role of martial arts in the teaching process of primary and secondary schools, he reintegrated content and culture [6]. However, none of the above studies have highlighted the importance and feasible solutions of martial arts education governance.

It is highly important to formulate a scientific martial arts system teaching and training method. Han considered the above problems and the current popular artificial intelligence technology and built a neural network algorithm to solve [7]. He used a computer to test a study of functional asymmetry in students and schoolchildren practicing martial arts. Bobrova involved students and schoolchildren practicing martial arts (taekwondo, karate) due to software determining functional asymmetry. He used two visual tests [8]. The role of visual learning is critical for a new generation of learners. John and Martin used topic modeling and sentiment analysis to examine a YouTube text feedback data set containing keywords related to martial arts learning. Topic modeling shows that many discussion topics in martial arts are closely related to learning, arts, and humanities [9]. Martial arts are considered a cultural heritage in China, and exploring special learning systems has become a hot research topic. Shibiao discussed the design and implementation of a martial arts learning system based on Silverlight and took Taijiquan as the research object. The conclusion shows that the proposed system is easy to use; therefore, users can better master Tai Chi [10]. However, none of the above studies have closely integrated artificial intelligence and martial arts education governance.

The novelty of this paper is that the governance of martial arts education will be from the perspective of structural functionalism. It analyzes the decisive role of the structural attributes of martial arts on its educational function and then analyzes the formation process of each individual education in martial arts education and the degree of recognition of these educational functions by experts. The article made a profound summary of the problems of Wushu education, not only made suggestions on the shortcomings of current Wushu education but also made a certain analysis of the development of Wushu education in the future.

2. Problems and Solutions in Governance of Martial Arts Education with Artificial Intelligence Technology

2.1. Structural Attributes of Martial Arts and Influence on Educational Function. According to the theory of structural functionalism, it can be known that the thing or system that has a specific function also has a specific structure. In a sense, the structure of a thing or system determines the function of the thing, and the change of the structure will also lead to the corresponding change of the function [11]. The reason for the change of the structure may be that one or some of the factors that constitute the structure have changed, and it may also be that the mode of action or connection between the factors that constitute the structure has changed. In the practice of martial arts, the structure is a crucial part, and the structure includes the body structure, the movement structure, and the structure that connects the whole. The connection between the structures is very close, and they cooperate with each other to achieve the effect of martial arts. Martial arts education has its own specific functions, that is, some functions that are different from other education methods. It is caused by the three basic factors that constitute martial arts education and their interaction and mutual connection. The greatest impact on their respective educational functions should be the educational content in their intermediary systems. Chinese classic traditional martial arts are shown in Figure 1.

As shown in Figure 1, Chinese martial arts include Shaolin, Taiji, Bagua, Wing Chun, Baji, and so on. The specific complex structure of martial arts determines its diverse properties. When martial arts exist in martial arts education as the main content of education, these attributes further determine that martial arts education has various educational functions. It can be said that the multifunctional characteristics of martial arts education are determined by the complex structure and diverse attributes of martial arts [12].

2.1.1. Influence of Martial Arts Attributes on Its Educational Function. The attribute of martial arts refers to martial arts as a social and cultural form, which is a martial art with national cultural characteristics [13]. This is the most fundamental attribute of martial arts, that is, the essential attribute of martial arts, and it has the greatest impact on the

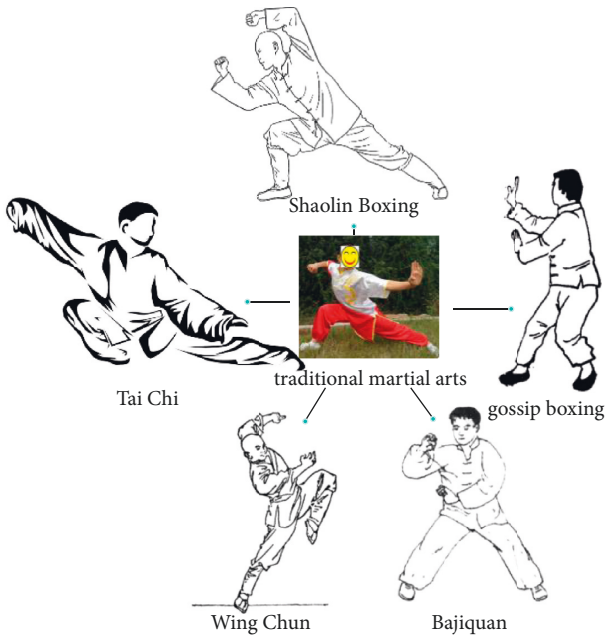


Figure 1: Chinese classic traditional martial arts.

educational function of martial arts. First, martial arts attributes require martial arts education to attach importance to moral etiquette education. Due to the violent characteristics of martial arts, martial arts education must pay attention to the promotion of benevolence, integrity, justice, responsibility, and other external morals, so as to regulate the use of violence by these violent holders. Due to the strong confrontational characteristics of martial arts combat, martial arts education must cultivate morality such as bravery and self-confidence because in order to defeat the opponent in actual combat, one must maintain arrogant fighting spirit. It overwhelms opponents in momentum. This requires cultivating students' bravery, self-confidence, and other qualities in the usual martial arts education. Especially for people who are beginners in martial arts, if they want to absorb the spirit and culture of martial arts, they must cultivate excellent qualities such as bravery in practice. Due to the difficult characteristics of martial arts techniques, martial arts education must improve morals such as perseverance, tenacity, and patience. Because it is difficult to achieve success in martial arts without these qualities of will, these qualities are strictly cultivated in students in martial arts education. In the study of martial arts, willpower is one of the most basic requirements. Only after hard training can you achieve better results in martial arts. Second, the martial arts attributes require that martial arts education must develop intelligence. The winning factors of martial arts combat confrontation have various characteristics. To defeat an opponent not only requires superb skills and ingenious tactics but also requires superb wisdom. Martial arts confrontation has always been an activity of fighting wits and courage, so in the usual martial arts education, we must pay attention to developing the intelligence of martial arts practitioners [14].

2.1.2. The Influence of Martial Arts Cultural Attributes on Its Educational Function. The cultural attribute of martial arts refers to the rich cultural connotation of the Chinese nation in martial arts, which is also an important attribute of martial arts. Some scholars even regard the cultural attributes of martial arts as the essential attributes of martial arts. On the one hand, martial arts itself are a kind of culture, and learning martial arts is to learn a distinctive national body culture. On the other hand, martial arts carry rich national cultural connotations, and receiving martial arts education helps to enrich one's own traditional national knowledge.

2.1.3. Influence of Martial Arts Sports Attributes on Its Educational Function. The sports attribute of martial arts means that martial arts have a better function of keeping fit and strengthening the body, which determines that martial arts education has a better function of strengthening the body [15]. On the one hand, many technical movements of martial arts meet the requirements of medical science, and learning these technical movements through martial arts education can play a better role in fitness. On the other hand, the process of martial arts education is also a process of improving physical function, developing physical strength, and enhancing physical fitness. Regular practice is also conducive to the formation of sports habits.

2.2. Basic Structure and Relationship of Martial Arts Teaching Mode. The teaching mode of martial arts is identical with the teaching mode of physical education. They all exist in a certain space and time. The space shows the established teaching theories and goals, the position of teachers and students in teaching and their relationship, and the time shows how to arrange the teachers' "teaching" and the students' "learning" [16]. Therefore, we can think that the basic structure of martial arts teaching is the established teaching theory, teaching objectives, and teacher-student arrangement that appear in time and space. The basic structure of the martial arts teaching mode and its relationship are shown in Figure 2.

As shown in Figure 2, the teaching guiding ideology of artificial intelligence-assisted martial arts elective courses should be the guiding ideology of physical education established on the basis of the national education policy, basic teaching theories, and teaching ideas. It is mainly reflected in the humanized teaching of "student's development as the center," "learning to teach," and "problem-oriented." It can also elevate students' knowledge of martial arts to a higher level, which means that students' knowledge of martial arts does not just stay on the surface of martial arts movements. Through the combination of practical experience, the comprehensive ability of students is improved, and the teaching is "student-centered" throughout. It is also connected with the learning of knowledge before class, the internalization of knowledge in class and after class, and students' autonomous learning and daily life style. It finally achieves the purpose of promoting the all-round development of students' morality, intelligence, physique and

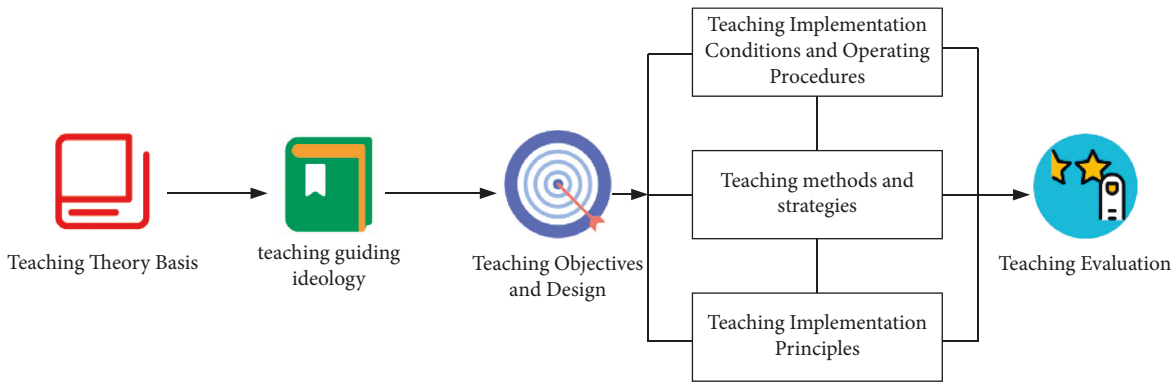


Figure 2: Basic structure and relationship of martial arts teaching mode.

beauty. The classic martial arts movements are shown in Figure 3.

As shown in Figure 3, artificial intelligence is a product born under the highly informatized society, which is different from traditional martial arts classroom teaching. Traditional martial arts teaching is mainly "teacher-centered," occupying the entire classroom with knowledge and skills, explanations, and demonstrations. In addition, the teaching form of large-class elective courses (more than 40 people or more) cannot well cultivate students' interest in martial arts and develop students' personality and comprehensive practical ability [17]. On the contrary, the teaching of artificial intelligence-assisted martial arts electives builds a good online learning environment for students with the new media (artificial intelligence) teaching platform. It realizes equal opportunities for teachers and students to communicate before, during, and after class. Its training of students has changed from "indoctrination" to "targeted" guidance, allowing students to explore the mysteries of martial arts independently. Students are participants and masters of learning. Finally, they can share their research results, exchange topics, experience fun, and learning experiences with the whole class, so as to realize the deep internalization of knowledge and skills. By cultivating students' interest in martial arts learning, it improves students' comprehensive practice ability and develops students' learning personality. This makes the teaching and learning process more fun, and the teacher-student relationship is more harmonious [18].

2.3. Target Tracking Algorithm Based on Deep Learning. In this paper, combined with the background of actual camera shooting and the dynamic model of martial arts movement, we establish a new martial arts tracking system to achieve high-precision tracking. At the same time, once the tracking fails, the target recognition calculation is used to recalculate the position of the martial arts in the screen and continue to execute the target tracking algorithm. For the other part, the algorithms for estimating rotational speed and rotational direction require the use of martial arts spatial structures and camera models. It estimates three-dimensional spatial structure information on a two-dimensional image. Such an information structure can enable better data transmission, higher efficiency in the system, and accurate positioning of human joints when modeling martial arts postures. In the case of obtaining enough data, a visualization system for martial arts data analysis is built to facilitate martial arts students and martial arts coaches to obtain the required information [19]. This paper proposes an end-to-end approach that combines human pose prediction and human action recognition, as shown in Figure 4.

As shown in Figure 4, by combining the reflected spatial 3D information with the skeleton data, richer behavioral features can be obtained, and the final recognition rate can be improved [20]. Therefore, this paper proposes a two-stream fusion method to fuse video data and skeletal joint data, as shown in Figure 5.

As shown in Figure 5, after introducing the attention mechanism, each frame of the video image is first generated by the convolutional network with the attention mechanism. It then feeds the data into a convolutional long short-term memory network in time series and extracts the results.

2.3.1. Constructing Spatiotemporal Graph Convolution. The convolution of the graph needs to deal with discrete feature points in space, and its definition is different from the two-dimensional convolution. The traditional two-dimensional convolution algorithm is image-based, and the convolution operation can be achieved by using a filter and an image pixel matrix to perform a dot product operation [21]. We can think of the input image and output feature map as a two-dimensional matrix grid, and the two-dimensional convolution operation can be understood as a nonlinear mapping of input features to output features. The output of a 2D convolution operation at m positions can be defined:

$$f_{\text{out}}(m) = \sum_{i}^{H} \sum_{j}^{H} f_{\text{in}}(K(m, i, j)) * \omega(i, j). \tag{1}$$

Then, by redefining the sampling function K and the weighting function ω, the above convolution formula can be extended to a graph convolution formula. It completes the extraction of local features of key points in the space through the graph convolution operation in the spatial domain. It connects the temporal convolution network (TCN) after the spatial domain graph convolution to extract the local

Figure 3: Classic martial arts moves.

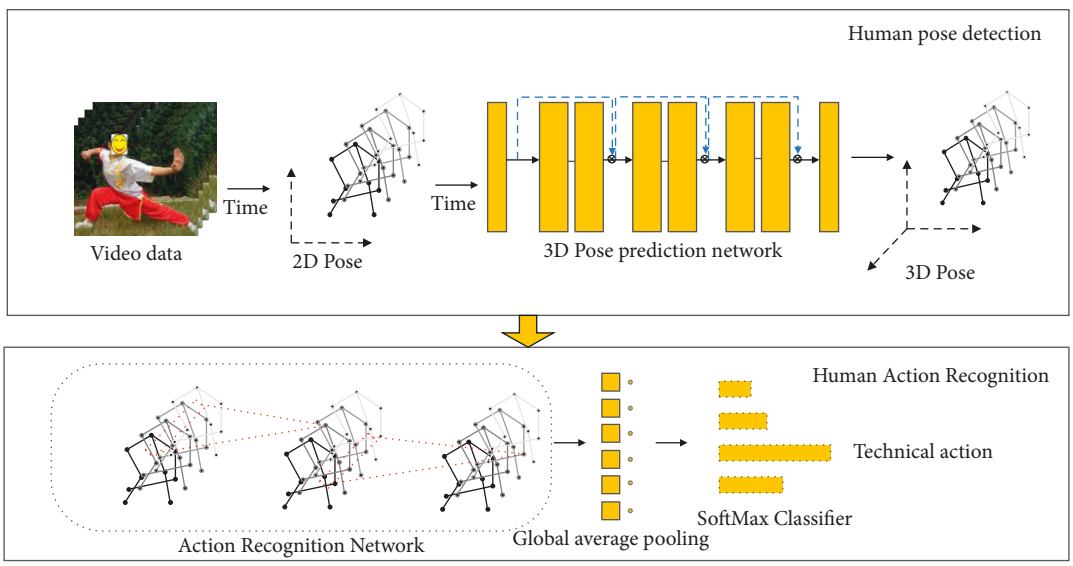


Figure 4: Martial arts action recognition method based on local node information.

features of key points between adjacent frames, as shown in Figure 6.

As shown in Figure 6, in the time-domain graph convolution, each convolution operation is equivalent to completing the convolution operation on t frame nodes. It then moves to the next frame according to the step size, completes the convolution of all frames of this node, and then performs the convolution of the next node [22].

2.3.2. Sampling Function and Weight Function. For a two-dimensional convolution operation, the sampling function is defined on a pixel matrix centered at position x and with filters as regions. Therefore, the sampling function can be defined as follows:

$$K(p_{bm}, p_{bn}) = p_{bn}. \tag{2}$$

On the graph, the weight function w defines a filter similar to a 2D convolution. Each position in the two-dimensional convolution operation filter provides a weight value, so the weight function of graph convolution can be constructed in this way, the weight function $\omega(p_{bm}, p_{bn})$.

$$\omega(p_{bm}, p_{bn}) = \omega'(w_{bm}(\text{pbn})). \tag{3}$$

2.3.3. Constructing Spatial Graph Convolution. By using the sampling and weighting functions defined in formulas (2) and (3), formula (1) can be reconstructed to obtain the convolution expression for the spatial graph:

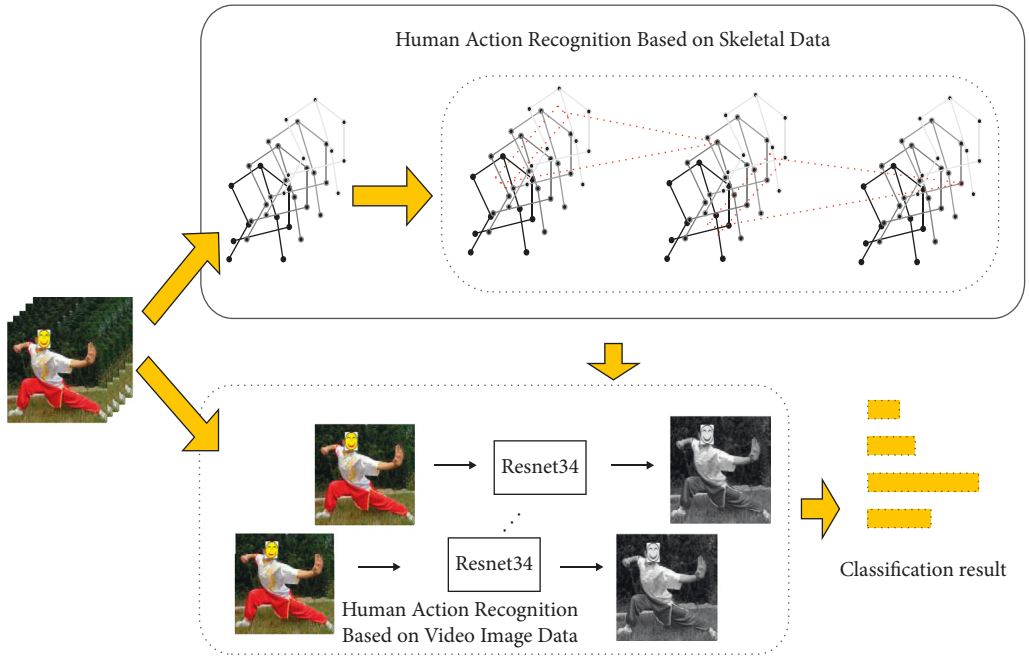


Figure 5: Two-stream fusion method combining video image data and skeletal joint point data.

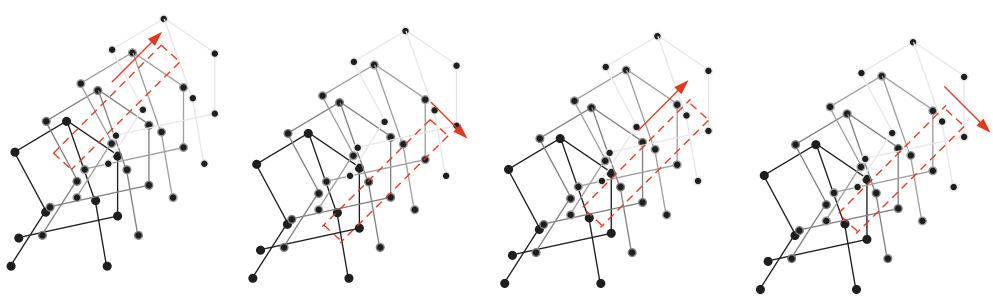


Figure 6: Time domain graph convolution process.

$$f_{\text{out}}(p_{bm}) = \sum_{p_{bn} \in T p_{bm}} \frac{1}{\phi_{bm}(p_{bn})} f_{\text{in}}(p_{bm}) * \omega(p_{bm}, p_{bn}). \quad (4)$$

After substituting formulas (2) and (3) into formula (4), the final graph convolution formula in space is obtained as shown in

$$f_{\text{out}}(p_{bm}) = \sum_{p_{bn} \in T p_{bm}} \frac{1}{\phi_{bm}(p_{bn})} f_{in}(p_{bm}) * \omega'(w_{bm}(\text{pbn})). \quad (5)$$

However, the skeleton diagram sequence can only represent the node information of each frame in the video, which represents a kind of information in the spatial dimension. But it cannot represent the coherence between video frames [23]. In this way, the human body posture in martial arts learning is modeled, and the simulation of joint points is deep into the space, so that the simulation of human body posture can achieve high accuracy. The spatiotemporal modeling of the video frame sequence is shown in Figure 7.

As shown in Figure 7, the spatiotemporal modeling in this paper is to obtain the spatiotemporal model by connecting the same nodes between two adjacent skeleton graphs, which is a data model starting from the spatio-temporal structure. The significance of this model is to explore the movement trajectories of the same joint points in the process of time change, so as to judge the behavior of the characters [24, 25]. There are two kinds of edges in the constructed spatiotemporal model. One is the spatial edge formed by natural connectivity between nodes in the space, and the other is the connected edge between the same nodes in the time dimension.

2.4. Attitude Estimation Algorithm Based on Coordinate Regression. Deep pose is one of the first methods to use coordinate regression in deep neural networks. It uses an end-to-end approach to predict the human body key points from the global perspective of the human body and then locates the human body key points from the features. It greatly simplifies the prediction of key points. The pose estimation algorithm based on coordinate regression takes a whole image as the input of the model and uses a simple 7-layer convolutional neural network as the characteristic

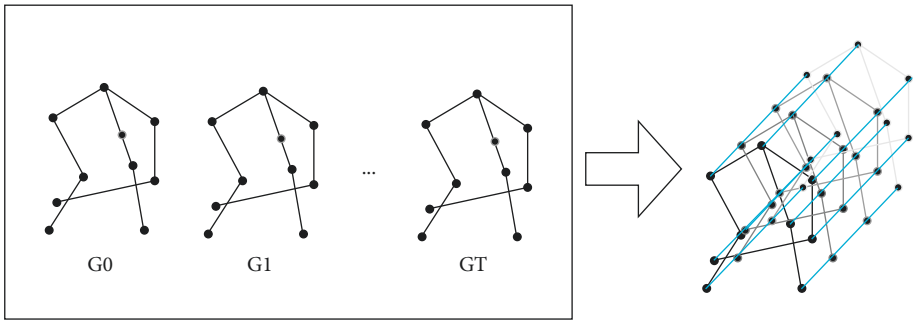


Figure 7: Sequence spatiotemporal modeling.

special zone network. Finally, it is fully connected into a multidimensional vector of corresponding coordinates, such as (x, y) representing the coordinates of a key point. It needs to return to five key points in total, then the vector and supervision information output by the network are both a vector of length 10.

For the posture of the human body, the joint points are the best way to measure the action, and the overall movement of the human body can be simulated through the movement of the joint points. Suppose the human body has k joint points, represented by a vector:

$$\begin{aligned} z &= \left(\ldots, z_i^T, \ldots\right)^T, \\ i &= \{1, \ldots, k\}. \end{aligned} \tag{6}$$

Representing the absolute coordinates of the predicted pose vector as in

$$z^* = \psi(x; \theta). \tag{7}$$

The loss function used is L2 loss, and then the model can be written as follows:

$$\arg\min_{\theta} \sum_{(x,z)\in D_N} \sum_{i=1}^{k} \left\| z_i - \phi(x; \theta) \right\|_2^2. \tag{8}$$

In essence, the convolutional neural network based on coordinate regression is to regress the size offset of each key point from the image boundary. However, the information provided by this supervision method is relatively small, the convergence speed of the entire network is slowed down, and the error in the actual model training is large.

For convolutional neural networks, the calculation formula of a single convolutional layer is as follows:

$$\begin{aligned} \text{params}_l &= \text{weights} + \text{bias}, \\ \text{params}_l &= c_{\text{out}}^l \times \left(k_{\text{width}}^l \times k_{\text{height}}^l \times c_{\text{in}}^l\right) + c_{\text{out}}^l. \end{aligned} \tag{9}$$

In particular, in depthwise separable convolutional layers

$$\text{params}_l = c_{\text{in}}^l \times \left(k_{\text{width}}^l \times k_{\text{height}}^l\right) + c_{\text{in}}^l. \tag{10}$$

At this time, $c_{\text{in}}^l = c_{\text{out}}^l$ and $(k_{\text{width}}^l \times k_{\text{height}}^l)$ in parentheses represent the number of weights of a convolution kernel. Then, the total parameters of the model are

$$\text{Params} = \sum_{l=1}^{L} \text{params}_L. \tag{11}$$

Each motion detection algorithm has its own characteristics. If it uses background subtraction, it must build the same background model as the actual background. The difference operation can only be performed if a valid background model has been established. In order to find the area of interest, it is necessary to build a background model, and the method of building a solid background model is the most important step of background subtraction.

Assuming that the background image model is $f_d(t)$ and the current frame image is $f_c(t)$, the image after the difference algorithm is shown in

$$f_d(a, b, t) = \left| f_b(a, b, t) - f_c(a, b, t) \right|. \tag{12}$$

On the premise that the scene environment is not so complicated, statistical filtering can be used to infer the background image. Adaptive background correction can be achieved by performing multiple averaging operations on the background image, as shown in

$$B_k = \frac{1}{N}\left(f_k + f_{k-1} + \cdots + f_{k-N+1}\right). \tag{13}$$

The parameters are important parameters for correcting background images using statistical averaging. If the object to be moved is not always displayed in the background image, better results can be obtained by properly selecting the parameters, and a more accurate background model can be obtained.

The mean filter method is most often used to construct the background model, as shown in

$$B_t(a, b) = \frac{1}{L} \sum_{i=0}^{L-1} A_{t-1}(a, b). \tag{14}$$

The premise of this algorithm is to have a memory space that can store frame video images. The background calculation formula is shown in

$$B_t(a, b) = \lambda A_t(a, b) + (1 - \lambda) B_{t-1}(a, b). \tag{15}$$

In the moving target detection algorithm, the biggest advantage of background subtraction is that the operation is simple, the implementation is simple, and the calculation amount is small. Therefore, the purpose of real-time detection can be basically achieved, and detection of the target to be moved can also be performed correctly.

After minimizing the above formula, we get:

$$H_t = \frac{\sum_{j=1}^{t} \overline{G_j} F_j}{\sum_{j=1}^{t} \overline{F_j} F_j}. \tag{16}$$

During the training process, the numerator and denominator of the above formula are regarded as a whole for iterative optimization. After the training is completed, if there is a new image area z, first calculate the value Z after its discrete Fourier transformation, and then obtain the response score of this area by the following formula:

$$y = \alpha^{-1}\{\overline{H_t} Z\}. \tag{17}$$

α^{-1} stands for inverse Fourier variation, and finding the largest y finds the location of the tracked martial arts performer.

When estimating the scale of martial arts performers, it is similar to the above calculation, except that the position and scale dimensions are considered at the same time, and f is the characteristic area. There are a total of d scale dimensions; h and g are also similar to the above, but only have more scale dimensions. The loss function to be optimized is calculated as follows:

$$\xi = \sum_{l=1}^{d} \left\| h^l * f^l \right\|^2 = \lambda \sum_{l=1}^{d} \left\| h^l \right\|^2. \tag{18}$$

Among them, λ represents the regular term, and the H of the Fourier space is obtained after solving:

$$H^l = \frac{\overline{G} F^l}{\sum_{k=1}^{d} F^k F^k + \lambda}. \tag{19}$$

3. Experiment of Artificial Intelligence Technology in Martial Arts Education Governance

3.1. Importance of Martial Arts Education in Various Aspects

3.1.1. Martial Arts Education Enriches Physical Knowledge and Increases Physical Skills. In the process of development, martial arts have been influenced and nurtured by traditional Chinese medicine and health preservation. Many scientific knowledge and theories of traditional Chinese medicine and health preservation have become the guiding ideology of martial arts practice, and martial arts technical movements are also formed under the guidance of traditional Chinese medicine theory. These technological movements also correspond to modern scientific knowledge and theories. Martial arts education has always been a traditional fitness program and has an important position in the elderly group. With the development of martial arts culture, more and more young groups love fitness sports and combine them with modern fitness theory. The effect of martial arts education on enriching physical knowledge and increasing physical skills is shown in Figure 8.

As shown in Figure 8, the proportion of experts who believe that martial arts training is very useful for enriching sports knowledge is 70.2%, indicating that most experts recognize the role of martial arts training in enriching sports knowledge. In terms of increasing physical skills, the percentage of experts who thought martial arts training is very useful in increasing physical skills was 83%, indicating that most experts recognized the role of martial arts training in increasing physical skills.

3.1.2. Martial Arts Education Develops Practitioners' Physical Strength and Develops Sports Habits. Physical fitness refers to the physical ability to perform a sport or activity. It includes the ability to perform sports, occupations, and a range of other physical movements. It is not identical to the concept of physical fitness but focuses on the expression of the functional level of physical movement. In China, it includes physical qualities such as strength, speed, and coordination, as well as protective qualities such as adaptability, endurance, and immunity. Physical fitness is a reflection of individual physical fitness. In China, the measurement of physical fitness is also a test that every college student needs to pass. Physical fitness is also an important indicator to measure a person's potential and ability. Through martial arts education, the functions of body organs and tissues can be trained. This helps develop physical qualities such as strength, speed, stamina, and flexibility and improves the body's defenses such as fitness and stamina. The role of martial arts training in developing physical habits and fitness is shown in Figure 9.

As shown in Figure 9, the proportion of experts who think that martial arts education is very or relatively large in developing sports habits is 83.0%, which indicates that most experts agree that martial arts education plays a role in developing sports habits. The proportion of experts who think that martial arts education plays a very large or relatively large role in developing physical strength is 78.7%, which shows that most experts approve of the role of martial arts education in developing physical strength.

3.1.3. Martial Arts Education Cultivates Self-Awareness and Cultivates Independence. In terms of student self-control, martial arts education will cultivate students' effective self-regulation. Martial arts education attaches great importance to the education of students' independence, autonomy, and self-discipline. It requires students to learn to think independently, learn to rely on themselves, learn to control themselves, learn to persist, and learn to motivate themselves. Because only with these abilities and these qualities can he achieve his dream of becoming a martial arts master. This long-term education and edification process is conducive to students' effective self-regulation. The effect of martial arts education on developing self-awareness and fostering independence is shown in Figure 10.

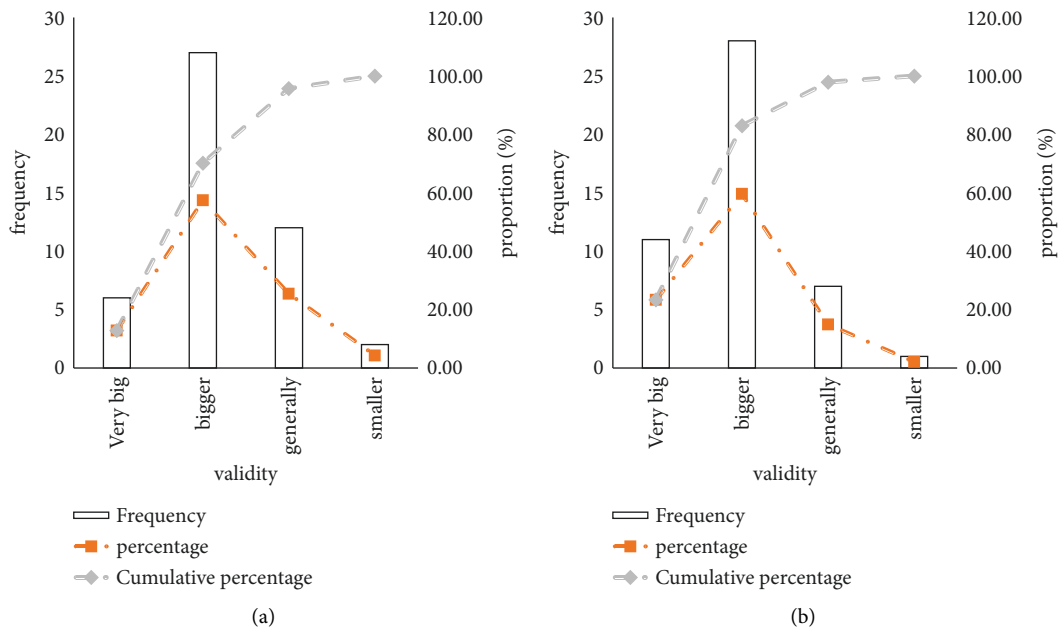


Figure 8: The effect of martial arts education on enriching physical knowledge and increasing physical skills: (a) effects on enriching physical knowledge and (b) effects on increasing physical skills.

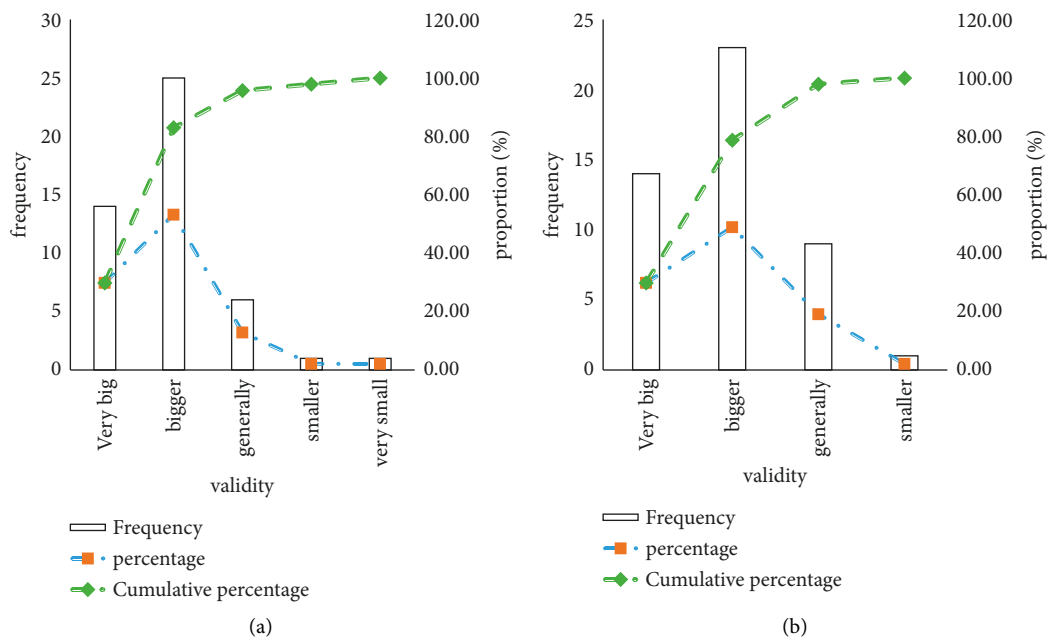


Figure 9: The effect of martial arts education on developing sports habits and developing physical strength: (a) the effect of martial arts on the formation of sports habits and (b) the effect of martial arts on the development of physical strength.

As shown in Figure 10, 70.2% of experts believe that martial arts education has a very large or relatively large role in developing self-awareness and independence. This shows that most experts agree on the role of martial arts education in developing self-awareness and independence.

3.2. Results of the Impact of AI-Based Flipped Classroom Teaching on Students' Martial Arts Learning. The students were divided into experimental group and control group to conduct martial arts teaching experiments. After the teaching experiment, the martial arts skills, theory, active participation attitude, learning attitude, self-inquiry ability, analysis, and problem-solving ability of the students in the two classes were tested and analyzed. In this paper, the independent sample T test was carried out on the obtained data, and the paired T test was carried out on the data of the students in the two groups before and after the experiment. Table 1 shows the comparative analysis of students' martial arts learning in the first two classes of the experiment.

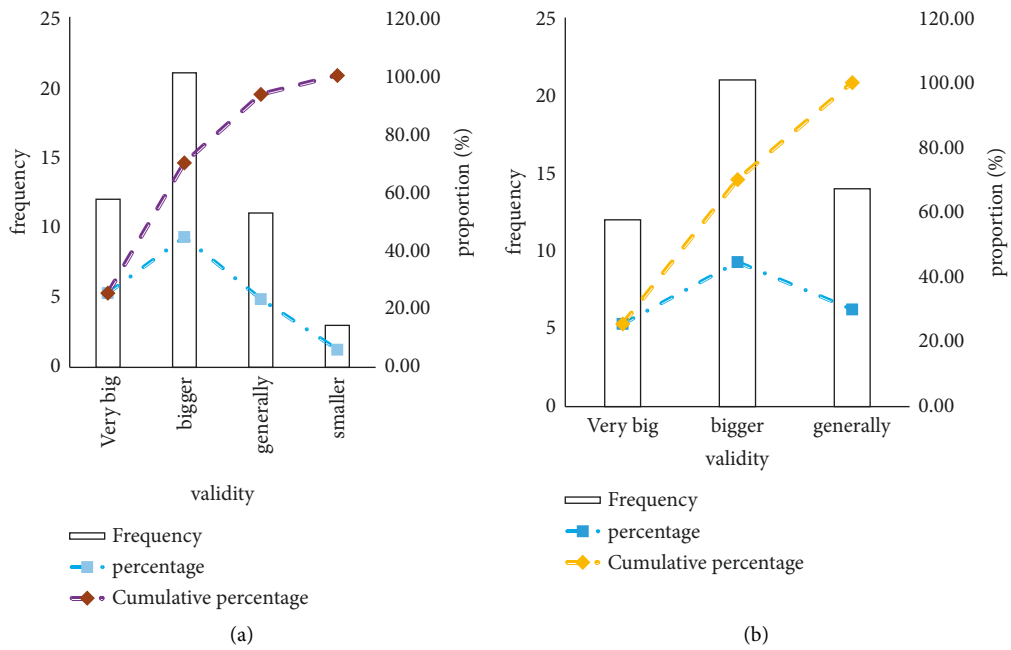


Figure 10: The effect of martial arts education on developing self-awareness and developing independence: (a) effect on developing self-awareness and (b) effect on developing independence.

Table 1: Analysis of martial arts learning situation of students in the first two classes of the experiment.

Survey dimensions	Experimental class	Control class	T value	P value
Learning interest	14.00 ± 2.28	13.57 ± 2.39	0.529	0.648
Independent research ability	14.30 ± 2.14	13.87 ± 2.17	0.453	0.945
Active participation attitude	12.87 ± 2.77	13.90 ± 1.93	0.099	0.077
Analytical problem-solving skills	12.97 ± 2.24	12.87 ± 1.53	0.824	0.062

As shown in Table 1, students in the first two classes of the experiment conducted a questionnaire on their learning situation. The learning situation is mainly analyzed from the four dimensions: students' learning interest, active participation attitude, self-inquiry ability, and problem-solving ability. This paper analyzes the data obtained from the questionnaire. The analysis results show that the P value of students' interest in learning in the two classes is 0.648, the P value of independent inquiry ability is 0.945, the P value of active participation attitude is 0.077, and the ability to analyze and solve problems is 0.062. The P values of the four dimensions are all greater than 0.05, and the data show that the learning situation of the students in the two classes is basically the same, and there is no significant difference. Table 2 shows the comparative analysis of students' martial arts learning situation in the two classes before and after the experiment.

As shown in Table 2, the analysis results show that there are some changes in the values of students' interest in learning, active participation attitude, self-exploration ability, and analysis and problem-solving ability of the students in the control class, but the changes are not large. The P value of learning interest is 0.725, the P value of independent inquiry ability is 0.078, the P value of active participation attitude is 0.835, and the P value of analytical problem-solving ability is 0.000. Except for analyzing the problem-solving ability, the P values for the remaining three were all greater than 0.05. It indicated that there was no significant difference in the students' active participation attitude, learning interest, and self-inquiry ability before and after the experiment. The P value for analyzing problem-solving ability was 0.001. If the P value is less than 0.01, it means that there is a very significant difference in the problem-solving ability of the students in the control class.

It can be seen from the above results that the students in the control class have improved their ability to analyze and solve problems under the traditional classroom learning. Learning interest, active participation attitude, and self-inquiry ability did not improve. The reason for this result may be the traditional classroom teaching method is relatively boring and single. The way of class has not changed for so many years. During the class, the teacher will explain, demonstrate, and correct errors. Most of the time in the class is the teacher's demonstration and the students imitate the movements. The whole practice process loses interest. It cannot fully mobilize students' enthusiasm and interest in learning and cannot make students fall in love with martial arts. In traditional classrooms, teachers will organize students to practice in groups throughout the teaching process, and students will discuss and analyze in groups. For the movements that do not know, we collectively discuss and practice. Therefore, this is what makes the students'

Table 2: Comparative analysis of students' martial arts learning situation in the two classes before and after the experiment.

Survey dimensions	Experimental class	Control class	T value	P value
Learning interest	13.57 ± 2.59	13.77 ± 1.68	−0.352	0.725
Independent research ability	13.87 ± 2.17	14.70 ± 1.57	−1.757	0.078
Active participation attitude	13.90 ± 1.93	13.77 ± 2.24	0.145	0.835
Analytical problem-solving skills	12.87 ± 1.53	14.73 ± 2.25	−4.24	≤0.001

Table 3: Test of martial arts learning situation of students in experimental class before and after the experiment.

Survey dimensions	Experimental class	Control class	T value	P value
Learning interest	14.00 ± 2.52	16.80 ± 1.78	−5.457	≤0.001
Independent research ability	14.30 ± 2.57	16.87 ± 1.27	−5.147	≤0.001
Active participation attitude	12.87 ± 2.87	16.70 ± 1.76	−6.167	≤0.001
Analytical problem-solving skills	12.97 ± 2.27	15.87 ± 1.57	−6.13	≤0.001

Table 4: Test of students' martial arts learning situation in the two classes after the experiment.

Survey dimensions	Experimental class	Control class	T value	P value
Learning interest	16.80 ± 1.42	13.77 ± 1.72	7.683	≤0.001
Independent research ability	16.87 ± 1.52	14.70 ± 1.27	5.673	≤0.001
Active participation attitude	16.70 ± 1.75	13.77 ± 2.27	6.125	≤0.001
Analytical problem-solving skills	15.87 ± 1.25	14.73 ± 2.12	2.525	0.014

analytical and problem-solving abilities improve. Table 3 shows the test of martial arts learning of students in the experimental class before and after the experiment.

As shown in Table 3, the analysis results show that the values of students' interest in learning, active participation attitude, self-exploration ability, and analytical problem-solving ability have changed, and the changes have been large. The P value of the students' learning interest before and after the experiment was 0.001, the P value of active participation attitude was 0.001, the P value of active inquiry ability was 0.001, and the P value of analysis and problem-solving ability was 0.001. The P values of the four are less than 0.01, which means that the students in the experimental class have very significant differences in their active participation attitude, learning interest, self-inquiry ability, and analysis and problem-solving ability. After 4 weeks of experiments, it is shown that AI flipped classroom teaching can improve students' interest in learning martial arts, drive students' enthusiasm for learning, and cultivate students' ability to actively explore and solve problems. The reason for this result may be students preview the Taijiquan video uploaded by the teacher before class and learn about the history and culture of Taijiquan through online Taijiquan materials and links. Before class, they restrained themselves according to the teacher's requirements, conducted online classroom learning, discussed with their classmates and teachers about the problems they did not understand, and completed the homework. During class, students learn with their own preclass questions, and the teacher will focus on teaching the students' feedback. The difficult points before the class are solved by the teacher's explanation in the class, and their own practice is solved. After class, they review carefully. Students review the content of the previous class online and preview the new content of the next class. Before class, during class, and after class, students will be organized to discuss difficult points to improve students' ability to explore and solve problems by themselves. Table 4 shows the test table of students' martial arts learning situation in the two classes after the experiment.

As shown in Table 4, the analysis results show that the P value of students' interest in learning in the two classes is 0.001, the P value of active participation attitude is 0.001, and the P value of independent inquiry ability is 0.001. The three P values are all less than 0.01, which means there is a very significant difference. The P value of analytical problem-solving ability is 0.014, which is less than 0.05, indicating a significant difference. From the above results, we know that the overall effect of AI flipped classroom is better than that of traditional classroom, and AI flipped classroom can not only mobilize students' interest in learning but also improve students' active participation attitude, self-inquiry ability, and problem-solving ability. The AI teaching model can improve the learning effect of students. Most of the reasons are due to vivid and flexible teaching videos and online self-learning without time and geographical restrictions. To a large extent, it has stimulated students' enthusiasm for learning and improved students' interest in learning.

4. Conclusion

According to the actual situation of teaching, it should flexibly use as many teaching methods, learning organization forms, and teaching aids as possible. It helps to stimulate students' interest in learning, improve students' learning enthusiasm and initiative, and thus promote the teaching effect. The design of teaching methods is related to the presentation of teaching effects. At present, Wushu education relies more on interest as the driving force for learning. In the future, it should be standardized with

systematic teaching theories, so that teaching methods and teaching effects can promote each other. In the past, teaching methods were mainly based on lectures and demonstrations, and the organizational form of learning was relatively stable. There is a method in teaching, but there is no fixed method. Martial arts teachers should actively seek some teaching methods that are suitable for martial arts teaching and can stimulate the interest of learners. It can also innovate some teaching methods and means that are suitable for martial arts teaching and that students like, so as to stimulate students' interest, improve teaching efficiency, and ensure the realization of teaching purposes. At present, more electronic teaching methods can be used in martial arts teaching. This teaching method can be used not only in technical teaching but also in traditional culture teaching and martial arts education. By watching videos of martial arts technique moves, one can gain a deeper understanding of the technique and learn faster and more regularly. Watching different martial arts competition videos can also stimulate interest in martial arts and broaden students' horizons. By allowing students to appreciate some educational martial arts movies, animations, etc., it can make students nurtured and infected, which is beneficial to moral education. The role of the teacher in the overall classroom design is crucial, and a large part of the student's learning effect depends on the way the teacher teaches. This is especially true for martial arts teachers. Without a rich theoretical foundation, it is not effective to teach movements unilaterally.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the Ministry of Education's Industry-University Cooperation Collaborative Education Project (project No. 202102277012); Heilongjiang Province Philosophy and Social Sciences Support and Joint Construction Project (project No. 20TYE332); Chinese University Sports Association Project (project No. L202103001); and the Ministry of Education Humanities and Social Sciences Research Youth Fund Project (No. 21YJC890016).

References

[1] K. Sangjin and P. T. Seop, "A study on the development of in fact physical education program applied fundamental motor skill of mixed martial arts," *The Korean Journal of Growth and Development*, vol. 25, no. 1, pp. 129–136, 2017.

[2] W. Mastnak, "Sports and martial arts activities for public health purposes: the musician's risk profiles and exercise-based health care as a model," *Journal of Public Health*, vol. 25, no. 3, pp. 231–241, 2017.

[3] R. J. Rotunda and S. Ryan, "Challenges in implementing a time-limited martial-arts curriculum in middle-school physical education classes: a research consultation case," *Case Studies in Sport and Exercise Psychology*, vol. 3, no. 1, pp. 71–76, 2019.

[4] N. A. Ujuagu, T. N. Uzor, S. N. Igwilo, and E. E. Akpu, "Assessing physical education curriculum on martial arts for junior secondary school: pedagogy for effective self defense program and technique," *International Journal Of Advance Research And Innovative Ideas In Education*, vol. 7, no. 7, pp. 225–230, 2020.

[5] E. Akehurst, J. Southcott, and K. Lambert, "Kick start – martial arts as a non-traditional school sport: an Australian case study of Taekwondo for Years 7–12 students," *Curriculum Studies in Health and Physical Education*, vol. 11, no. 1, pp. 83–98, 2019.

[6] C. Wang and J. Liu, "A study on the teaching content of martial arts in primary and secondary schools from the perspective of cultural inheritance," *Advances in Physical Education*, vol. 8, no. 1, pp. 1–6, 2018.

[7] Q. Han, S. Huo, and R. Li, "Martial arts routine training method based on artificial intelligence and big data of lactate measurement," *Journal of Healthcare Engineering*, vol. 2021, pp. 1–8, Article ID 5522899, 2021.

[8] V. V. Romanenko, O. O. Podrihalo, L. V. Podrigalo, S. S. Iermakov, Z. V. Sotnikova-Meleshkina, and O. V. Bobrova, "The study of functional asymmetry in students and schoolchildren practicing martial arts," *Physical Education of Students*, vol. 24, no. 3, pp. 154–161, 2020.

[9] P. P. John and J. T. Martin, "Topic modeling and sentiment analysis of martial arts learning textual feedback on YouTube," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 3, pp. 2712–2718, 2020.

[10] D. Shibiao, "Design and implementation of a martial arts learning system based on Silverlight," *Agro Food Industry Hi-Tech*, vol. 28, no. 1, pp. 1862–1866, 2017.

[11] A. Sukhoverkhov, A. A. Klimenko, and A. S. Tkachenko, "The influence of daoism, chan buddhism, and confucianism on the theory and practice of east asian martial arts," *Journal of the Philosophy of Sport*, vol. 48, no. 2, pp. 235–246, 2021.

[12] C. I. Chude and S. Schaaf, "A unique cause of sciatica in A masters martial arts athlete: 1264," *Medicine & Science in Sports & Exercise*, vol. 53, p. 416, 2021.

[13] C. S. Fukazawa, S. Charles, and M. Arts, "Applications in higher education," *Staps*, vol. 116, no. 2, pp. 124–126, 2017.

[14] M. Bae, "Martial arts education in the history of elementary physical education curriculum," *The Korean Journal of the Elementary Physical Education*, vol. 24, no. 4, pp. 49–61, 2019.

[15] P. S. Kim, "A study on police martial arts education," *Korean Journal of Sports Science*, vol. 29, no. 4, pp. 175–187, 2020.

[16] E. R. Hwang and T. Y. Kim, "Intensification of the education of public health, hygiene, and martial arts during the Japanese colonial period (1937–1945)," *Journal of Exercise Rehabilitation*, vol. 14, no. 2, pp. 160–167, 2018.

[17] J. Lee, "Trend analysis of adapted physical education and exercise rehabilitation using martial arts for the elderly in South Korea: a systematic review," *Korean Journal of Clinical Geriatrics*, vol. 22, no. 1, pp. 15–21, 2021.

[18] Y. W. Jung and H. T. Oh, "The implication of posthumanism in physical education and sport," *The Journal of the Korean Society for the Philosophy of Sport Dance & Martial Arts*, vol. 28, no. 4, pp. 33–44, 2020.

[19] T. Shouyan, "Recognition and simulation of martial arts training behavior based on virtual reality," *Agro Food Industry Hi-Tech*, vol. 28, no. 1, pp. 2345–2348, 2017.

[20] E. Fuente, "Recentering the cartographies of karate: martial arts tourism in okinawa," *Ido Movement for Culture*, vol. 21, no. 3, pp. 51–66, 2021.

[21] J. Y. Lee and S. K. Kim, "The influence of Chinese martial arts school female athletes' athletic emotion, athletic commitment, and athletic persistence intention," *Journal of Korean Association of Physical Education and Sport for Girls and Women*, vol. 35, no. 2, pp. 77–90, 2021.

[22] D. F. Albertini, "Trending in human ARTs: jumping on the artificial intelligence and machine learning bandwagon," *Journal of Assisted Reproduction and Genetics*, vol. 38, no. 7, pp. 1605-1606, 2021.

[23] B. Follmer, L. V. Andreato, and V. Coswig, "Combat-ending submission techniques in modern mixed martial arts," *Ido Movement for Culture*, vol. 21, no. 2, pp. 6–10, 2021.

[24] K. Sas-Nowosielski and K. Kostorz, "The morality of practicing martial arts and combat sports," *Ido Movement for Culture*, vol. 21, no. 2, pp. 57–68, 2021.

[25] J. Jin and D. Ren, "Teaching team construction and teaching reform of the school of communication under the background of new liberal arts - taking sichuan university of media and communications as an example," *Contemporary Education Research*, vol. 6, no. 1, pp. 6–10, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8901180, 10 pages
https://doi.org/10.1155/2022/8901180

Research Article

Modeling the Linkages between Bitcoin, Gold, Dollar, Crude Oil, and Stock Markets: A GARCH-EVT-Copula Approach

Feng Jin,[1] **Jingwei Li**,[2] **and Guangchen Li**[3]

[1]*School of International Trade and Economics, University of International Business and Economics, Beijing 100029, China*
[2]*School of Insurance and Economics, University of International Business and Economics, Beijing 100029, China*
[3]*School of Economics, Beijing Wuzi University, Beijing 101149, China*

Correspondence should be addressed to Feng Jin; 201800152003@uibe.edu.cn

Received 7 June 2022; Accepted 27 July 2022; Published 27 August 2022

Academic Editor: Lele Qin

This paper aims to analyze and compare the ability of bitcoin, gold, and dollar to diversify the risk of traditional market such as crude oil and stock markets. Specifically, we model the linkages between bitcoin, gold, dollar, crude oil, and stock markets using the GARCH-EVT-copula approach. The results show that the gold market is in the central position among these markets, which is consistent with the status of gold as a major safe asset. Before the outbreak of COVID-19, bitcoin and the dollar also had the ability to diversify risks, although less effective than gold. However, during the COVID-19 period, gold loses its dominant position and gold, bitcoin, and dollar can no longer act as a hedge. We measure the value at risk (VaR) and expected shortfall (ES) of simulated portfolios constructed based on these five markets and use several backtesting methods to check the validity of the risk measures. The backtesting results show that our model can provide accurate risk measures before and within the COVID-19 period, which may help investors and risk managers construct the optimal portfolios.

1. Introduction

Bitcoin has attracted great attention around the world since its introduction in 2008. Proposed by Nakamoto [1], bitcoin is a peer-to-peer electric cash system that allows online payments to be sent directly from one party to another without going through a financial institution. The essence of bitcoin indicates that it may serve as a medium of exchange, which is one of the core functions of money. However, there have been many debates on whether bitcoin can be seen as a currency, speculative asset, or just a bubble [2–5]. Some studies find that the return of bitcoin is much more volatile than traditional financial markets and fiat currency [6, 7]. In early 2013, the unit price of bitcoin was only less than 100 dollars. However, it has multiplied several hundred times and reached more than 67,000 dollars at the end of 2021. Therefore, many researchers believe that bitcoin behaves more like a speculative asset. The bitcoin market has been increasingly attractive to international investors.

Recently, a growing literature has focused on the relationship between bitcoin and conventional markets, which has important implications for investors and policymakers [8–11]. Bitcoin is found to be connected with commodity markets [12–14], foreign exchange markets [15, 16], and stock markets [17–19]. However, the relationship between bitcoin and conventional markets is not as strong as that between the conventional markets, making it possible to use bitcoin as a hedge or safe haven for investors during market turmoil [20, 21].

Historically, gold has long been seen as a store of value and a trustful safe asset. The US dollar, the most popular currency in the world, can also maintain a relatively stable value and hedge risks. Dyhrberg [22] compares bitcoin with gold and the dollar and finds bitcoin has several similarities, which indicate that bitcoin has some hedging capabilities and can be useful in risk management. Bouri et al. [20] use the dynamic conditional correlation model to examine whether bitcoin can act as a hedge and safe haven for major world stock indices, bonds, oil, gold, the general commodity

index, and the US dollar index. They find that bitcoin has hedge and safe haven properties against Asia Pacific stocks. Shahzad et al. [23] compare gold and bitcoin and find that bitcoin can also be used as a safe haven and hedging instrument for G7 stock markets. However, whether bitcoin can act as "digital gold" and become a safe haven are still under discussion. Smales [7] investigates the asset characteristics of Bitcoin over the periods 2011–2018 and believes that bitcoin does not have the potential to be a safe haven. Conlon and McGee [24] also cast doubt on the ability of bitcoin to provide shelter from turbulence in traditional markets. They find that bitcoin fails to be a safe haven for S&P 500 during the COVID-19 bear market. There are still some gaps in existing studies, which leave space for our research. On one hand, opinions have not reached a consensus on whether bitcoin can be used to diversify portfolio risk. More empirical evidence is needed to analyze the characteristics of bitcoin. On the other hand, many studies only focus on the linear relationship between bitcoin and other markets, which may lead to inaccurate results. In this paper, we try to fill these gaps.

In this paper, we study the linkages between bitcoin, gold, dollar, and two conventional markets—the crude oil and stock market. Bouri et al. [20] have investigated similar markets using the DCC-GARCH model. However, GARCH type models can only depict the linear relationship and need to assume asset distribution beforehand [25]. This paper employs the GARCH-EVT-copula approach to characterize the intermarket dependency structure. Specifically, first we use the ARMA-EGARCH-t to model the volatility of each market. Then, the extreme value theory (EVT) is used to model the tail risk of each market. Finally, we employ the R-vine copula to depict the dependence structure of the five markets and analyze the market relationships. This model allows us to provide accurate risk measures of the portfolio of these assets, which can help investors and risk managers control the portfolio risk.

This paper employs the GARCH-EVT-copula method to study the links between bitcoin, gold, dollar, crude oil, and stock markets. We focus on describing the dependence structure between markets. We find that gold is the central market during the whole sample period, which is consistent with the status of gold as a major safe haven asset. The outbreak of COVID-19, however, changed the dependence structure between these markets. Before COVID-19, bitcoin can act as a hedge, as it is negatively correlated with the crude oil and stock markets. When COVID-19 began to spread worldwide, gold is no longer in the central position, and gold, bitcoin, and dollar can no longer be seen as hedges but diversifiers. We also show that our model can provide accurate risk measures before and within the COVID-19 period, which facilitates the risk management for international investors and risk managers.

Our paper contributes to the existing literature in three parts. First, we study the relationship between bitcoin, gold, dollar, crude oil, and stock markets simultaneously. As far as we know, there have not been enough studies investigating the relationship between the five markets. Moreover, the existing literature usually only compares bitcoin with gold, to analyze whether bitcoin can diversify investment risks. However, few studies consider the dollar and analyze the interaction between these markets. This paper studies the relationship between five markets, which is a more comprehensive analysis framework. Second, the extreme correlations of the five markets are considered. When analyzing the bitcoin market, it is necessary to take the tail behavior of markets into consideration [26]. Based on the extreme value theory, we depict the extreme risk between markets by modeling the tail distribution of market returns. It can allow us to analyze the relationship between these markets more comprehensively and study whether bitcoin can diversify risks in terms of traditional market fluctuations. Third, the copula method is used to analyze the relationship between markets. The GARCH type models, most commonly used in existing literature, can only depict the linear relationship between markets [27]. In this paper, the R-vine copula is presented to overcome the limitation.

The remainder of this paper is organized as follows. Section 2 introduces the methodology. Section 3 deals with the data and presents the empirical results. Section 4 concludes the paper.

2. Methodology

2.1. The Framework of GARCH-EVT-Copula. This paper proposes the GARCH-EVT-copula method to study the links between bitcoin, gold, dollar, crude oil, and stock markets. Specifically, we first calculate the return of each market, and the ARMA-EGARCH-t model is used to model the volatility. Then, the extreme value theory is employed to model the tail risk by using the standardized residual of the ARMA-EGARCH-t model. The ARMA-GARCH-t and EVT are used to model the marginal distribution of each market. Next, we use the R-vine copula model to describe the dependence structure of these markets. Finally, we calculate and backtest the value at risk (VaR) and expected shortfall (ES) of simulated portfolios to test the performance of the model. The steps are presented in Figure 1.

2.2. ARMA-EGARCH-T Model. Abundant studies show that the time series of financial markets exhibit leptokurtosis, fat tails, and volatility clustering. The GARCH type models are commonly used to model these features. Besides, the returns of financial assets usually respond differently to positive and negative information, which is called the asymmetric effect. In this paper, we employ ARMA (1, 1)-EGARCH (1, 1)-t model to characterize each market:

$$\mathrm{r}_t = a_0 + a_1 r_{t-1} + b_1 \varepsilon_{t-1} + \varepsilon_t. \tag{1}$$

In the conditional mean model, r_t is the asset return on day t, a_0 is the constant term, a_1 is the coefficient of the lagged return, ε_t is the residual, and b_1 is the coefficient of the lagged residual. We assume e_t follows the t-distribution with degree of freedom v:

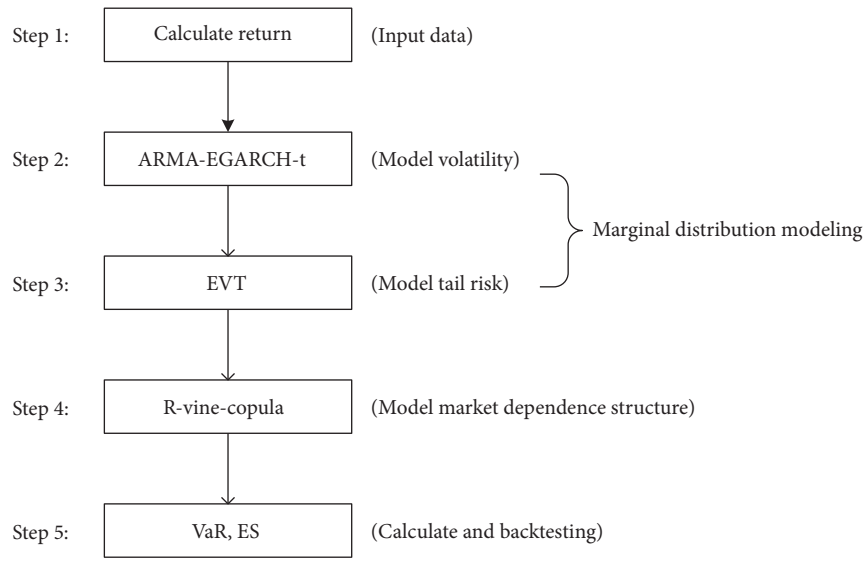


Figure 1: The steps of GARCH-EVT-copula approach.

$$\varepsilon_t = \sigma_t e_t,\ e_t \sim t(v),$$
$$\ln\sigma_t^2 = \omega + \alpha\frac{|\varepsilon_{t-1}|}{\sigma_{t-1}} + +\gamma\frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \beta\ln\sigma_{t-1}^2. \tag{2}$$

In the conditional variance equation, σ_t^2 is the conditional variance on day t, and γ is the parameter measuring the asymmetric effect. If γ is significantly different from 0, the asymmetric effect exists in the market.

After modeling the market return, we calculate the standardized residual, which is the conditional return filtered by volatility estimates using the ARMA-EGARCH-t model. The standardized residual of each market will be used in the following EVT analysis.

2.3. Extreme Value Theory. Some big events may cause the market prices to rise or fall simultaneously, which may affect the dependence structure between markets. Therefore, it is very necessary to measure the extreme correlation before investigating the dependence structure among markets [25]. Since the tail risks of financial assets are usually associated with huge gains or losses, we measure the extreme risks of these markets by using the extreme value theory (EVT) to model these returns' tail distributions.

We first set the upper and lower tail thresholds, which will divide the data into three parts. For the data between the upper and lower tail thresholds, we use the Gaussian kernel density estimation to obtain the cumulative distribution function (CDF). The upper and lower parts are modeled using the peaks over threshold (POT) method. The conditional tail distribution function $F_u(y)$ can be written as

$$F_u(y) = p(z - u \le y \mid z > u),\ 0 \le y \le z_F - u. \tag{3}$$

Here, z is the conditional return filtered by the ARMA-EGARCH-t model, u is the preset threshold, y represents the extreme statistic, and $z_F \le \infty$ represents the right endpoint of the distribution. $F_u(y)$ can be rewritten as

$$F_u(y) = \frac{F(u+y) - F(u)}{1 - F(u)} = \frac{F(z) - F(u)}{1 - F(u)}. \tag{4}$$

Balkema and Haan (1974) and Pickands (1975)show that the distribution beyond the threshold can be approximately modeled as the generalized Pareto distribution (GPD) for a sufficiently large threshold.

$$F_u(y) \approx G_{\xi,\beta}(y) = \begin{cases} 1 - \left(1 + \frac{\xi}{\beta}y\right)^{1/\xi}, & \xi \ne 0 \\ 1 - e^{-y/\beta}, & \xi = 0 \end{cases}, \tag{5}$$

where β is the scale parameter and ξ is the shape parameter. When $\xi \ge 0$, we have $z \ge u$; when $\xi < 0$, we have $u \le z \le u - \beta/\xi$, and for any $z > u$, $y = z - u$. By combining equations (5) and (6), the $F(z)$ can be expressed as

$$F(z) = (1 - F(u))G_{\xi,\beta}(z - u) + F(u). \tag{6}$$

We use the historical simulation method to estimate $F(u)$, that is, $F(u) = n - N_u/n$, where n and N_u represent sample size and observation that exceeds the tail threshold, respectively. We introduce $F(u)$ into equations (7) and obtain the tail estimation $\widehat{F}(z)$.

$$\widehat{F}(z) = \begin{cases} 1 - \frac{N_u}{n}\left(1 - \frac{\xi}{\beta}(z-u)\right)^{1/\xi}, & \xi \ne 0 \\ 1 - \frac{N_u}{n}e^{-z-u/\beta}, & \xi = 0 \end{cases}. \tag{7}$$

The copula function requires uniform margins. Therefore, we use the probability density transformation and make the series uniformly distributed on [0, 1].

2.4. R-Vine Copula Model. A copula is a multidimensional joint distribution function that can capture the dependence structure of various assets. In general, the dependence structures between different assets are different. Using the same copula function to depict the dependence structure between each pair of markets is not a good choice. To solve this problem, Bedford and Cooke [30] propose the R-vine (regular vine) copula model, which can select the most suitable copula functions from various pair-copula families.

According to Aas et al. [31]; the joint density function of R-vine can be decomposed as

$$f(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} f(x_i) \prod_{k=n-1}^{1} \prod_{j=n}^{k+1} C_{m_{k,k}, m_{j,k} | m_{j+1,k}, \ldots, m_{n,k}} \left(F_{m_{k,k} | m_{j+1}, k, \ldots, m_{n,k}}, F_{m_{j,k} | m_{j+1,k}, \ldots, m_{n,k}} \right), \tag{8}$$

where $f(x_i)$ is the marginal density and $C_{m_{k,k}, m_{j,k} | m_{j+1,k}, \ldots, m_{n,k}}(.,.)$ represents the pair-copula density. F is the conditional distribution function, which can be expressed as

$$F_{p|q} = \frac{\partial C_{pq_j | q_{-j}} \left(F\left(p \mid q_{-j}\right), F\left(q_j \mid q_{-j}\right) \right)}{\partial F\left(q_j \mid q_{-j}\right)}. \tag{9}$$

Here, q_j represents one arbitrarily chosen component of vector q and q_{-j} represents the vector that excludes this component. For more information on the R-vine copula method, we can refer to Aas et al. [31].

2.5. VaR and ES Calculation and Backtesting. In this section, we test the performance of the GARCH-EVT-copula model on risk management. We build several portfolios using the five assets and calculate the value at risk (VaR) and expected shortfall (ES) of the simulated portfolios.

We first calculate the simulated return of each asset. Using the dependence structure of the R-vine copula model, we perform the Monte Carlo simulation to simulate the marginal series of each asset, as suggested by Janekova et al. [32, 33]. In our analysis, we generate a 5-dimension array with 5000 random observations. Note that each simulated series is uniformly distributed on [0, 1]. Then, we use the EVT fitting inversely and transform the simulated marginal series into standard residuals $z_{i,t+1}$. And, we use the ARMA (1,1)-EGARCH (1, 1)-t model in Section 2.2 to forecast the conditional volatility $\sigma_{i,t+1}$ and conditional average $\mu_{i,t+1}$ of each asset. Finally, the simulated return $X_{i,t+1}$ of each asset can be calculated by

$$X_{i,t+1} = \mu_{i,t+1} + z_{i,t+1}\sigma_{i,t+1}, i = 1, 2, \ldots, 5. \tag{10}$$

We then construct several portfolios and calculate the value at risk (VaR):

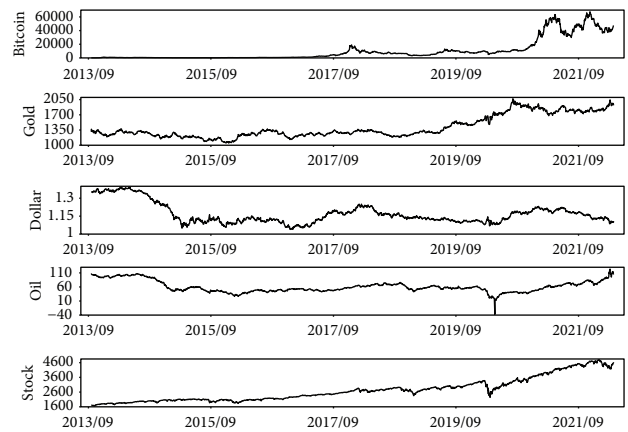


Figure 2: The price trends of five markets.

$$VaR_\alpha(R) = \min\{c\colon P(R \le c) \ge \alpha\}. \tag{11}$$

Here, $R = \sum_{i=1}^{5} w_i X_i$. and w_i is the portfolio weight of asset i. The VaR represents the minimum loss no more than the given value c with probability α. In this paper, we use two methods to backtest the VaR, the unconditional coverage test proposed by Kupiec (1995) and the conditional coverage test suggested by Christoffersen and Pelletier (2004).

To better measure the risk of the portfolio, the ES is also introduced:

$$\mathrm{ES}_\alpha(R) = E\left[R \ge VaR_\alpha(R)\right]. \tag{12}$$

Following Rockafellar and Uryasev [36] and Acerbi and Tasche [37], the ES can be calculated using the following equation:

$$\mathrm{ES}_\alpha(R) = \frac{1}{1-\alpha} \int_\alpha^1 VaR_\beta(R) d\beta. \tag{13}$$

To check the validity of ES, we use the bootstrap method suggested by McNeil and Frey [38]. For the tests for VaR and ES, the null hypotheses are the same, i.e., the model can provide accurate risk measurement. If the p value is larger than the given significant level such as 5%, we cannot reject the null hypothesis.

3. Data and Empirical Results

In this study, we use the daily closing price of bitcoin, gold, crude oil, dollar, and stock market from September 17, 2013, to March 28, 2022. Specifically, the bitcoin price data is retrieved from the coinmarketcap website (https://www.coinmarketcap.com). We use the per ounce of gold futures prices on the New York Mercantile Exchange to represent the gold market, the price of WTI crude oil futures to represent the crude oil market, the dollar-euro rate to represent the dollar market, and the S&P 500 Index to represent the stock market. The crude oil data is obtained from the EIA website, and the gold price, dollar, and S&P 500 data are obtained from the Wind database. For simplicity, we call them bitcoin market, gold market, dollar market, oil market, and stock market, respectively. The

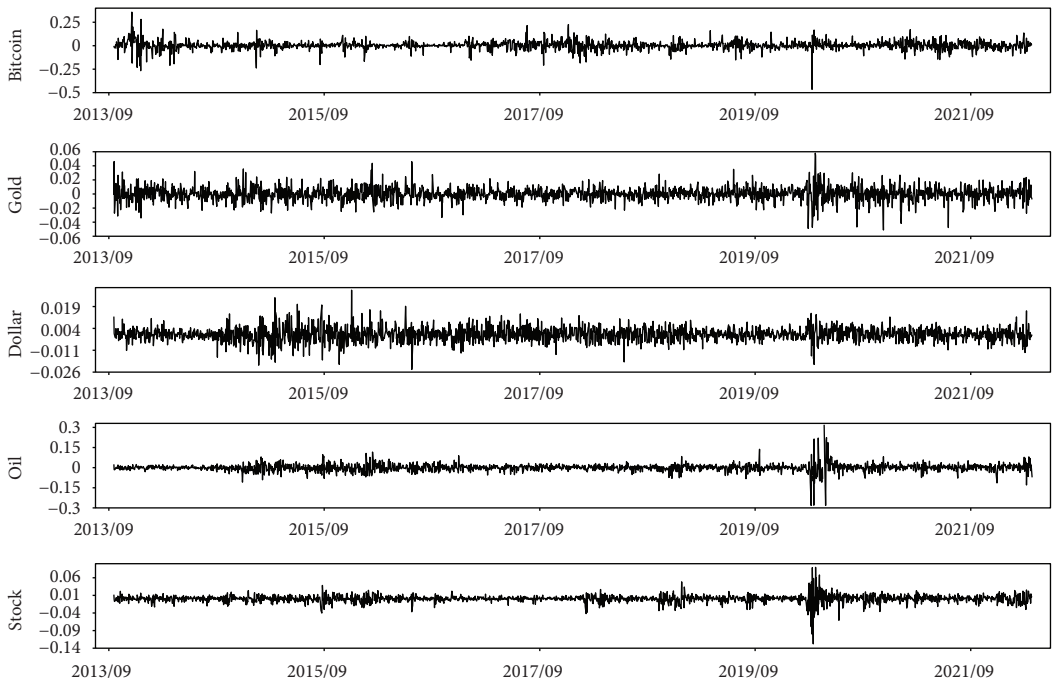


Figure 3: The daily returns of five markets.

Table 1: Descriptive statistics of the returns.

	Bitcoin	Gold	Dollar	Oil	Stock
Observations	2134	2134	2134	2134	2134
Mean	0.0023	0.0002	−0.0001	0.0003	0.0005
S.D.	0.0457	0.0095	0.0048	0.0295	0.0109
Min	−0.4647	−0.0511	−0.0242	−0.2822	−0.1277
Max	0.3575	0.0581	0.0302	0.3196	0.0897
Skewness	−0.5200	−0.0299	0.0585	0.1661	−0.9862
Kurtosis	14.2187	7.0228	5.5921	28.0320	23.8222
J-B statistics	11000^{***} (0.0000)	1439^{***} (0.0000)	599^{***} (0.0000)	56000^{***} (0.0000)	39000^{***} (0.0000)
ARCH	62.023^{***} (0.0000)	40.645^{***} (0.0000)	39.411^{***} (0.0000)	273.683^{***} (0.0000)	352.842^{***} (0.0000)
ADF	-12.099^{***} (0.0000)	-9.083^{***} (0.0000)	-8.055^{***} (0.0000)	-7.665^{***} (0.0000)	-11.516^{***} (0.0000)

Note. p values are in the parentheses. *** indicates the significant level at 1%.

Table 2: The results of ARMA (1,1)-EGARCH (1, 1)-t model.

	Bitcoin	Gold	Dollar	Oil	Stock
α_0	0.0017^{***}	0.0002^{*}	−0.0001	−0.0000	0.0006^{***}
α_1	-0.8894^{***}	-0.3706^{***}	0.8455^{***}	-0.3197^{***}	-0.2424^{***}
b_1	0.8802^{***}	0.3053^{***}	-0.8662^{***}	0.2814^{***}	0.1731^{***}
ω	-0.1567^{***}	-0.1344^{***}	-0.0777^{***}	-0.0807^{***}	-0.3775^{***}
α	0.4196^{***}	0.0902^{***}	0.1044^{***}	0.1291^{***}	0.2407^{***}
β	0.9726^{***}	0.9856^{***}	0.9928^{***}	0.9898^{***}	0.9619^{***}
γ	0.0645^{**}	0.0285^{**}	0.0138	-0.0882^{***}	-0.1839^{***}
LL	3530.112	5949.549	7047.405	4370.925	6184.461

Note. LL is the log-likelihood value of the estimation; *, **, and *** indicate the significant level at 10%, 5%, and 1%, respectively.

logarithmic return is calculated for each market using $r_t = \ln(P_t/P_{t-1})$, where r_t is the daily return and P_t is the closing price at day t. The prices and returns of the five markets are shown in Figures 2 and 3, respectively. We can observe the volatility clustering of each market. Moreover, all the markets showed significant price changes in early 2020, when COVID-19 began to spread around the world. This change may also influence the market relationship, which needs further analysis.

The descriptive statistics of the returns are shown in Table 1. The standard deviations indicate that bitcoin market is the most volatile market. All returns show the obvious

Table 3: BDS test results of standard residuals.

	Bitcoin	Gold	Dollar	Oil	Stock
BDS	1.2275 (0.2196)	−0.4898 (0.6243)	0.4229 (0.6724)	1.2273 (0.2197)	1.2972 (0.1946)

Note. p values are in the parentheses.

Table 4: Results of tail thresholds and EVT fitting.

	Lower tail			Upper tail		
	μ_L	ξ_L	β_L	μ_U	ξ_U	β_U
Bitcoin	−−0.7004	0.2951	0.5180	0.7258	0.2463	0.3953
Gold	−1.0964	−0.0310	0.6878	1.1099	0.0970	0.6028
Dollar	−1.2238	0.1736	0.4190	1.2080	−0.0305	0.6330
Oil	−1.2179	0.0721	0.6637	1.1191	0.0243	0.4836
Stock	−0.2661	0.1416	0.6547	1.1181	−0.0031	0.4107

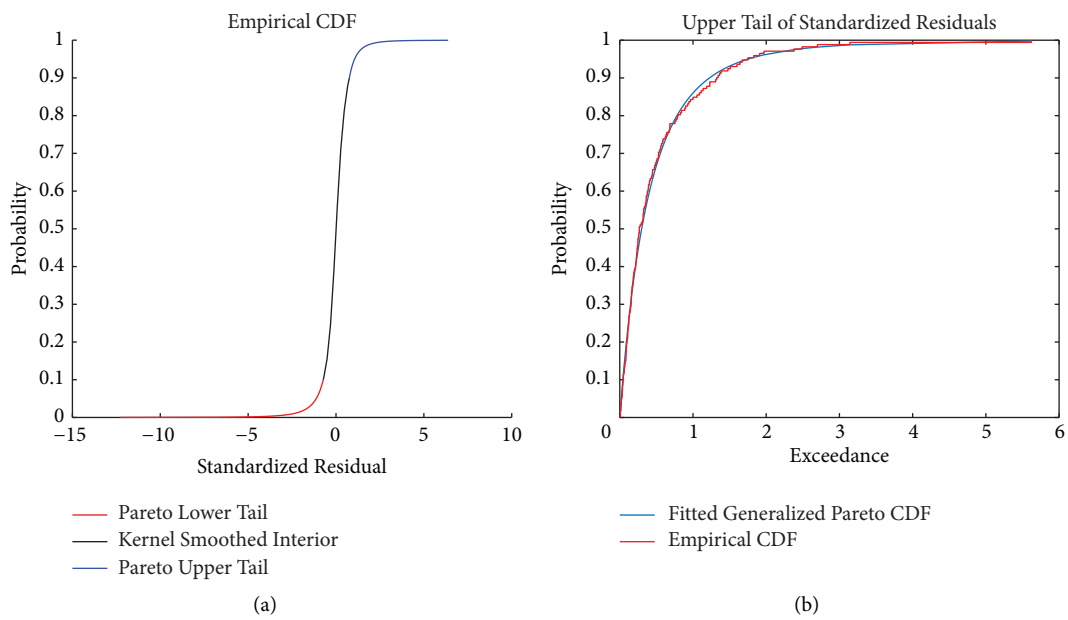


Figure 4: Distribution curve of residual and CDF fitting analysis of the bitcoin market.

feature of leptokurtosis, which is also confirmed by the J-B test. The ARCH test demonstrates that the returns have noticeable ARCH effects, which denotes that the GARCH type model is necessary to model the marginal distribution of each market. The ADF test reveals that all the returns are stationary.

Table 2 shows the coefficients of the ARMA (1, 1)-EGARCH (1, 1)-t model in each market. We can find that most of the coefficients are significant at 1% level, denoting that the model can fit the return series of five markets well. The leverage effect exists in all the markets except the dollar market. The coefficients γ are positive for the bitcoin and gold market, denoting that the positive news would cause larger volatilities. For oil and stock markets, the coefficients γ are negative, indicating that the negative news has a larger effect on the market volatilities. We then extract the standard residual sequence from the ARMA (1, 1)-EGARCH (1, 1)-t model. Before using the EVT method, the standard residual sequence needs to be independent identically distributed.

We use the BDS test proposed by Broock et al. [39], which is designed to test whether a random sequence is i.i.d (identical independent distributed). Table 3 shows that we cannot reject the null hypothesis that the sequence is i.i.d. Therefore, the standard residual series of each market can be used in the EVT analysis.

An appropriate threshold needs to be determined before employing the EVT method. A very small threshold will lead to too much tail data, which will not meet the preconditions of the EVT method. However, a very large threshold will result in too little tail data and affect the model's performance. According to DuMouchel [40], we select 10% as the threshold and obtain five corresponding upper (μ_U) and lower tail (μ_L) threshold values of market returns. The EVT fitting parameters are reported in Table 4. We find that the upper tail parameters (ξ_U) of bitcoin, and gold and oil markets are larger than 0, indicating that these markets present fat tails. Taking the bitcoin market as an example, we draw the

Table 5: K–S test results of marginal distribution.

	Bitcoin	Gold	Dollar	Oil	Stock
K–S	0.0222 (0.3409)	0.0176 (0.6332)	0.0124 (0.9436)	0.0146 (0.8383)	0.0154 (0.7865)

Note. p values are in the parentheses.

Table 6: Estimation results of R-vine copula.

		The whole period				Without COVID-19				During COVID-19			
	Edge	2,1	2,3	5,2	5,4	2,1	2,3	5,2	5,4	2,1	2,3	5,1	5,4
	Copula	Gumbel	Frank	Student t	Frank	Joe	Frank	Student t	Frank	Student t	Student t	Clayton	Student t
Tree1	Kendall's τ	0.05	0.24	−0.06	0.18	0.02	0.24	-0.09	0.17	0.15	0.21	0.18	0.20
	Up	0.07	—	0.00	—	0.05	—	0.00	—	0.06	0.01	—	0.11
	Low	—	—	0.00	—	—	—	0.00	—	0.06	0.01	0.21	0.11
	Edge	5,1|2	5,3|2	4,2|5		5,1|2	3,1|2	4,2|5		3,1|2	5,2|1	4,1|5	
	Copula	Clayton	Student t	Student t		Frank	Frank	Student t		Frank	Student t	Gaussian	
Tree2	Kendall's τ	0.03	0.01	0.06		−0.02	−0.00	0.09		0.08	0.03	0.07	
	Up	—	0.02	0.00		—	—	0.00		—	0.03	—	
	Low	0.00	0.02	0.00		—	—	0.00		—	0.03	—	
	Edge	3,1|5,2	4,3|5,2			5,3|1,2	4,1|5,2			5,3|1,2	4,2|5,1		
	Copula	Joe	Student t			Student t	Gaussian			Gumbel	Student t		
Tree3	Kendall's τ	0.01	0.01			-0.00	-0.01			0.08	-0.01		
	Up	0.03	0.00			0.02	—			0.11	0.00		
	Low	—	0.00			0.02	—			—	0.00		
	Edge	4,1| 3,5,2				4,3| 5,1,2				4,3| 5,1,2		
	Copula	Gaussian				Clayton				Student t			
Tree4	Kendall's τ	0.00				0.03				0.01			
	Up	—				—				0.02			
	Low	—				0.00				0.02			

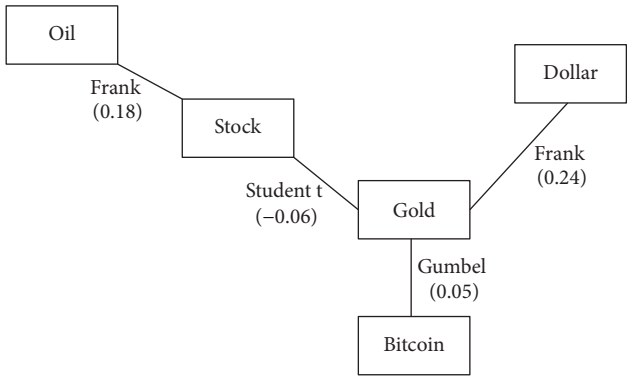


Figure 5: The estimated five-dimensional R-vine tree of the whole sample.

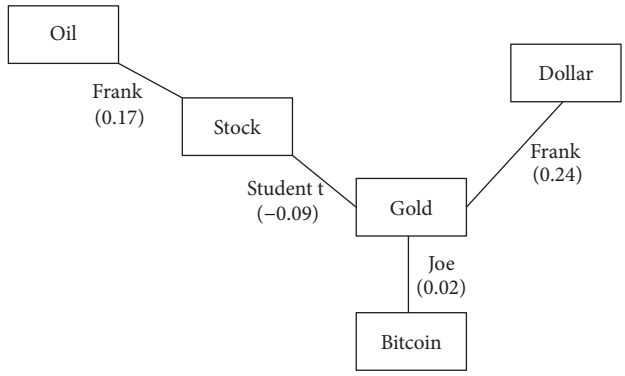


Figure 6: The estimated five-dimensional R-vine tree before COVID-19.

fitted cumulative distribution function curve in Figure 4, and we find it obtains an excellent fitting.

The K–S test (Kolmogorov–Smirnov test) is used to test whether the transformed marginal distribution of each series is uniformly distributed on [0, 1]. The results of Table 5 cannot reject the null hypothesis that the data follow the uniform distribution of [0, 1], indicating that the adjusted series satisfy the prerequisite conditions for the R-vine copula model.

Table 6 shows the R-vine structure between markets. An advantage of the R-vine copula is that it can make the choices of copula functions more extensive and flexible, which can depict the relationship between markets more accurately. The optimal copula functions are selected by the AIC criterion. In Table 6, numbers 1 to 5 represent bitcoin, gold, dollar, oil, and stock markets. We also present the structure of tree 1 of the R-vine copula in Figure 5. We annotate the most suitable copula function and Kendall's τ on the lines linking two markets. The Kendall's τ determines the direction and intensity of market dependence. As shown in Table 6 and Figure 5, during the whole sample period, gold is at the center of these markets, indicating its close interconnection with the rest of the markets, which is consistent with the current status of gold as a major global safe haven asset. We can also find a negative correlation between stock and gold markets. Moreover, the oil market is positively associated with the stock market. The relationships between bitcoin and gold markets, as well as gold and dollar markets,

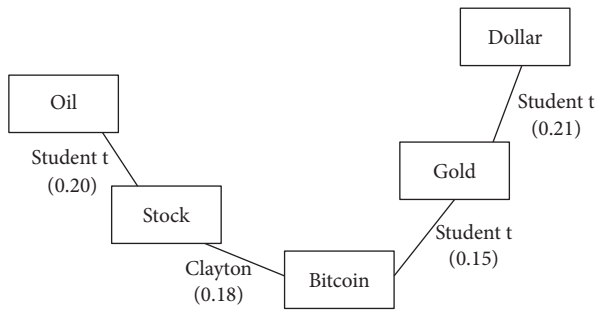


Figure 7: The estimated five-dimensional R-vine tree during COVID-19.

Table 7: Results of VaR and ES backtesting.

	Portfolio 1			Portfolio 2			Portfolio 3		
	VaR		ES	VaR		ES	VaR		ES
Test	LR_{uc}	LR_{cc}	McNeil	LR_{uc}	LR_{cc}	McNeil	LR_{uc}	LR_{cc}	McNeil
Panel A: the whole sample									
90%	0.8818	0.9876	0.4601	0.2761	0.5408	0.3311	0.8123	0.7888	0.1304
95%	0.8364	0.9673	0.3800	0.5471	0.3671	0.0919	0.7493	0.8044	0.1442
97.5%	0.8868	0.6991	0.2460	0.1656	0.2601	0.7326	0.3925	0.5375	0.1858
99%	0.2149	0.4068	0.9904	0.1038	0.2370	0.9998	0.0733	0.1767	0.6055
Panel B: without the COVID-19									
90%	0.1478	0.1099	0.3379	0.2319	0.4770	0.1812	0.5784	0.8485	0.2590
95%	0.2393	0.3926	0.3134	0.6267	0.5925	0.1166	0.8529	0.7138	0.1839
97.5%	0.5644	0.7834	0.4697	0.7458	0.7946	0.1570	0.8971	0.8881	0.1607
99%	0.5576	0.8060	0.8942	0.2414	0.4657	0.2653	0.2786	0.5227	0.4108
Panel C: within the COVID-19									
90%	0.3142	0.5646	0.9524	0.0313	0.0975	0.9961	0.6826	0.9185	0.4415
95%	0.7732	0.5354	0.7085	0.4092	0.2479	0.9929	0.1777	0.1134	0.7451
97.5%	0.5650	0.6567	0.9897	0.5650	0.6567	0.9999	0.1970	0.2912	0.9863
99%	0.8077	0.9373	0.9999	0.6967	0.9125	0.9999	0.8077	0.9373	0.9996

Note. The weights of bitcoin, gold, dollar, crude oil, and stock in portfolio 1 are 20%, 20%, 20%, 20%, and 20%. The weights in portfolio 2 are 10%, 10%, 10%, 10%, and 60%, respectively. The weights in portfolio 3 are 10%, 10%, 10%, 35%, and 35%, respectively.

are also positive. One possible explanation is that the price decline in the traditional capital market will drive investors to seek suitable safe haven markets, further leading to price increases in the markets such as gold, bitcoin, and dollar markets. Similarly, investors' demand for gold, bitcoin, and dollar may drop when the traditional assets are rolling, which leads to the decline of their prices [41].

Considering that the COVID-19 epidemic has brought great impacts worldwide and may bring changes to the market dependence structure, we investigate the subsamples without COVID-19 and during COVID-19. According to Azimli [42] and Umar et al. [43], the period without COVID-19 is defined as before January 1, 2020, and the period within COVID-19 covers the days from January 2, 2020, to the last day of the sample. Following Bouri et al. [20], a hedge is defined as an asset that is uncorrelated or negatively correlated with another asset on average, and a diversifier is defined as an asset that has a weak positive correlation with another asset on average. The Tree 1 structures of the period without COVID-19 and during COVID-19 are shown in Figures 6 and 7, respectively. We can find that, before the outbreak of COVID, the market structure of the five markets is the same as that in the whole sample period. The Kendall's τ of between each pair of markets also does not show a significant change. When the gold market acts as a conditional market, the relationship between the bitcoin market and the stock market is negative (−0.02), as shown in Tree 2, indicating that investors can incorporate bitcoin into their portfolios to reduce investment risks. Similarly, the dollar market can also diversify the risk of stock markets, though not as effective as gold and bitcoin markets. For the oil market, the Kendall's τ between bitcoin and oil markets is negative (−0.01) when choosing the gold and stock markets as conditional markets, as shown in Tree 3. Therefore, bitcoin is also a hedge for the oil market under this circumstance.

However, during the COVID-19 period, the gold market is no longer in the center position and the linkages between markets change a lot. During the COVID-19 period, the relationship between bitcoin market and stock market becomes positive (Kendall's τ is 0.18), indicating that the bitcoin market is no longer a hedge but a diversifier for stock market. It is similar to gold and dollar markets, which are positively related to the stock market. It indicates that COVID-19 has brought a great impact on many markets around the world, even on safe-haven markets. The gold,

bitcoin, and dollar cannot diversify risks as they did before COVID-19. Nevertheless, as we will demonstrate below, the GARCH-EVT-copula model can provide accurate risk measures. The investors can control the portfolio risk, at least to some extent, by adjusting the weights of each asset.

Based on the dependence structure of the five markets, we construct three portfolios with different asset weights and conduct backtesting to test the risk measurement accuracy of the model. As shown in Table 7, we test the three portfolios under four upper tail quantiles, 90%, 95%, 97.5%, and 99%. We can find that almost all the P values are larger than 0.05, even in the period with COVID-19. The results denote that the GARCH-EVT-copula model of various portfolios has passed the VaR and ES backtesting (provide accurate risk measures). The model we constructed can measure the risks of the five market combinations very well.

The above empirical results show that, in general, gold is the most important and effective asset to diversify the risk of traditional markets, including the crude oil and stock markets in our analysis. Bitcoin, which is gaining popularity in recent years, also has the ability to diversify risk. Although not as effective as gold, bitcoin still behaves better than the US dollar in terms of risk diversification. The outbreak of COVID-19, however, changed the interdependence structure between these markets. Gold lost the central position and can no longer be a hedge. Bitcoin also becomes a diversifier rather than a hedge. Therefore, it may not be a good choice to invest in bitcoin after the market downturn caused by big events such as the COVID-19. Then, we construct different portfolios by changing the weight of each asset and test the performance of the GARCH-EVT-copula model on risk management. The results show that this model can obtain accurate risk measurement before and within COVID-19, making it a potential tool for portfolio construction and risk management.

4. Conclusions

This paper uses the GARCH-EVT-copula model to analyze the relationship between bitcoin, gold, dollar, crude oil, and stock markets. Our findings indicate that the gold market is central in these markets during the sample period, which is consistent with the status of gold as a major safe haven. We also find that, before the outbreak of COVID-19, bitcoin and dollar also had the ability to diversify risks, although not as effective as gold. However, when COVID-19 began to spread around the world, gold is no longer the center of these markets, and gold, bitcoin, and dollar can no longer be seen as a hedge. Nevertheless, we demonstrate that the model we use in this paper can provide accurate risk measures and help international investors or risk managers to control the risk of their portfolios.

Our results can provide some implications for investors and risk managers. In terms of the ability to diversify portfolio risk of crude oil and stock markets, we show that bitcoin is less effective than gold but better than the US dollar. However, bitcoin is also not a hedge during the market turmoil caused by external events such as COVID-19. Therefore, investors need to consider adding bitcoin to their portfolios carefully. In addition, the GARCH-EVT-copula method may help investors and risk managers analyze the relationship between multiple markets and control the risk of portfolios.

Unfortunately, like other approaches, the GARCH-EVT-copula approach used in this paper also has its limitations. A sufficiently long time series dataset is a prerequisite for modeling the relationship between multiple markets accurately, which makes this method unsuitable for short-term analysis such as one or two months. This method is also unable to detect the sudden structural changes in the market, as enough data after the structural changes are needed.

Data Availability

The data used in this study are derived from several sources. The bitcoin price data are downloaded from the coinmarketcap website at https://coinmarketcap.com/currencies/bitcoin/historical-data/. The WTI crude oil futures prices data are obtained from the EIA website at https://www.eia.gov/dnav/pet/hist/RCLC1D.htm. The rest data are obtained from the Wind database.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] S. Nakamoto, "A peer-to-peer electronic cash system," *Bitcoin.–URL*, vol. 4, 2008.

[2] E. T. Cheah and J. Fry, "Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin," *Economics Letters*, vol. 130, pp. 32–36, 2015.

[3] D. G. Baur, K. Hong, and A. D. Lee, "Bitcoin: medium of exchange or speculative assets?" *Journal of International Financial Markets, Institutions and Money*, vol. 54, pp. 177–189, 2018.

[4] A. D. Lee, M. Li, and H. Zheng, "Bitcoin: speculative asset or innovative technology?" *Journal of International Financial Markets, Institutions and Money*, vol. 67, Article ID 101209, 2020.

[5] Y. Son and Y. S. Lee, "A smart contract weakness and security hole analyzer using virtual machine based dynamic monitor," *Journal of Logistics, Informatics and Service Science*, vol. 9, no. 1, pp. 36–52, 2022.

[6] F. Almudhaf, "Pricing efficiency of Bitcoin trusts," *Applied Economics Letters*, vol. 25, no. 7, pp. 504–508, 2018.

[7] L. A. Smales, "Bitcoin as a safe haven: is it even worth considering?" *Finance Research Letters*, vol. 30, pp. 385–393, 2019.

[8] S. Corbet, A. Meegan, C. Larkin, B. Lucey, and L. Yarovaya, "Exploring the dynamic relationships between cryptocurrencies and other financial assets," *Economics Letters*, vol. 165, pp. 28–34, 2018.

[9] Y. Y. Gao and S. Y. Jin, "The impact mechanism between the incentive to hold financial assets, financial risk and innovation activities," *Journal of Logistics, Informatics and Service Science*, vol. 8, no. 2, pp. 80–102, 2021.

[10] J. W. Kim, "Blockchain technology and its applications: case studies," *Journal of System and Management Sciences*, vol. 10, no. 1, pp. 83–93, 2020.

[11] E. Bouri, M. Das, R. Gupta, and D. Roubaud, "Spillovers between Bitcoin and other assets during bear and bull markets," *Applied Economics*, vol. 50, no. 55, pp. 5935–5949, 2018.

[12] M. Y. Lin and C. L. An, "The relationship between Bitcoin and resource commodity futures: evidence from NARDL approach," *Resources Policy*, vol. 74, Article ID 102383, 2021.

[13] Y. J. Song and J. K. Lee, "A blockchain and internet of things based architecture design for energy transaction," *Journal of System and Management Sciences*, vol. 10, no. 2, pp. 122–140, 2020.

[14] K. Syuhada, D. Suprijanto, and A. Hakim, "Comparing golds and Bitcoins safe-haven roles against energy commodities during the COVID-19 outbreak: a vine copula approach," *Finance Research Letters*, vol. 46, Article ID 102471, 2022.

[15] M. Ozyesil, "A research on i?nteraction between bitcoin and foreign exchange rates," *Pressacademia*, vol. 6, no. 1, pp. 55–62, 2019.

[16] R. B. Palazzi, G. D. S. R. Júnior, and M. C. Klotzle, "The dynamic relationship between Bitcoin and the foreign exchange market: a nonlinear approach to test causality between Bitcoin and currencies," *Finance Research Letters*, vol. 42, Article ID 101893, 2021.

[17] C. Dirican and I. Canoz, "The cointegration relationship between Bitcoin prices and major world stock indices: an analysis with ARDL model approach," *Pressacademia*, vol. 4, no. 4, pp. 377–392, 2017.

[18] A. Lahiani, A. jeribi, and N. B. Jlassi, "Nonlinear tail dependence in cryptocurrency-stock market returns: the role of Bitcoin futures," *Research in International Business and Finance*, vol. 56, Article ID 101351, 2021.

[19] K. Q. Nguyen, "The correlation between the stock market and Bitcoin during COVID-19 and other uncertainty periods," *Finance Research Letters*, vol. 46, Article ID 102284, 2022.

[20] E. Bouri, P. Molnár, G. Azzi, D. Roubaud, and L. I. Hagfors, "On the hedge and safe haven properties of Bitcoin: is it really more than a diversifier?" *Finance Research Letters*, vol. 20, pp. 192–198, 2017.

[21] A. Kliber, P. Marszałek, I. Musiałkowska, and K. Świerczyńska, "Bitcoin: safe haven, hedge or diversifier? Perception of bitcoin in the context of a countrys economic situation—a stochastic volatility approach," *Physica A: Statistical Mechanics and Its Applications*, vol. 524, pp. 246–257, 2019.

[22] A. H. Dyhrberg, "Bitcoin, gold and the dollar–A GARCH volatility analysis," *Finance Research Letters*, vol. 16, pp. 85–92, 2016.

[23] S. J. Shahzad, E. Bouri, D. Roubaud, and L. Kristoufek, "Safe haven, hedge and diversification for G7 stock markets: gold versus bitcoin," *Economic Modelling*, vol. 87, pp. 212–224, 2020.

[24] T. Conlon and R. McGee, "Safe haven or risky hazard? Bitcoin during the COVID-19 bear market," *Finance Research Letters*, vol. 35, Article ID 101607, 2020.

[25] W. Yu, K. Yang, Y. Wei, and L. Lei, "Measuring Value-at-Risk and Expected Shortfall of crude oil portfolio using extreme value theory and vine copula," *Physica A: Statistical Mechanics and Its Applications*, vol. 490, pp. 1423–1433, 2018.

[26] J. H. Kwon, "Tail behavior of Bitcoin, the dollar, gold and the stock market index," *Journal of International Financial Markets, Institutions and Money*, vol. 67, Article ID 101202, 2020.

[27] R. Chemkha, A. BenSaïda, and A. Ghorbel, "Connectedness between cryptocurrencies and foreign exchange markets: implication for risk management," *Journal of Multinational Financial Management*, vol. 59, 2021.

[28] A. A. Balkema and L. De Haan, "Residual life time at great age," *The Annals of Probability*, vol. 2, no. 5, pp. 792–804, 1974.

[29] J. Pickands III, "Statistical inference using extreme order statistics," *The Annals of Statistics*, pp. 119–131, 1975.

[30] T. Bedford and R. M. Cooke, "Vines: a new graphical model for dependent random variables," *Annals of Statistics*, vol. 30, no. 4, pp. 1031–1068, 2002.

[31] K. Aas, C. Czado, A. Frigessi, and H. Bakken, "Pair-copula constructions of multiple dependence," *Insurance: Mathematics and Economics*, vol. 44, no. 2, pp. 182–198, 2009.

[32] J. Janekova, J. Fabianova, and M. Fabian, "Assessment of economic efficiency and risk of the project using simulation," *International Journal of Simulation Modelling*, vol. 18, no. 2, pp. 242–253, 2019.

[33] J. Janekova, J. Fabianova, and J. Kadarova, "Selection of optimal investment variant based on Monte Carlo simulations," *International Journal of Simulation Modelling*, vol. 20, no. 2, pp. 279–290, 2021.

[34] P. Kupiec, "Techniques for verifying the accuracy of risk measurement models," *The Journal of Derivatives*, vol. 3, no. 2, pp. 173–184, 1995.

[35] P. Christoffersen and D. Pelletier, "Backtesting value-at-risk: a duration-based approach," *Journal of Financial Econometrics*, vol. 2, no. 1, pp. 84–108, 2004.

[36] R. T. Rockafellar and S. Uryasev, "Conditional value-at-risk for general loss distributions," *Journal of Banking & Finance*, vol. 26, no. 7, pp. 1443–1471, 2002.

[37] C. Acerbi and D. Tasche, "On the coherence of expected shortfall," *Journal of Banking & Finance*, vol. 26, no. 7, pp. 1487–1503, 2002.

[38] A. J. McNeil and R. Frey, "Estimation of tail-related risk measures for heteroscedastic financial time series: an extreme value approach," *Journal of Empirical Finance*, vol. 7, no. 3-4, pp. 271–300, 2000.

[39] W. A. Broock, J. A. Scheinkman, W. D. Dechert, and B. LeBaron, "A test for independence based on the correlation dimension," *Econometric Reviews*, vol. 15, no. 3, pp. 197–235, 1996.

[40] W. H. DuMouchel, "Estimating the stable index α in order to measure tail thickness: a critique," *Annals of Statistics*, vol. 11, no. 4, pp. 1019–1031, 1983.

[41] R. Selmi, W. Mensi, S. Hammoudeh, and J. Bouoiyour, "Is Bitcoin a hedge, a safe haven or a diversifier for oil price movements? A comparison with gold," *Energy Economics*, vol. 74, pp. 787–801, 2018.

[42] A. Azimli, "The impact of COVID-19 on the degree of dependence and structure of risk-return relationship: a quantile regression approach," *Finance Research Letters*, vol. 36, Article ID 101648, 2020.

[43] Z. Umar, F. Jareño, and A. Escribano, "Dynamic return and volatility connectedness for dominant agricultural commodity markets during the COVID-19 pandemic era," *Applied Economics*, vol. 54, no. 9, pp. 1030–1054, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5977713, 10 pages
https://doi.org/10.1155/2022/5977713

Research Article

Factors Affecting Chinese Short-Term International Students' Cross-Cultural Adaptation in Psychology, Learning, and Life

Haiyan Zhang[1] **and Mingsheng Li**[2]

[1]*Department of College English Teaching, School of Languages and Communication Studies, Beijing Jiaotong University, Beijing, China*
[2]*Department of Communication, Journalism and Marketing, Massey University, Wellington, New Zealand*

Correspondence should be addressed to Haiyan Zhang; zhanghaiyan@bjtu.edu.cn

Received 8 June 2022; Accepted 5 July 2022; Published 20 August 2022

Academic Editor: Lele Qin

Although Chinese international students' cross-cultural adaptation has achieved intense research, factors in developing Chinese SISs' cross-cultural adaptation remain underresearched. This study examined the factors through a survey of Chinese SISs' transitional adaptation in psychology, life, and learning. Mixed-method research was conducted: a survey of 155 SISs from a top Chinese university undertaking study across 16 countries and in-depth interviews with 15 SISs. Results indicate that knowledge of the host country and university, language proficiency, sense of participation, and engagement are the crucial factors in developing Chinese SISs' cross-cultural adaptation. These factors reveal significant correlations with the students' adaptive performances in psychology, life, and learning. However, the factor of duration indicates no significant correlation with students' cross-cultural adaptation, which demonstrates an inconsistency with the previous studies. The findings of this study highlight the need for developing Chinese SISs' sense of engagement, enhancing the language training, and building up the knowledge of the host cultures previous to the study abroad.

1. Introduction

Higher Education Internationalization has received increasing attention from nations in the world. It plays significant role in promoting cross-cultural communication between nations, cultivating internationalized talents, and facilitating national development. China has been ranked first as the largest international students' resource nation since 2015, and the number of Chinese students studying overseas has reached 703,500, according to the data issued by the Ministry of Education of China on December 14, 2020, increasing by 6.25% compared with the one of the previous year. Noticeably, the number of short-term students, particularly the short-term Exchange Programs students between Chinese and foreign universities, indicates a sharp increase due to lower financial costs, less time consumption, and easier application.

International students are expected to cultivate both global learning abilities and cross-cultural competence. As Assadourian [1] put it in the EarthEd, students should be helped to develop their cross-cultural competence and interlinguistic proficiency, which are regarded as the Life Skills for sustainable life (p.4). It is recognized that cross-cultural adaptability is one of the key facets to cross-cultural competence development. Understanding and addressing the adjustment issues not only helps the university administrators facilitate international education management, but also assists students in developing their cross-cultural and global learning competencies [2]. It is essential to explore the adaptation issues, such as the adaptive factors, for the SISs. A study of the Chinese SISs' cross-cultural adaptation in dimensions of psychology, life, and learning can provide a reflective vision for the global SISs to improve their learning efficiency. Additionally, it offers a referential lens

for the university administrators of the joint programs to efficiently prepare, guide, and serve this group of students to successfully complete their overseas studies.

2. Previous Research

2.1. Short-Term International Education and Cross-Cultural Adaptation. As to the domain of short-term international education, research mainly focuses on the aspects of teaching and administration, social effects, suggestions, and strategies, etc. Teaching and administration in short-term international education are conducted, to a large extent, in an interdisciplinary sense by examining the programs' operation model, outcomes, learning and assessment, and motivation and goals (e.g. [3–5]). Moreover, recent studies from the perspectives of communication, social-economics, and sociology reveal that short-term international education has generated quite positive social effects. Not only does it greatly assist students in cultivating their "soft techniques," including character development, global awareness, international citizenship, and the like, but also the "hard technique" like employment competitiveness and internationalization disposition. Besides, short-term international education, which is thought to be the key factor in promoting long-term global education, can also help students figure out the complex global issues such as aging society, gender inequality, and environmental protection. [6–9]. Additionally, based on the current short-term overseas educational development and issues, it is suggested that both sides of the universities, in collaboration, should offer students adequate support. Strategies including the pre-/in/postinterference and guidance in the learning process are regarded as quite necessary activities [3, 10–12]. These suggestions and strategies can greatly facilitate international students' cross-cultural transition and adaptation.

As to cross-cultural adaptation, overseas short-term learning is beneficial but problematic. On the one hand, short-term overseas study can sharpen students' cross-cultural sensitivity, cultivate their cross-cultural awareness, improve their adaptation competence, and enlighten their self-reflection on home culture and cultural identity (e.g., [13–18]). On the other hand, a recent study on short-term international education shows that although short-term international education can benefit students in overcoming logistical and financial barriers [19], SISs actually experience higher levels of sociocultural adjustment difficulties, psychological distress, and social pressure. (e.g., [20–23]). However, the aspects and levels of adjustment difficulties need to be empirically explored in the research of SISs' cross-cultural adaptation.

2.2. Cross-Cultural Adaptation: Factors in Theoretical and Empirical Studies. Cross-cultural adaptation is an inevitable issue for strangers, including international students, sojourners, and migrants from their home culture to the host culture. In a new cultural and social environment, student sojourners will have to adapt themselves to the new environment through psychological and behavioral adjustments. Cross-cultural adaptation has been highly studied by cross-cultural researchers in theory and practice.

Kim and Ruben [24] argued that strangers would experience huge adaptation depression since the internal balance was broken totally after entering the strange cultural environment. Lysgaard [25] and Oberg [26] constructed a cross-cultural adaptation model with four phases of honeymoon, rejection, regression, and recovery to explore the adaptation stages over time. Gudykunst and Hammer [27] examined the negative effects of cross-cultural uncertainty and anxiety. Gudykunst et al. [28], Hammer et al. [29], and Chen [30] emphasized that psychological adjustment and depression should be measured as the key predictor for cross-cultural competence. These theories demonstrate that the study of students' psychological adaptation is essential to addressing cross-cultural adaptation issues. Besides, adaptability to the host social life, and cultural and learning environments is an equally important predictor of examining international students' cross-cultural competence. As Abe and Wiseman [31] found in their research on the Japanese international students studying in the US that students' adjustment to the new cultural environment and to the different social system was the basic factor to the sojourners' cultural adaptation. In addition, in her theory of cross-cultural adaptation, Kim [32] argued that the development of cross-cultural adaptation was dynamic, and the key factors to cross-cultural competence included familiarity with the social environment and functional fitness. Therefore, it is equally vital to investigate students' adaptation by examining the social and living environments.

Empirically, studies of the international students' psychological, social-cultural, life, or academic adaptations suggest that in academic studies, international students unavoidably encounter acculturative stress and difficulties in these dimensions [33, 34], such as the assessment models, academic writing ability, teacher-student relationships that can influence students' academic adaptation [35–37]. In the mean time, use of social sources, satisfaction with the host university, and challenge-coping greatly account for the students' levels of psychological adaptation [38–40]. These factors, including initial across-cultural transition, learning strategies, leisure engagement, course-participation, bilingual competence, etc., are proved to be significant contributors to the international students' general adaptability including social-cultural, well-being, and academic adaptation as well [41–44]. These studies demonstrate that cross-cultural adaptation is a quite complex and dynamic process, and factors in developing students' acculturative competencies could vary in terms of cultural distances, contexts, situations, and student groups.

2.3. Chinese International Students' Cross-Cultural Adaptation. As the largest international student group in the world, the cross-cultural experiences of Chinese international students have been subject to intensive research. Studies indicate that cross-cultural adaptation becomes the primary issue that Chinese international students encounter, and students' social-cultural and learning adaptation is associated with

communication, interaction, engagement, and social support from the host cultures. (e.g., [45–49]). Noticeably, these studies focus primarily on long-term Chinese international students. However, whether Chinese SISs will experience similar barriers in their cross-cultural adaptation or not is underresearched.

3. Research Objective and Hypothesis

As to the solution to SISs' cross-cultural in-adaptation, many researchers share the view that instructions and training for SISs in advance is an essential measure. However, what specific instructions and training for what sort of in-adaptation needs to be further scrutinized, which highly involves the case analysis with empirical research. Consequently, this paper intends to study the Chinese SISs' cross-cultural adaptation to psychology, social life, and learning during their participation in the overseas short-term programs between*** University and its foreign counterparts in other parts of the world.

It is hypothesized that (1) The preprogram training for understanding the cultural environment of the host country and university is particularly essential for the SISs to facilitate their cross-cultural adaptation in psychology, life, and learning, and (2) a senses of openness and participation will facilitate students' overseas learning, cross-cultural adaptation, and sustainable development.

4. Method

4.1. Cross-Cultural Adaptation Assessment. As to the cross-cultural adaptation assessment, there are comparatively fewer scales made by researchers. Scales such as the Sociocultural Adaptation Scale (SCAS) proposed by Searle and Ward and the Cross-Cultural Adaptability Inventory (CCAI) proposed by Kelley and Meyers are the frequently used scales by researchers to test the cross-cultural communicators' adaptability [50]. However, these adaptation scales made by non-Asian researchers are not quite applicable to assessing Chinese international students' adaptation. Taking CCAI for instance, it is not appropriate to be adopted as an assessment tool to evaluate Chinese international students. For one thing, CCAI is proved to be partially credible and effective [51]. For the other, this scale puts more stress on the communicators' individual predisposition. As it is, cross-cultural adaptation is quite complex and dynamic, involving individual, social, and contextual factors. Additionally, factors in evaluating cross-cultural competence are neither necessarily the same among cultures,nor are distributed consistently in that different cultures may include different factors to investigate students' cross-cultural competence [52]. Therefore, the evaluation of international students' adaptability is supposed to be made through multifaceted and comprehensive scales and so is the study of Chinese SISs' adaptation. This paper will adopt the revised scales based on Zung Self-appraisal Depression Rating Scale and Zhu's Three-Dimension Adaptation Scales (2011) in psychology, life, and academic environment to evaluate Chinese SISs' cross-cultural adaptation.

4.2. Data Collection and Theoretical Frame. This research was carried out through qualitative and quantitative methods in the fall semester of 2019. Among the 319 undergraduates from*** University participating in the overseas short-term programs (12 to 18 months) all over the world, 158 subjects were randomly selected to respond to the questionnaire. Besides, 15 students with different major backgrounds were chosen to attend the in-depth interviews. 158 Questionnaires were sent to the subjects through emails, with 155 effective questionnaires collected, and in-depth interviews were conducted through social media of We-chat. The interviews were digitally recorded and transcribed verbatim.

Apart from the basic information on the subjects, the questionnaire is composed of three sections to examine the students' psychological adaptation (20 items), social life (4 factors, 17 items), and learning (7 factors, 23 items), respectively. The design of the questionnaire is underpinned by the previous theories and research outcomes from the American psychologists Lazarus et al. [53], Bochner et al. [54], and Zhu [55]. The "Stress, Appraisal and Coping" model proposed by Lazarus examined the relationship between life and psychological adaptation among international students. Bochner et al. found that interpersonal social networking was an important predictor of life adaptation for international students. Zhu initiated Three-Dimension cross-cultural adaptation: the scale of psychology, social culture, and academy, pointing out that these three aspects were closely related to each other. Zhang and Dai [56] applied Zhu's Three-Dimension cross-cultural adaptation scale to examine the adaptation competence of international students in China. The psychological adaptation scale is based on Zung Self-appraisal Depression Rating Scale, and the other two scales of "social cultural adaptation" and "academic adaptation" were made by Zhu himself. Zhu's Three-Dimension adaptation scale was adopted to examine the international students who are learning the Chinese language and culture or studying for degrees in China. Similar three-dimension adaptation research was undertaken to study the international students in the U.S. For instance, the effects of the international students' initial cross-cultural transition from home to the host culture were examined through the lens of the international students' psychological well-being and social and academic adaptation [41]. This paper uses the Three-Dimension adaptation scales to understand the acculturative issues that Chinese SISs studying overseas are facing. Besides, the Three-Dimension questionnaire is revised to make it more appropriate to investigate the Chinese SISs. The revised questionnaire is acceptable with higher reliability ($a = 0.79$).

4.3. Questionnaire Design. The basic information includes the respondents' age, gender, major, names of the currently attending university and living country, duration/time spent abroad, language proficiency test results, and their knowledge about the country and the university before the

overseas study. These items are factors influencing the subjects' adaptation to psychology, life, and learning.

The Self-rating Depression Scale (SDS) initiated by Zung in 1965, was adopted with a slight modification to examine the subjects' psychological status, whether or not they felt anxious during their life and learning abroad. It is frequently adopted in the study of cross-cultural adaptation and indicated higher reliability [57]. There are 20 items, 10 positive and 10 negative items, respectively, with a 4-point rating testing the respondents' emotion, sleep status, appetite, sex desire, thinking ability, interests, etc. The 4-point rating is from Seldom, Sometimes, Often, and Pretty often, and the subjects score 1, 2, 3, and 4 correspondingly in the positive items, and vice versa in the negative items. Those who score lower than 53 are evaluated as normal in psychology, suffering no anxiety in their life and studying abroad, indicating a healthy adaptation in psychology. Those who score between 53 and 60 are claimed as patients with slight/medium depression, and those who score higher than 60 are claimed as patients with serious depression. Subjects with medium and serious depression indicate they are suffering a medium to serious anxiety in their life and study and their poor adaptation to psychology.

The questionnaire on the subjects' adaptation in their life was designed in the form of self-rating with a 5-point scale based on four factors, including interpersonal relationships, communicative language proficiency, daily life, and their understanding of the local culture such as customs, social politics, etc. There are 17 descriptive items in total. The 5-point scale self-rating is from Totally Disagree, Disagree, Not Sure, Agree, to Totally Agree. Subjects were to score 1, 2, 3, 4, and 5 correspondingly, and their scores indicated their overseas life adaptation.

The questionnaire on the subjects' adaptation in their learning was examined through seven factors with 23 subdescriptions examining students' academic adaptation in terms of language proficiency, course structure, learning content, learning approaches, host university's academic evaluation, and communication with the faculties and classmates about their learning. The survey on students' learning adaptation was designed in self-rating with a 5-point scale and scoring. Points scored by the subjects served as indicators of their adaptation to the learning environment abroad.

Fifteen students with different majors and durations abroad attending the short-term overseas study programs were selected for the in-depth and structured interviews to further explore how the subjects adapted themselves in psychology, life, and learning abroad. The qualitative research method is adopted to evaluate the students' cross-cultural adaptation in a more comprehensive way.

4.4. Research Questions. This survey is conducted with the intention of addressing the following questions:

Q1: Whether or not there exists a correlation between the time SISs spend overseas and their psychological anxiety?

Q2: Whether or not the degree of the respondents' knowledge about the host universities and countries before their study abroad has a significant correlation with their adaptation to psychology, life, and learning abroad?

Q3: What is the correlation, either positive or negative, among the subjects' adaptation to psychology, life, and learning?

5. Results

5.1. Data Interpretation of the Subjects' Basic Information. A total of 155 subjects, 82 girls and 73 boys with an average age of 20.5, effectively responded to the questionnaires. The majority of the subjects major in science and Engineering (61%), the rest in arts (17%) and finance and accounting (22%). These subjects were studying at 75 universities in 16 countries, including 57 respondents studying in the US, 37 in the European countries, 28 in Canada, 18 in Australia, etc. (see Figure 1). Most of the participants achieved higher points according to the language proficiency test results, 50 subjects scored IELTS above 7.0, and 41 subjects scored in TOFEL more than 90. Generally, those with medium and above language proficiency account for 58.7% of the total. Despite the 16 different countries the subjects visited, they experienced similar learning culture environments such as English-mediated instruction, assessment criteria, western education system, etc. Besides, out of the 155 subjects, 114 subjects were attending universities in which English is Spoken. Therefore, the learning environment for all the subjects to adapt to can be regarded as almost the same.

As to the length of their stay overseas, among these surveyed students, 41 respondents reported having studied abroad 1 to 3 months, 24 respondents, 4 to 6 months, 19 respondents, 7 to 12 months, and 71 respondents, more than 12 months, accounting about for 26%, 16%, 12%, and 46%, respectively (see Figure 2). As to the item of degree the respondents knew about the country before the study abroad, 60.7% of the subjects stated that they "know a little" and "know nothing" about the culture of the host country, and only 3.9% "know well" about the country. Similarly, 63.9% of the subjects thought that they "know a little" and "know nothing" about the host universities before taking part in the program, and 9.0% admitted that they "know well" about the university (see Table 1).

Generally, the in-depth interviews indicated the students attending the short-term programs qualified themselves with good language proficiency in that they were selected among the top students with good performance both in the major study and language proficiency. Besides, all the interviewees thought they did not attend any lectures on the introduction to the culture of the host universities and countries and were not given any instructions to facilitate their transition from home to abroad. They, however, received some instructions on the visa application. Before their departure for the visiting universities, they were kept busy with all kinds of application documentation. Generally, the results based on the interviews and questionnaires revealed that the subjects had poor preparation to know about the host countries and universities in advance.

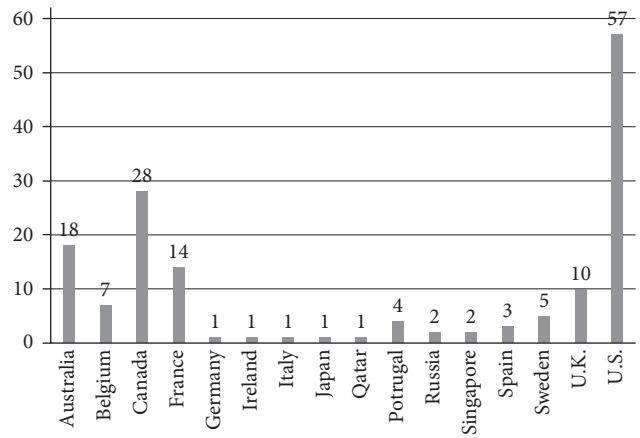


Figure 1: The distribution of the subjects in 16 countries.

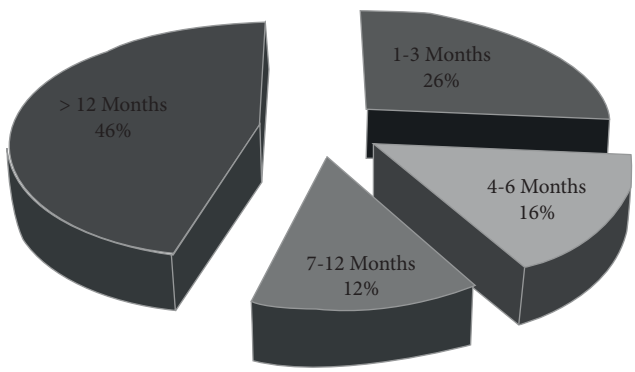


Figure 2: The subjects duration abroad.

Table 1: Extents the SISs know about the host country and university.

	Frequency		Percentage	
	Country	University	Country (%)	University (%)
Know nothing	19	19	12.3	12.3
Know a little	75	80	48.4	51.6
Know much	55	42	35.5	27.1
Know well	6	14	3.9	9.0
In sum	155	155	100.0	100.0

5.2. Data Analysis of the Three-Dimension Adaptation. As to the survey about the students' psychological adaptation, based on the SDS results and the evaluation criteria of "the higher scoring, the more severe depression." 129 respondents scored lower than 53, indicating they suffered no anxiety and depression in their studies and daily life. 17 respondents were regarded as patients with mild depression, suffering certain levels of anxiety since they scored between 53 and 60, and 9 respondents suffered severe depression in that they scored more than 60 (see Table 2). Generally, the respondents indicated their poor performance in psychology in the negative items of "Depression severe in the mornings and mild in the nights," "difficulty in decision-making," and "decreasing ability in dealing with difficulty," scoring in the top three among all the items with marks of 446, 397, and 337 points. The SDS results illustrate that most of the surveyed students (about 83%) fulfilled their short-term study abroad and were adapting well without anxiety. Those suffering from mild depression accounted for 11%, and those suffering from severe depression accounted for about 6%.

Table 2: The surveyed students' SDS marks and depression levels.

SDS marks	Depression levels	Frequency	Percentage (%)
0–53	Normal	129	83
53–60	Mild depression	17	11
>60	Severe depression	9	6
In sum	—	155	100.0

Students' adaptation in their social life abroad varies dramatically from aspects to items in terms of scoring. The surveyed students indicated their best adaptation with the average points of 626 in total in the aspect of "daily life" including shopping for necessities, transportation, communications, food, climate, and weather, and their worst adaptation with the average points of 536 in the aspect of "interpersonal relationship" including the language communication ability, the extent to which the students engaged in local life such as taking part in the campus and community activities. Throughout the 17 items, the surveyed students scored poorly particularly in the three items—Joining in the associations or clubs on campus, engaging in the activities held by the community, and willingness to communicate with the local people. These results implied that Chinese SISs had a weak sense of participation and engagement in the foreign culture during their overseas study.

Learning adaptation was examined from 7 aspects with 23 descriptive items. The top three scoring items understood the multiple evaluations of the students' performances, knowing about the punishment for academic cheating, piracy, copying, and assignment-fulfilling, with total points of 681, 653, and 643, respectively. This could probably be ascribed to the fact that Chinese students had grown a strong sense of academic integrity on the one hand, and that they had grasped the discipline knowledge and conventions on the other hand. This finding greatly helps to change the "stereotyped and stigmatized image of the Chinese international students as one without caring about Academic Integrity" in foreign countries such as New Zealand [58]. Nevertheless, the last three scoring items had much to do with the students' language ability during their overseas studies. The results revealed that the surveyed students had difficulty in understanding teachers, teaching content, and expressing ideas in classes, with total points of 446, 456, and 468, respectively. Moreover, supposing analysis of variance $a = 0.10$, according to the Sig. value ($p > 0.05$) in Table 3, it indicates the equal variances. Consequently, based on the *T&P* values under the condition of equal variances, students scoring higher than the average point of 16 in their language proficiency in the dimension of academic adaptation demonstrated a dramatic difference in the Three-Dimension adaptation from those scoring lower than 16 at the 0.01 level

Table 3: Levene's test & T-test for the equality of means.

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error value	95% confidence interval for difference	
									Lower-bound	Upper-bound
Psychology	Equal variances	0.045	0.832	−3.023	153	0.003	−4.465	1.477	−7.383	−1.547
	Unequal variances			−2.983	130.961	0.003	−4.465	1.497	−7.426	−1.504
Life	Equal variances	3.858	0.051	5.226	153	0.000	4.814	0.921	2.994	6.633
	Unequal variances			4.998	113.681	0.000	4.814	0.963	2.906	6.722
Learning	Equal variances	0.159	0.691	6.046	153	0.000	9.195	1.521	6.190	12.199
	Unequal variances			6.005	134.540	0.000	9.195	1.531	6.166	12.223

($T_{\text{psy.}} = -3.023$, $P_{\text{psy.}} = 0.003$; $T_{\text{lif.}} = 5.226$, $P_{\text{lif.}} = 0.000$; $T_{\text{lea.}} = 6.046$, $P_{\text{lea.}} = 0.000$), and those with better language ability show a healthier psychological status, and better life and academic adaptation (see Tables 3 and 4). Brown [59] found in his research exploring the incidence of the stress of the international students that the academic cultural differences and language ability greatly accounted for the students' academic stress. For Chinese SISs, the academic evaluation in the foreign cultures, especially the western cultures, puts more stress on the students' critical evaluation and participation in class, which was closely related to the students' language ability.

5.3. Key Factors to Short-Term Adaptation. Based on SPSS (V.20) data analysis, there is no significant correlation between the time of the students' staying abroad and their adaptation in psychology, life and learning (see Table 5). It does not necessarily mean that the longer the students stay abroad, the better adaptation they can achieve. Those staying abroad for less-than-3-month period do not necessarily suffer less psychology depression, and have poorer performances in life and learning than those staying abroad for more than 12 months. Moreover, it reveals a quite positive correlation between the extent the students know about the host country and their adaptation to life and the learning environment ($p = 0.000$, $r = 0.330$; $p = 0.000$, $r = 0.383$), a negative correlation between the extent students' knowledge about the host country and their anxiety ($p = 0.000$, $r = -0.424$) (see Table 5). Similarly, there is a positive correlation between the extent students' knowledge about the host university and their adaptation to life and the learning environment ($p = 0.000$, $r = 0.280$; $p = 0.000$, $r = 0.498$), and a negative correlation between the extent students' knowledge about the host university and their psychological anxiety ($p = 0.001$, $r = -0.257$) (see Table 5). The data suggest that the better that the students know about the host country and university, the better adaptation they could achieve. Also, students' adaptations in psychology, life, and learning correlate with each other. There is a negative correlation between psychology and life, and psychology and learning—the less depressed the students feel during their stay abroad, the more easily they can adapt themselves to the life and study ($p = 0.000$, $r = -0.438$; $p = 0.000$, $r = -0.365$).

In terms of gender variables, there is no significant difference between male and female students in their adaptation in psychology, life, and learning ($T = 1.437$, $p = 0.153$; $T = -0.726$ $p = 0.469$; $T = -0.009$ $p = 0.993$). As to majors, students majoring in arts present the significant differences than those majoring in finance and accounting in the psychological adaptation at $p < 0.05$ level ($T = -2.076$, $p = 0.042$). Arts students majoring in communication, law, and languages, have a better psychological adaptation than finance and accounting students. However, as far as the time staying abroad is concerned, there is a significant difference between the period of 1–3 months and that of more than 12 months in their adaptation in life ($T = -2.408$, $p = 0.018$) at the $p < 0.05$ level, but no significant difference in the psychological adaptation and learning adaptation. The findings show that students' language ability presents a positive correlation with their adaptation to the curriculum and course structure ($p = 0.000$, $r = .281$), which highlights the importance of language preparation before taking part in short-term programs.

6. Discussion

6.1. Staying Time and Psychological Adaptation Status. Culture-shock Theory initiated by Oberg [26] argued that people living abroad for a certain time tended to suffer difficulties in life and the negative emotion in cross-cultural practices. In spite of the hard times, sojourners tended to be enjoyable and feel excited at the beginning stage of living abroad, which is named by Oberg as the "honeymoon" stage. Lysgaard [25] explored the correlation between the time people spent abroad and their psychological adaptation, arguing that those staying from 6 to 18 months in the U.S. experienced poorer psychological situations. Moreover,

Table 4: Set of statistics of the adaptation in psychology, life, and learning.

	Language proficiency	N	Mean	SD	Standard error of the mean
Psychology	≥16	65	40.45	9.508	1.179
	<16	90	44.91	8.747	0.922
Social life	≥16	65	50.37	6.535	0.811
	<16	90	45.56	4.934	0.520
Academic adaptation	≥16	65	92.26	9.571	1.187
	<16	90	83.07	9.176	0.967

Table 5: The correlations between duration, extents SISs' knowing about the host country and university, language performance, and SISs' adaptation to psychology, life, and learning, respectively.

		Psychology	Life	Learning
Duration	Pearson correlation	−0.070	0.151	0.088
	Sig.(2-tailed)	0.385	0.060	0.274
	N	155	155	155
Psychology	Pearson correlation	1	−0.438**	−0.365**
	Sig. (2-tailed)		0.000	0.000
	N	155	155	155
Know about the host country	Pearson correlation	−0.424**	0.330**	0.383**
	Sig. (2-tailed)	0.000	0.000	0.000
	N	155	155	155
Know about the host university	Pearson correlation	−0.257**	0.280**	0.498**
	Sig. (2-tailed)	0.001	0.000	0.000
	N	155	155	155
Language performance	Pearson correlation	−0.377**	0.527**	0.647**
	Sig. (2-tailed)	0.000	0.000	0.000
	N	155	155	155

Ward et al. [57] pointed out that people at the beginning of living abroad suffered from depression to the largest extent. Obviously, the previous theories and research findings demonstrate that there exists a correlation between staying time and psychological adaptation status.

Findings in this particular research on Chinese SISs, however, contradict the findings made in the previous study, demonstrating no significant correlation between these two variables ($r = -0.070$, $p = 0.385$). Besides, the results also demonstrate no significant difference in the psychological anxiety between the surveyed students staying abroad for less than 3 months and for more than 12 months ($T = 1.338$, $p = 0.184$). In consequence, students staying more than 12 months abroad do not necessarily suffer less from psychological anxiety than those at the beginning stage, particularly 1–3 months. The findings fail to support the earlier theory of Culture Shock, U-Curve, and the important argument by Ward et al. [57] that people tend to encounter a higher level of depression, especially at the beginning stage of living abroad. So these results highlight the significance to study this unique group so as to make the appropriate and feasible measures to develop their adaptation ability in psychology for the future research focus.

6.2. Knowledge of the Host Country and University. SISs are unable to choose their overseas study destinations. They are enrolled in the programs established between the universities at home and abroad. Consequently, unlike the other students intending to study for a degree can choose their host countries and universities, the SISs do not bother to search or explore more information about the target country and university they head for. Good knowledge of the target country and host university can undoubtedly facilitate the SISs' adaptation in a new culture within a short stay. All the interviewees reported that they should have fully prepared themselves before their leaving for overseas study. Findings demonstrate the significant correlation between knowledge of the host country and university and the adaptation in the three dimensions. Specifically, there is a significant negative correlation between the SISs' anxiety and how much they know about the country and the university, respectively (country: $r = -0.424$, $p = 0.000$; university: $r = 2.257$, $p = 0.001$), and a significant positive correlation between the life and learning adaptation and the degree they know about the country and university, respectively (country = 0.330, $p = 0.000$; $r = 0.383$, $p = 0.000$; university: $r = 0.280$, $p = 0.000$; $r = .498$, $p = 0.000$). The findings back up the argument made by the previous study that preintercultural development assessments or predeparture training should be given to students ready to study abroad [11, 13, 59]. Due to inadequate preparation, the surveyed Chinese SISs were less interculturally competent. What specific content should be instructed to students in the pretraining calls for further research.

Additionally, adequate knowledge to the host countries and universities helps a lot of the SISs' figure out what cultural contexts they will encounter with. However, merely knowing the target learning cultural environment is not so helpful in easing the intercultural shock or inadaptability without SISs' reflection on the intercultural differentiation between Chinese culture and the visiting cultures in terms of learning. Chinese culture should be taken into consideration including Chinese learning, social networking, communication between teachers and students, etc. Not only can reflection be of help for SISs to bear a comparative mind between cultures at home and overseas, but it can assist the subjects in raising their awareness to adjust their behaviors in the new environment.

6.3. Correlation of Psychological Adaptation with the Adaptation in Life and Learning. Lazarus el al. [53] proposed the model of "stress, appraisal and coping" from the perspective of psychological adaptation, which provides the theoretical basis for the study of international students' psychological change due to the pressure from life changes. Zhu [55] proposed the Three-Dimension adaptation in psychology, social culture, and academic environment and argued that the three dimensions were interrelated. Many researchers, Zhang and Dai [56], for instance, have adopted the Three-Dimension analysis model to study the cross-cultural adaptation of international students. This paper, however, examined not only how the SISs performed in their adaptations in the three dimensions but also to what extent the three adaptations were correlated each other. Findings reveal a significantly negative correlation of psychological adaptation with the adaptation in life and learning ($r = -0.438$, $p = 0.000$; $r = -0.365$, $p = 0.000$): the less psychological anxiety, the better adaptation performance in life and learning. The life and learning adaptations, nevertheless, present a significantly positive correlation ($r = 0.581$, $p = 0.000$). It should be noted that although most of the surveyed SISs demonstrate no suffering from psychological pressure, it deserves adequate attention since it can impose negative influences upon the student's life and learning adaptation. Effective measures for easing the SISs' anxiety or depression should be investigated in future study.

7. Conclusions

This empirical research focused on the study of the factors in developing the Chinese SISs' cross-cultural adaptation in psychology, life, and learning when they attended the overseas short-term programs established by ***University and its counterparts all over the world. The following conclusions are drawn from this study: (1) Those surveyed SISs generally have a normal psychological adaptation, and a few need psychological interference and necessary therapy; (2) On the whole, Chinese SISs should be trained to become aware of the importance of participation and engagement as the key factors for Chinese SISs to adapt themselves to the life and learning abroad; (3) necessary and adequate pre-program training and preparation should be carried out among the students in two aspects: increasing the language proficiency, especially speaking and listening comprehension, and building up a large body of knowledge about the countries and universities where they are going to study. According to Ting-Toomy [60], cultural and social knowledge is the most important component and it enhances cultural self-awareness and other-awareness. For SISs, necessary knowledge of the host country and university is essential for their shorter time abroad.

Additionally, the data and findings from this research cannot support some previous theories and research outcomes such as Culture Shock and its Honey Moon stage, the correlation between staying time abroad and cross-cultural adaptation. Therefore, the cross-cultural adaptation study of the SISs deserves more qualitative and quantitative analysis to summarize the nature of cross-cultural adaptation. Also, the research on the Chinese SISs should be undertaken with a sense of heterogeneity, and the research methodology and perspectives call for a localized and particular view of heterogeneity for the study of Chinese international students.

Data Availability

All the data acquried in this research are collected by the authors and their research team through interviews, questionnaires, etc. Data collection lasted 2 to 3 months.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was funded by the 2021 China Education Association for International Exchanges, Ministry of Education of People's Republic of China, Project No. CEAIE-RE-HG-Y-2021-16 and also funded by Teaching and Reform Projects issued by Beijing Jiaotong University (China High-Speed Railway Go Globally and the Intercultural Communication Cases Studies, Project No. 275210529306), sponsored by Central Chinese Universities Teaching and Reform issued by Ministry of Education.

References

[1] S. Assadourian, *EarthEd (State of the World): Rethinking Education on a Changing Planet*, Island Press, Washing D.C, U.S.A, 2017.

[2] A. Shafaei and N. A. Razak, "Internationalisation of higher education: conceptualising the antecedents and outcomes of cross-cultural adaptation," *Policy Futures in Education*, vol. 14, no. 6, pp. 701–720, 2016.

[3] H. W. Allen, "What shapes short-term study abroad experiences? A comparative case study of students' motives and goals," *Journal of Studies in International Education*, vol. 14, no. 5, pp. 452–470, 2009.

[4] R. S. Core, "Assessing global learning in short-term study abroad: population, environment, and society in Shanghai," *Teaching Sociology*, vol. 45, no. 4, pp. 399–408, 2017.

[5] A. C. Landon, M. A. Tarrant, D. L. Rubin, and L. Stoner, "Beyond "Just do it": fostering higher-order learning

outcomes in short-term study abroad," *AERA Open*, vol. 3, no. 1, 2017.

[6] K. Bell, B. Moorhead, and H. Boetto, "Social work students' reflections on gender, social justice and human rights during a short-term study programme to India," *International Social Work*, vol. 60, no. 1, pp. 32–44, 2017.

[7] D. F. Cushing, M. Pennings, D. Willox, R. Gomez, C. Dyson, and C. Coombs, "Measuring intangible outcomes can be problematic: the challenge of assessing learning during international short-term study experiences," *Active Learning in Higher Education*, vol. 20, no. 3, pp. 203–217, 2017.

[8] M. Kato and K. Suzuki, "Effective or self-selective: random assignment demonstrates short-term study abroad effectively encourages further study abroad," *Journal of Studies in International Education*, vol. 23, no. 4, pp. 411–428, 2018.

[9] C. J. Wynveen, G. T. Kyle, and M. A. Tarrant, "Study abroad experiences and global citizenship: fostering pro-environmental behavior," *Journal of Studies in International Education*, vol. 16, no. 4, pp. 334–352, 2011.

[10] B. Bartram, ""Brits abroad": the perceived support needs of U.K. learners studying in higher education overseas," *Journal of Studies in International Education*, vol. 17, no. 1, pp. 5–18, 2012.

[11] R. Brooks and J. Waters, "Fees, funding and overseas study: Mobile UK students and educational inequalities," *Sociological Research Online*, vol. 16, no. 2, pp. 19–28, 2011.

[12] D. Sachau, N. Brasher, and S. Fee, "Three models for short-term study abroad," *Journal of Management Education*, vol. 34, no. 5, pp. 645–670, 2010.

[13] S. C. Davies, A. A. Lewis, A. E. Anderson, and E. R. Bernstein, "The development of intercultural competency in school psychology graduate students," *School Psychology International*, vol. 36, no. 4, pp. 375–392, 2015.

[14] P. Dorsett, S. Larmar, and J. Clark, "Transformative cross-cultural learning: a short-term international study tour," *Journal of Social Work Education*, vol. 55, no. 2, pp. 1–14, 2019.

[15] J. E. Jon, "Realizing internationalization at home in Korean higher education: promoting domestic students' interaction with international students and cross-cultural competence," *Journal of Studies in International Education*, vol. 17, no. 4, pp. 455–470, 2013.

[16] S. Koyanagi, "Impact of intercultural communication during short-term study-abroad of Japanese students: analysis from a perspective of cognitive modification," *Journal of Intercultural Communication Research*, vol. 47, no. 2, pp. 105–120, 2018.

[17] E. A. Tuleja, "Aspects of intercultural awareness through an MBA study abroad program: going "backstage"," *Business Communication Quarterly*, vol. 71, no. 3, pp. 314–337, 2008.

[18] F. Wolff and C. Borzikowsky, "cross-cultural competence by international experiences? An investigation of he impact of educational stays abroad on cross-cultural competence and its facets," *Journal of Cross-Cultural Psychology*, vol. 49, no. 3, pp. 488–514, 2018.

[19] N. Blankvoort, V. C. Kaelin, S. Poerbodipoero, and S. Guidetti, "Higher education students' experiences of a short-term international programme: exploring cultural competency and professional development," *Educational Research*, vol. 61, no. 3, pp. 356–370, 2019.

[20] J. C. Bunch, S. D. Rampold, M. Cater, and J. J. Blackburn, "The impact of a short-term international experience on undergraduate students' cultural competency," *Journal of Agricultural Education*, vol. 59, no. 4, pp. 120–136, 2018.

[21] K. A. Crowne and R. L. Engle, "Antecedents of cross-cultural adaptation stress in short-term international assignments," *Organization Management Journal*, vol. 13, no. 1, pp. 32–47, 2016.

[22] S. R. Fitzsimmons, D. J. Flanagan, and X. A. Wang, "Business students' choice of short-term or long-term study abroad opportunities," *Journal of Teaching in International Business*, vol. 24, no. 2, pp. 125–137, 2013.

[23] A. Oreilly, D. A. Ryan, and T. M. Hickey, "The psychological well-being and sociocultural adaptation of short-term international students in Ireland," *Journal of College Student Development*, vol. 51, no. 5, pp. 584–598, 2010.

[24] Y. Y. Kim and B. D. Ruben, *Cross-cultural transformation: a systems theory*, Y. Y. Kim and W. B. Gudykunst, Eds., pp. 299–321, Sage publications, Newbury Park, CA, U.S.A, 1988.

[25] S. Lysgaard, "Adjustment in a foreign society: Norwegian Fullbright grantees visiting the United States," *International Social Science Bulletin*, vol. 7, pp. 45–51, 1955.

[26] K. Oberg, "Cultural shock: adjustment to new cultural environments," *Practical Anthropology*, vol. 7, no. 4, pp. 177–182, 1960.

[27] W. B. Gudykunst and M. R. Hammer, "Dimensions of cross-cultural effectiveness: culture specific or culture general?" *International Journal of Intercultural Relations*, vol. 8, no. 1, pp. 1–10, 1984.

[28] W. B. Gudykunst, M. R. Hammer, and R. L. Wiseman, "An analysis of an integrated approach to cross-cultural training," *International Journal of Intercultural Relations*, vol. 1, no. 2, pp. 99–110, 1977.

[29] M. R. Hammer, W. B. Gudykunst, and R. L. Wiseman, "Dimensions of intercultural effectiveness: an exploratory study," *International Journal of Intercultural Relations*, vol. 2, no. 4, pp. 382–393, 1978.

[30] G. M. Chen, "Relationships of the dimensions of intercultural communication competence," *Communication Quarterly*, vol. 37, no. 2, pp. 118–133, 1989.

[31] H. Abe and R. L. Wiseman, "A cross-cultural confirmation of the dimensions of intercultural effectiveness," *International Journal of Intercultural Relations*, vol. 7, no. 1, pp. 53–67, 1983.

[32] Y. Y. Kim, *Becoming Intercultural: An Integrative Theory of Communication and Cross-Cultural Adaptation*, Sage publications, Thousand Oaks, CA, U.S.A, 2011.

[33] V. E. Meza and G. Gazzoli, "International students' acculturation and adaptation: the case of an indigenous group studying in Switzerland," *Journal of Hospitality and Tourism Education*, vol. 23, no. 2, pp. 14–22, 2011.

[34] Y. F. Zhou and J. Todman, "Patterns of adaptation of Chinese postgraduate students in the United Kingdom," *Journal of Studies in International Education*, vol. 13, no. 4, pp. 467–486, 2009.

[35] M. Blasco, "Making the tacit explicit: rethinking culturally inclusive pedagogy in international student academic adaptation," *Pedagogy, Culture & Society*, vol. 23, no. 1, pp. 85–106, 2015.

[36] T. J. Young and A. Schartner, "The effects of cross-cultural communication education on international students' adjustment and adaptation," *Journal of Multilingual and Multicultural Development*, vol. 35, no. 6, pp. 547–562, 2014.

[37] B.. , H. Yu and E. Wright, "Academic adaptation amid internationalisation: the challenges for local, mainland Chinese, and international students at Hong Kong's universities," *Tertiary Education and Management*, vol. 23, no. 4, pp. 347–360, 2017.

[38] S. Bordia, P. Bordia, M. Milkovitz, Y. X. Shen, and S. L. D. Restubog, "What do international students really

want? An exploration of the content of international students' psychological contract in business education," *Studies in Higher Education*, vol. 44, no. 8, pp. 1488–1502, 2019.

[39] J. Y. Kim, "Acculturation phenomena experienced by the spouses of Korean international students in the United States," *Qualitative Health Research*, vol. 22, no. 6, pp. 755–767, 2011.

[40] A. S. Mak, P. Bodycott, and P. Ramburuth, "Beyond host language proficiency: coping resources predicting international students' satisfaction," *Journal of Studies in International Education*, vol. 19, no. 5, pp. 460–475, 2015.

[41] Z. Cemalcilar and T. Falbo, "A longitudinal study of the adaptation of international students in the United States," *Journal of Cross-Cultural Psychology*, vol. 39, no. 6, pp. 799–804, 2008.

[42] C. Lee, Y. T. Sung, Y. L. Zhou, and S. Lee, "The relationships between the seriousness of leisure activities, social support and school adaptation among Asian international students in the U.S," *Leisure Studies*, vol. 37, no. 2, pp. 197–210, 2018.

[43] O. Kovtun, "International student adaptation to a U.S. college: a mixed methods exploration of the impact of a specialized first-year course at a large midwestern institution," *Journal of Student Affairs Research and Practice*, vol. 48, no. 3, pp. 349–366, 2011.

[44] B. H. Yu, L. Vyas, and E. Wright, "Crosscultural transitions in a bilingual context: the interplays between bilingual, individual and interpersonal factors and adaptation," *Journal of Multilingual and Multicultural Development*, vol. 41, no. 7, pp. 600–619, 2019.

[45] M. Fong, "Chinese international students' adaptive orientations to cross-cultural compliment interactions with the Caucasian Americans," *China Media Research*, vol. 15, no. 3, pp. 102–115, 2019.

[46] S. Kang, P. Yossuck, C. Panyadee, and B. Ek-lem, "Influencing factors of cross-cultural adaptation process of Chinese students studying in the upper Northern Thai universities," *Mediterranean Journal of Social Sciences*, vol. 10, no. 1, pp. 65–74, 2019.

[47] Y. Wang and S. J. Sun, "Examining Chinese students' Internet use and cross-cultural adaptation: does loneliness speak much?" *Asian Journal of Communication*, vol. 19, no. 1, pp. 80–96, 2009.

[48] Y. Yu and G. Stoet, "Encountering non-Christian Chinese international students: cross-cultural adaptive practices of local Christian organisations in the UK," *Journal of Beliefs and Values*, vol. 41, no. 3, pp. 305–321, 2019.

[49] C. Y. Zhu and Y. Gao, "Communication with Chinese international students:Understanding Chinese international students' learning difficulties and communication barriers," in *Proceedings of the Conference Paper presented to the British Educational Research Association Conference 2012*, pp. 4–6, University of Manchester, England, U.K, September 2012.

[50] X. D. Dai, *A Study on Cross-Cultural Competence*, Foreign Language Teaching and Research Press, Beijing, China, 2018.

[51] D. L. Goldstein and D. H. Smith, "The analysis of the effects of experiential training on Sojourners cross-cultural adaptability," *International Journal of Intercultural Relations*, vol. 23, no. 1, pp. 157–173, 1999.

[52] R. L. Wiseman and H. Abe, "Finding and explaining differences: a reply to Gudykunst and Hammer," *International Journal of Intercultural Relations*, vol. 8, no. 1, pp. 11–16, 1984.

[53] R. S. Lazarus, A. Delongis, S. Folkman, and R. Gruen, "Stress and adaptational outcomes: the problem of confounded measures," *American Psychologist*, vol. 40, no. 7, pp. 770–779, 1985.

[54] S. Bochner, B. M. Mcleod, and A. L. Lin, "Friendship patterns of overseas students: a functional model," *International Journal of Psychology*, vol. 12, no. 4, pp. 277–294, 1977.

[55] G. H. Zhu, *A study of international adaptational problems of the international students in Chinese universities*, PhD. Thesis, East China Normal University, Shanghai, 2011.

[56] Y. M. Zhang and G. S. Dai, "Longitudinal analysis of cross-cultural adaptation condition of college students from Hong Kong, Macao, Taiwan & overseas," *Youth Studies*, vol. 1, pp. 49–56, 2016.

[57] C. A. Ward, S. Bochner, and A. Furnham, *The Psychology of Culture Shock*, Routledge, Philadelphia, PA, U.S.A, 2001.

[58] M. S. Li, *Academic integrity: exploring the issues of plagiarism facing Chinese students in the New Zealand universities*, D. M. Velliaris, Ed., IGI Global, Hershey PA, U.S.A, 2017.

[59] L. Brown, "The incidence of study-related stress in international students in the initial stage of the international sojourn," *Journal of Studies in International Education*, vol. 12, no. 1, pp. 5–28, 2007.

[60] S. T. Toomey, *The matrix of face: an updated face-negotiation theory*, W. B. Gudykunst, Ed., pp. 71–92, Sage, Thousand Oaks, CA, U.S.A, 2005.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5766587, 12 pages
https://doi.org/10.1155/2022/5766587

Research Article

Influencing Factors Identification and the Correlation Analysis of Business Environment in the Guangdong-Hong Kong-Macao Greater Bay

Yuli Yu,[1,2] Haitao Yao ,[2] and Wanhua Zhuang[1,2]

[1]*Zhuhai College of Science and Technology, Zhuhai, Guangdong 519041, China*
[2]*Business School of Macau University of Science and Technology, Macau 999078, China*

Correspondence should be addressed to Haitao Yao; 2109853wbb30001@student.must.edu.mo

Received 24 June 2022; Accepted 25 July 2022; Published 16 August 2022

Academic Editor: Lele Qin

The outline of the development plan issued by CPC Central Committee and the State Council for the Guangdong Hong Kong Macao Bay Area clearly pointed out that the Guangdong-Hong Kong-Macao Bay Area should be built into a vibrant world-class urban agglomeration, an international science and technology innovation center, an important support for the construction of the "the Belt and Road," and a demonstration area for in-depth cooperation between the mainland and Hong Kong and Macao; and a high-quality life circle suitable for living, working, and traveling should be created to become a model of high-quality sustainable development. In order to develop the Guangdong-Hong Kong-Macao Bay Area, it is extremely important to enhance the regional business environment. This paper focuses on five influencing factors: policy support, talent guarantee, market supervision, financial support, and cultural promotion. Based on one-way ANOVA and Cobb Douglas function, this paper makes an empirical study on the two important node cities of Zhuhai and Macao. The results show that (1) different factors have different degrees of significant impact on the regional business environment, among which the industry type has the greatest impact, and the duration of enterprise registration has the least impact; (2) when the factors act alone, there is a significant positive correlation between the evaluation dimensions, but most of the correlation degrees are not much different. Finance and talents are the weaknesses of the business environment in the two cities. (3) When the factors are combined, different factors have significant differences in different regions. Zhuhai mainly benefits from policy support, while Macao mainly benefits from market supervision. (4) Regional integration can produce significant association relationship, among which cultural promotion is an important factor. These five important factors have been effectively identified, which have played a leading role in the further design and development direction of the Guangdong-Hong Kong-Macao Bay Area in the future and have an extremely important enlightenment for the study of the business environment in this region.

1. Introduction

The construction and sustainable development of the Guangdong-Hong Kong-Macao Bay Area are an important strategic decision at the national level. In February, 2019, the CPC Central Committee and the State Council issued the outline of the development plan for the Guangdong Hong Kong Macao Bay Area, which clearly pointed out that the Guangdong-Hong Kong-Macao Bay Area should be built into a vibrant world-class urban agglomeration, an international science and technology innovation center, an important support for the construction of the "the Belt and Road," and a demonstration area for in-depth cooperation between the mainland and Hong Kong and Macao; and a high-quality life circle suitable for living, working, and traveling should be created to become a model of high-quality sustainable development. The new strategic positioning requires the greater Bay Area cities to be equipped with a good regional business environment to provide all-round and deep support for high-quality business, from trade circulation to high-tech from cultural creativity to service industry. A good regional business environment is

conducive to the rapid and high-quality growth of enterprises and can effectively enhance the core competitiveness of the city. It is an important embodiment and foundation of the economic strength of Guangdong-Hong Kong-Macao Great Bay area. However, the business environment of cities in the Guangdong-Hong Kong-Macao Greater Bay Area is quite different. Important node cities play different roles in the development of the Greater Bay Area, and important node cities play different roles in the development of the Greater Bay area. For example, Hong Kong needs to consolidate and enhance its status as an international financial, shipping, trade center, and international aviation hub. It should promote high-end and high-growth development in finance, commerce, logistics, and professional services and build itself into a more competitive international metropolis. Guangzhou should give full play to the leading role of a national central city and a comprehensive gateway city, comprehensively enhance its functions as an international business center and a comprehensive transportation hub, cultivate and enhance its functions as a scientific, educational, and cultural center, and strive to build itself into an international metropolis. Shenzhen should give full play to the leading role of the special economic zone, the national economic center city, and the national innovation city, accelerate the construction of a modern and international city, and strive to become a city of innovation and creativity with world influence. In order to fully stimulate the economic vitality of the Guangdong-Hong Kong-Macao Greater Bay Area and continuously optimize the regional economy, it is particularly important to explore the influencing factors of the regional business environment of important node cities.

2. Literature Review

"Business environment" was first proposed by the "doing business" project of the International Finance Corporation of the world bank group. It refers to the sum of all kinds of surroundings and conditions accompanying the whole process of enterprise activities. It is a systematic project for designing economic and social reform and opening to the outside world in many fields. Since the World Bank first released the Doing Business Report in 2003, it has taken 17 years to objectively measure the business environment of 190 economies, providing objective basis, comparison, and reference for each economy to create a good business environment. However, due to the differences in the political and economic systems of countries around the world, the World Bank's measurement indicators cannot effectively match the actual situation of countries and regions [1]. In recent years, under the initiative of the central government to improve the "rule of law, internationalization, and facilitation" business environment, local governments at all levels in China have actively explored ways to optimize the business environment in line with local development realities. First, the World Bank business is used as a template to intercept some evaluation indicators in line with the current situation of local economic development. Second, with the help of the intellectual support of institutions of higher learning, scientific research institutions and other units carry out in-depth cooperation for comprehensive evaluation. Therefore, many domestic scholars have put forward different research directions on the influencing factors of business environment. Yang [2] used factor analysis to measure the business environment of Shandong, Jiangsu, Zhejiang, and Guangdong provinces from three first-level perspective of market environment, policy and government environment, and legal environment. Wu and Zhang [3] constructed 10 first-level indicators, including overall evaluation, government efficiency, administrative approval, market supervision, legal environment, credit environment, financial environment (financing environment), human resources environment, social environment, and infrastructure environment from the three dimensions of overall perception, government environment perception, and factor environment perception. Peng and Ma [4] selected four first-class indicators, that is, demand identification, service capability, service function, and service supply as evaluation dimensions. Yan [5] built a business environment satisfaction evaluation model based on five first-class indicators, including government policies, talent protection, market supervision, legal environment, and financial support. Peng et al. [6] selected 23 indicators from the four aspects of economic environment, market environment, basic environment, and supporting environment to build an evaluation index system for regional business environment.

Many scholars have done the research on business environment and satisfaction evaluation, but the application of evaluation system in Guangdong-Hong Kong-Macao Greater Bay Area is pretty new and meaningful. Based on the research results of the world bank and domestic and foreign scholars on the business environment, this paper focuses on five soft environment aspects: policy support, talent security, market supervision, financial support, and cultural promotion. The policy support includes the compliance of policy objectives, the degree of government information disclosure, and the government's response to demands. Talent security includes talent cultivation, supporting services and apartment housing. Market regulation includes regulation of code of conduct, reasonable frequency of regulation, and attention to fairness of conduct. Financial support includes the financial base, the number of financial institutions, and the fit of financial services. Cultural promotion includes the atmosphere of innovation and vitality, the level of opening to the outside world, cultural industries, or cultural brands.

3. Research Methodology

3.1. Basic Information about Sample Data. The outline of the Guangdong-Hong Kong-Macao Great Bay Area Planning clearly points out that it is necessary to "give play to the leading role of the strong alliance between Hong Kong and Shenzhen, Guangzhou and Foshan, and Macao and Zhuhai" and give Hong Kong and Shenzhen, Guangzhou and Foshan, and Macao and Zhuhai very high political standards. However, in reality, the weight of this pole is obviously insufficient, and the degree of economic connectivity and integration is far less than the other two poles. In order to solve this objective

contradiction in theory, based on the research foundation of the 2020 Guangdong Province innovation and strengthening school project (Research on the path of Zhuhai Macao coordinated optimization of business environment), this paper analyzes the influencing factors based on the statistical data of the regional business environment of Australia Zhuhai one pole. The specific results are shown in Table 1.

It can be seen from Table 1 that the data source comes from the middle-level and above employees of enterprises registered in Zhuhai or Macao. The degree of business integration between the two cities is low, and only 22.6% of enterprises have business intersection. The proportion of private enterprises and small- and medium-sized enterprises is large, indicating that the two cities have strong market activity. As a transportation hub city, the proportion of Commerce and trade circulation industry (such as wholesale, retail, transportation, warehousing, leasing, and business services) is relatively high, up to 28.2%. In addition, the scale of new enterprises in the two cities is not very prominent, there are few mature enterprises, and growth enterprises account for a large proportion.

3.2. Sample Data Reliability and Validity Tests. Due to the research on the source of statistical data, reliability and validity tests were carried out on the sample data in order to objectively test the sample data to truly reflect the degree of variables and ensure that scientifically refined measurement dimensions further fit the reality and maintain the stability of the test. The results are shown in Table 2, in which the KMO values are greater than 0.7, and the significance level of Bartlett sphere test is less than 0.05, which meets the validation criteria and has good validity. The commonly used alpha reliability coefficient method is adopted in the study, and each reliability value is greater than 0.8, which shows that the scale has high reliability and can meet the research requirements.

3.3. Research Methods. The logical analysis of the objective data of the regional business environment assessment system has been highly respected, but the research based on the perception of market players is not good. Under the socialist market economic system, the market is the distributor of social resources. Considering the regional business environment, enterprise satisfaction should be an important part of the evaluation system. In order to measure the perception of market participants, this paper uses the customer satisfaction studied by American scholar Cardozo for reference and introduces enterprise satisfaction as the dependent variable, which is defined as the measurement of the gap between the actual feeling and expectation of market participants on the regional business environment. And this paper considers whether the regional business environment will continue to improve. In this paper, one-way ANOVA and Cobb Douglas function are used as research methods.

3.3.1. One-Way Analysis of Variance. When other factors are fixed and unchanged, the one-way variance only considers whether there is a significant difference in the mean value of dependent variables at different levels of a single factor and set in the test of the equality of K overall mean values:

H_0: $\mu_1 = \mu_2 = \cdots = \mu_k H_\alpha$: the means of k populations are not all equal.

The rejection rule is P-valued method: if so P-$\leq\alpha$, reject H_0.

Using one-way ANOVA, we aim to explore the ratio of the systematic deviation of a control factor to six measurement dimensions and the randomness deviation that cannot be explained by this factor and then derive the characteristics of whether there is a significant difference.

3.3.2. Cobb-Douglas Function. In order to objectively calculate the degree of influence of five measurement dimensions on the regional business environment, this paper constructs a regional business environment influencing factor model based on the transformation of the Cobb-Douglas function of the new economic growth theory. For the convenience of research, it is referred to as business environment (DB), policy support (PS), talent security (TG), market supervision (MS), financial support (FS), and cultural promotion (CS).

$DB = \mu PS^{\alpha} TG^{\beta} MS^{\varepsilon} FS^{\theta} CS^{\lambda}$. To eliminate the effects of heteroscedasticity, a logarithm can be obtained on both sides of the above equation:

$$\begin{aligned} Ln(DB) = {} & \ln(\mu) + \alpha \ln(PS) + \beta \ln(TG) + \varepsilon \ln(MS) \\ & + \theta \ln(FS) + \lambda \ln(CS). \end{aligned} \tag{1}$$

Among them, μ is the on-standardized coefficients $\alpha, \beta, \varepsilon, \theta, \lambda$ are the flexibility coefficients of policy support, talent security, market supervision, financial support, and cultural promotion.

4. Result

4.1. One-Factor ANOVA Analysis of Personal Position, Registered City of Enterprise, and Business Transactions. As shown in Table 3, in addition to cultural promotion, individual positions have significant differences in evaluation for the remaining five dimensions. Among them, the legal representative has the highest evaluation in several dimensions, followed by senior managers and the lowest middle managers. The legal representative and the senior managers have a more macro environment, and the difference between the two is also small. The middle managers have a weaker feeling about the 5 dimensions due to the limitations of the position. The strong commonality of cultural promotion has resulted in no significant differences found in different functions. The registered enterprises in the two cities have significant differences in the five evaluation dimensions, among which the perception of policy support and talent protection of registered enterprises in Zhuhai is higher, while the perception of registered enterprises in Macao in terms of market supervision, cultural promotion, and financial support is higher. Regarding balanced comprehensive factors, there is no significant difference in the

Table 1: Descriptive statistical analysis.

	Frequency	Proportion (%)
Position		
Middle managers	191	48.6
Top management	148	37.7
Legal representative	54	13.7
The city where the business is registered		
Zhuhai	225	57.3
Macau	168	42.7
The intersection of business in the two cities		
Yes	89	22.6
No	304	77.4
Nature of the company		
State-owned (including state-controlled) enterprises	16	4.1
Collective (including collective holding) enterprises	20	5.1
Company Limited by Shares	111	28.2
Limited liability company	151	38.4
Individual private enterprises	58	14.8
Hong Kong, Macao and Taiwan investment enterprises	19	4.8
Foreign-invested enterprises	13	3.3
other	5	1.3
Enterprise size		
Big business	58	14.8
Medium-sized businesses	121	30.8
Small business	125	31.8
Microenterprise	89	22.6
The industry of the company		
Agriculture, forestry, animal husbandry, fisheries	13	3.3
Manufacture	36	9.2
Construction	29	7.4
Wholesale trade	25	6.4
Retail	32	8.1
Transportation	22	5.6
Warehousing	14	3.6
Postal industry	10	2.5
Accommodation industry	20	5.1
Catering industry	36	9.2
Information transmission industry	20	5.1
Software and information technology services	27	6.9
Real estate development and operation	29	7.4
Realty management	15	3.8
Leasing and business services	18	4.6
Other unspecified industries	47	12.0
The length of time the company is registered		
Within 1 year (inclusive)	46	11.7
1–3 (inclusive) years	114	29
3–5 years	108	27.5
5–10 years	87	22.1
More than 10 years	38	9.7

Table 2: Sample reliability validity test.

	Approximate chi-square	degree of freedom	Significance	KMO	Clone Bach's alpha	The number of items
Government support	708.877	3	0.000	0.749	0.896	3
Talent guarantee	579.813	3	0.000	0.73	0.868	3
Market regulation	587.567	3	0.000	0.713	0.865	3
Financial support	530.979	3	0.000	0.728	0.856	3
Cultural promotion	688.103	3	0.000	0.75	0.893	3
Business environment	412.923	3	0.000	0.711	0.818	3

Table 3: One-factor ANOVA table for individual positions, registered cities, and business dealings.

Category	Specific projects	Policy support	Talent guarantee	Market regulation	Financial support	Cultural promotion	Business environment
Personal position (evaluation mean)	Middle managers	9.9424	9.4660	10.0785	9.1414	9.8010	9.8901
	Top management	10.3514	9.0000	10.3514	9.2635	10.0203	10.0676
	Legal representative	11.2963	10.8889	11.5000	9.6667	11.2963	11.5741
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.000	0.000	0.000	0.000	0.147	0.000
City of incorporation (evaluation mean)	Zhuhai	10.4756	9.8578	10.2267	9.0489	9.9067	10.2444
	Macau	10.0238	8.9881	10.5774	9.5417	10.3333	10.1131
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.013	0.000	0.034	0.005	0.018	0.351
There are business contacts between Zhuhai and Macao (evaluation mean)	Yes	11.2584	9.7865	11.2247	9.3034	10.2697	10.7079
	No	9.9967	9.3980	10.1283	9.2467	10.0362	10.0362
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.000	0.089	0.000	0.787	0.273	0.000

perception of the business environment of registered enterprises in the two cities, which shows that there is complementarity between the influencing factors of the business environment, and each has different urban advantages. There are significant differences in the business environment of business intersection concentration, and the specific performance of policy support and market supervision is the biggest difference between the business environment of Zhuhai and Macao. Enterprises with business dealings can feel different policy environments and market environments, and their average evaluation is significantly higher than that of a single city.

4.2. One-Way ANOVA of Industry Types. Table 4 shows that the degree of difference in the business environment of different types of enterprises is very prominent. Among the policy support, transportation, retail, leasing and business, and other commercial circulation industries have higher average evaluation values. The two governments allowed them to give full play to their location and geographical advantages and carry out many effective measures to promote the development of circulation formats. In addition, high-tech industries such as software and information technology service industries in Zhuhai and Macao are embracing new development opportunities. At the same time, the industrial structure of the two cities has shifted to the tertiary industry, the proportion of the primary industry is extremely low, and the average evaluation of the primary and secondary industries ranks last. In the talent guarantee, the government has given greater efforts to emerging industries such as software and information technology service industries, and emerging industries has achieved good results. In contrast, industries such as industry, agriculture, and postal and express delivery industry are difficult to attract higher-level talents due to the low entry threshold, and the talent guarantee is at a relatively backward level. In market supervision, in addition to high-tech and other key industries, in the catering and accommodation industry, because it involves the vital interests of the people, the regulatory behavior and frequency are more scientific and reasonable, and the average evaluation is higher. Among the financial support, leasing and business services have a relatively close relationship with finance, and the average evaluation value is higher. Due to the relatively weak financial foundation of Zhuhai and Macao, the evaluation of other industries is not prominent. In the promotion of culture, the two cities are both tourist cities, and catering, accommodation, and other export-oriented economy attract the strongest feelings of foreign floating populations, reaching more than 11.1, and software and information technology service industry and other key industries are also the focus of culture attraction of the two cities. In general, the average business environment evaluation of the catering and accommodation industry, which is mainly affected by tourists, and the key supported commercial circulation and high-tech industries is significantly different from that of other industries, and the average price of the primary and secondary industries is the lowest.

4.3. One-Factor ANOVA Analysis of the Nature of the Enterprise, Size of the Enterprise, and Length of Enterprise Registration. In the nature of enterprises, except for talent security and financial support, the other evaluation dimensions are significantly different (see Table 5). The developed private economy of the two cities is mainly expressed in the form of limited liability companies and individual private enterprises, and the policy inclination is relatively large. The investment enterprises in Hong Kong, Macao, and Taiwan are emerging in an endless stream, and the governments of the two places have paid close attention to them. Comparatively speaking, the two cities pay more attention to competition guarantees and give the private economy and other different types of enterprises an "open, just, and fair" market environment. The average market supervision evaluation of the private economy and other different types of enterprises is higher. In the promotion of

Table 4: One-Way ANOVA table for industry types.

Category	Specific projects	Policy support	Talent guarantee	Market regulation	Financial support	Cultural promotion	Business environment
Industry type (evaluation mean)	Agriculture, forestry, animal husbandry, fisheries	8.7692	7.3846	8.9231	8.5385	8.6154	8.8462
	Manufacture	8.7500	8.6667	9.3056	7.7222	8.8611	8.8056
	Construction	10.3448	9.3448	10.2414	9.2414	9.6552	10.2069
	Wholesale trade	10.1200	9.1600	9.9600	9.4400	9.7600	9.8400
	Retail	10.3438	10.0625	10.6875	9.0625	10.1563	10.4063
	Transportation	11.8636	9.0455	10.7727	9.5455	10.4545	10.4545
	Warehousing	10.2143	9.1429	10.4286	9.0714	10.2857	10.1429
	Postal industry	9.2000	8.5000	10.1000	9.4000	10.0000	9.9000
	Accommodation industry	10.6500	8.6000	10.8000	9.8500	11.1000	10.7500
	Catering industry	10.3889	10.3056	10.6667	9.6944	11.1111	10.7222
	Information transmission industry	10.5500	9.6000	10.6000	9.9000	10.3500	10.2500
	Software and information technology services	11.1852	11.0741	10.7407	9.3333	10.8148	10.8148
	Real estate development and operation	10.5172	9.8966	10.6897	9.0345	10.0000	10.4828
	Realty management	10.4000	8.7333	10.1333	9.2667	10.2667	10.0667
	Leasing and business services	10.3889	9.5556	10.5556	10.6111	9.8889	10.1111
	Other unspecified industries	10.2979	9.8298	10.6596	9.2979	9.9574	10.4468
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.000	0.000	0.001	0.000	0.000	0.000

culture, the private economy and other different types of enterprises are more in line with market demand, more likely to be affected by cultural appeal, and the average evaluation is higher. Overall, the business environment of the two cities is more friendly to the private economy and has a higher evaluation. At the same time, the proportion of the state-owned economy and the collective economy is low, and the perception and evaluation of policies, markets, and cultures are at a low level. From the scale of enterprises in Table 5, it can be seen that, in addition to financial support and cultural promotion, there are significant differences in policy support, talent protection, market supervision, and business environment. The average policy evaluation of small and micro enterprises is high, which is in line with the policy orientation of the two cities. The number of large enterprises is small, and the government also pays special attention. In recent years, the two cities of Zhuhai and Macao have vigorously introduced foreign populations and do a good job in supporting talents. The cultivation of talents and housing guarantee of large enterprises have been effectively alleviated. The talent requirements of small and micro enterprises are not high, which coincides with the demographic characteristics of strong mobility. At a result, the average talent evaluation of large and small and micro enterprises is higher than that of medium-sized enterprises. In market supervision, small and micro enterprises are mostly emerging industries. The market environment in Zhuhai and Macao is more tolerant, and the average evaluation of small and micro enterprises is also higher than that of large and medium-sized enterprises. In general, the business environment of Zhuhai and Macao cities pays more attention to small and micro enterprises, and the average evaluation value is higher. Due to industrial supporting facilities and industrial cluster effects, the perception and evaluation of large and medium-sized enterprises need to be improved. In the duration of registration, there were no significant differences in other evaluation factors except for cultural promotion and business environment. Factors such as cultural atmosphere, openness level, and cultural industry support require time to experience. The longer the enterprise exists, the stronger the perception of culture will be, and the higher the average evaluation of cultural role will be.

5. Analysis and Discussion on Different Influencing Factors on Regional Business Environment

As can be seen from the above, there is a significant influence relationship between the five influencing factors and the business environment, showing different role status between different categories. However, how correlated are any two influencing factors? It is a problem that must be faced squarely to explore the internal logical relationship between influencing factors. Further, it is necessary to explore the common role between the five influencing factors and the business environment, and to find out the role of different factors on the business environment. Based on this, the following is an analysis of the interaction between individual factors and the interaction of combined factors.

5.1. Degree of Individual Action. Table 6 analyzes the correlation of the overall data of Zhuhai and Macao, and it can be obtained that (1) there is a significant positive correlation between the six evaluation dimensions, of which the

Table 5: One-factor ANOVA table of the nature of the enterprise, the size of the enterprise, and the duration of the enterprise registration.

Category	Specific projects	Policy support	Talent guarantee	Market regulation	Financial support	Cultural promotion	Business environment
Nature of the enterprise (evaluation mean)	State-owned (including state-controlled) enterprises	9.1875	9.0000	9.3750	8.5000	8.9375	9.0625
	Collective (including collective holding) enterprises	8.5500	8.8500	9.1500	8.7500	9.3000	9.1000
	Corporation	10.0360	9.2252	9.9820	9.0090	9.7568	9.7477
	Limited liability company	10.7947	9.7748	10.8344	9.5762	10.4503	10.6887
	Individual private enterprises	10.2931	9.6552	10.7069	9.3448	10.3966	10.5517
	Hong Kong, Macao and Taiwan investment enterprises	10.4737	9.0000	10.2632	9.0526	9.8947	10.0000
	Foreign-invested enterprises	10.0000	9.7692	10.0769	9.4615	9.9231	9.9231
	Other	10.6000	9.8000	10.8000	9.0000	11.0000	10.0000
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.000	0.136	0.000	0.077	0.001	0.000
Enterprise size (average evaluation)	Big businesses	10.2241	9.5000	10.0862	9.4138	9.9655	9.9483
	Medium-sized businesses	9.9339	9.0248	10.0744	8.9339	9.8430	9.8099
	Small business	10.4000	9.6800	10.5920	9.4560	10.1920	10.4560
	Microenterprise	10.6292	9.8315	10.6742	9.3258	10.3596	10.4831
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.036	0.009	0.010	0.093	0.161	0.000
Business registration time (average evaluation)	Within 1 year (inclusive)	9.9348	9.6087	10.2174	9.6087	9.8043	10.0217
	1–3 (inclusive) years	10.1930	9.2281	10.1667	9.0702	9.7632	9.9912
	3–5 (inclusive) years	10.4907	9.4444	10.2778	8.9815	9.6759	10.0278
	5–10 (inclusive) years	10.2759	9.4598	10.7586	9.5517	10.6322	10.5977
	More than 10 years	10.3947	10.2895	10.6053	9.5263	11.3421	10.5000
	Total	10.2824	9.4860	10.3766	9.2595	10.0891	10.1883
Significance		0.459	0.056	0.080	0.053	0.000	0.007

optimization effect of building a soft environment and enhancing cultural strength on the business environment is becoming prominent. The business environment is affected by market supervision, policy support, and cultural promotion, and the correlation coefficient is above 0.6. The policies of Zhuhai and Macao are highly transparent, highly in line with market demand. Market supervision is relatively strong and pays attention to norms, and the cultural commonality of "openness and inclusiveness" plays a role in the penetration and aggregation of soft power, which is significantly improving the level of business environment. (2) Due to the current situation of financial foundation and the current situation of talents, it is difficult to give full play to the effectiveness of policies in the short term. The correlation coefficient between policy support and financial support and talent security is about 0.3, and the financial foundation of the two cities is relatively weak. The economic volume cannot support a more developed financial scale, and the policy dividend is difficult to see immediately in the short term. At the same time, the population size of the two cities has long been at the end of the Guangdong-Hong Kong-Macao Greater Bay Area urban agglomeration, the talent base is inherently insufficient, the attractiveness and advantages of talents are not obvious, and the high housing prices in the two cities are also an important loss of talent security.

Further, Table 7 compares the correlation between the variables of the two cities, and the following can be obtained: (1) there is a significant positive correlation between the six evaluation dimensions of the two cities of Zhuhai and Macao. The data show that the correlation degree of most of the evaluation dimensions is not much different. (2) In addition to market supervision, Zhuhai's degree of correlation between policy support and other dimensions is higher than that of Macao, especially the degree of correlation between policy support and talent protection, which shows that the Zhuhai government's policy effect in talent protection is stronger, and the implementation of the "Talent Plan" effectively attracts, trains, and serves all kinds of high-level and high-skilled talents. Macao's long-term talent supply is insufficient, and talent protection lacks a spatial foundation. (3) In addition to policy support, Macao's degree of correlation between market supervision and other dimensions is higher than that of Zhuhai, which reflects that Macao's industrial supervision, corporate credit, safety production, and other regulatory behaviors are more standardized, and more attention is paid to the frequency and level of supervision. Zhuhai's market supervision is dominated by traditional means, and the supervision method of "strong government and weak society" limits the level of supervision to a certain extent.

Table 6: Correlation analysis of the overall variables.

		Policy support	Talent guarantee	Market regulation	Financial support	Cultural promotion	Business environment
Policy support	Pearson correlation	1					
	Significance (bilateral)						
Talent guarantee	Pearson correlation	0.325**	1				
	Significance (bilateral)	0.000					
Market regulation	Pearson correlation	0.516**	0.402**	1			
	Significance (bilateral)	0.000	0.000				
Financial support	Pearson correlation	0.386**	0.228**	0.481**	1		
	Significance (bilateral)	0.000	0.000	0.000			
Cultural promotion	Pearson correlation	0.426**	0.344**	0.537**	0.487**	1	
	Significance (bilateral)	0.000	0.000	0.000	0.000		
Business environment	Pearson correlation	0.644**	0.518**	0.677**	0.495**	0.662**	1
	Significance (bilateral)	0.000	0.000	0.000	0.000	0.000	

Table 7: The correlation analysis between variables was conducted in Zhuhai and Macao.

		City	Policy support	Talent guarantee	Market regulation	Financial support	Cultural promotion	Business environment
Policy support	Pearson correlation	Zhuhai	1					
		Macau	1					
	Significance (bilateral)	Zhuhai						
		Macau						
Talent guarantee	Pearson correlation	Zhuhai	0.466**	1				
		Macau	0.292**	1				
	Significance (bilateral)	Zhuhai	0.000					
		Macau	0.000					
Market regulation	Pearson correlation	Zhuhai	0.478**	0.478**	1			
		Macau	0.565**	0.490**	1			
	Significance (bilateral)	Zhuhai	0.000	0.000				
		Macau	0.000	0.000				
Financial support	Pearson correlation	Zhuhai	0.438**	0.383**	0.455**	1		
		Macau	0.317**	0.384**	0.505**	1		
	Significance (bilateral)	Zhuhai	0.000	0.000	0.000			
		Macau	0.000	0.000	0.000			
Cultural promotion	Pearson correlation	Zhuhai	0.494**	0.488**	0.516**	0.421**	1	
		Macau	0.331**	0.395**	0.556**	0.538**	1	
	Significance (bilateral)	Zhuhai	0.000	0.000	0.000	0.000		
		Macau	0.000	0.000	0.000	0.000		
Business environment	Pearson correlation	Zhuhai	0.682**	0.617**	0.637**	0.455**	0.677**	1
		Macau	0.601**	0.500**	0.747**	0.599**	0.663**	1
	Significance (bilateral)	Zhuhai	0.000	0.000	0.000	0.000	0.000	
		Macau	0.000	0.000	0.000	0.000	0.000	

注: N(Zhuhai) = 225, N(Macau) = 168, ** indicates the significant correlation at level .01 (bilateral).

Table 8: Regression estimation of the Cobb-Douglas function model is carried out in the two cities.

City		Model	Nonstandardized coefficients		t	Significance	Tolerance	Coefficient of variance expansion	R^2	Durbin Watson
			Regression coefficients	Standard error						
Zhuhai	1	(Constant)	4.667	0.402	11.597	0.000			0.465	2.058
		Policy support	0.543	0.039	13.933	0.000	1	1		
	2	(Constant)	3.03	0.383	7.914	0.000			0.618	
		Policy support	0.366	0.038	9.638	0.000	0.756	1.324		
		Cultural promotion	0.349	0.037	9.413	0.000	0.756	1.324		
	3	(Constant)	2.147	0.387	5.54	0.000			0.669	
		Policy support	0.301	0.037	8.102	0.000	0.688	1.455		
		Cultural promotion	0.269	0.037	7.251	0.000	0.654	1.528		
		Market regulation	0.228	0.039	5.861	0.000	0.668	1.497		
	4	(Constant)	1.555	0.392	3.966	0.000			0.699	
		Policy support	0.263	0.036	7.204	0.000	0.652	1.533		
		Cultural promotion	0.228	0.037	6.217	0.000	0.615	1.625		
		Market regulation	0.186	0.038	4.869	0.000	0.631	1.584		
		Talent guarantee	0.179	0.039	4.638	0.000	0.657	1.522		
Macau	1	(Constant)	3.061	0.497	6.164	0.000			0.558	1.896
		Market regulation	0.674	0.047	14.482	0.000	1	1		
	2	(Constant)	1.939	0.478	4.055	0.000			0.647	
		Market regulation	0.495	0.05	9.852	0.000	0.691	1.446		
		Cultural promotion	0.29	0.045	6.443	0.000	0.691	1.446		
	3	(Constant)	1.36	0.465	2.926	0.004			0.691	
		Market regulation	0.369	0.054	6.831	0.000	0.528	1.894		
		Cultural promotion	0.285	0.042	6.74	0.000	0.691	1.447		
		Policy support	0.188	0.039	4.804	0.000	0.68	1.471		
	4	(Constant)	0.963	0.461	2.088	0.038			0.714	
		Market regulation	0.321	0.054	5.981	0.000	0.497	2.013		
		Cultural promotion	0.228	0.044	5.22	0.000	0.603	1.659		
		Policy support	0.183	0.038	4.837	0.000	0.679	1.473		
		Financial support	0.158	0.043	3.661	0.000	0.648	1.542		

Table 9: The two cities work together on regression estimation of the Cobb-Douglas function model.

	Model	Nonstandardized coefficients		t	Significance	Collinear statistics		R^2	Durbin Watson
		Regression system	Standard error			Tolerance	Coefficient of variance expansion		
1	(Constant)	4.217	0.332	12.711	0.000			0.459	
	Market regulation	0.575	0.032	18.214	0.000	1.000	1.000		
2	(Constant)	2.896	0.316	9.172	0.000			0.584	
	Market regulation	0.384	0.033	11.681	0.000	0.711	1.405		
	Cultural promotion	0.328	0.030	10.837	0.000	0.711	1.405		
3	(Constant)	2.000	0.301	6.640	0.000			0.661	
	Market regulation	0.271	0.032	8.443	0.000	0.611	1.637		
	Cultural promotion	0.274	0.028	9.789	0.000	0.681	1.468		
	Policy support	0.254	0.027	9.352	0.000	0.702	1.424		
4	(Constant)	1.510	0.297	5.087	0.000			0.693	1.999
	Policy support	0.228	0.031	7.284	0.000	0.583	1.717		
	Cultural promotion	0.250	0.027	9.283	0.000	0.668	1.497		
	Policy support	0.234	0.026	8.978	0.000	0.692	1.445		
	Talent guarantee	0.146	0.023	6.409	0.000	0.804	1.244		
5	(Constant)	1.386	0.302	4.592	0.000			0.696	
	Market regulation	0.213	0.032	6.631	0.000	0.550	1.817		
	Cultural promotion	0.234	0.028	8.363	0.000	0.614	1.628		
	Policy support	0.227	0.026	8.672	0.000	0.680	1.470		
	Talent guarantee	0.147	0.023	6.482	0.000	0.803	1.245		
	Financial support	0.055	0.027	2.036	0.042	0.683	1.463		

5.2. Degree of Joint Action. Table 8 uses the Wald stepwise regression method to test the coefficients of the Cobb-Douglas function model and estimate the regression in two cities. The Durbin-Watson coefficient is at (1, 3), the tolerance >0.1, the variance expansion coefficient is <10, the basic default random error term does not have autocorrelation, and the regression analysis does not exist in multicollinearity. The measurement shows that the index selection is scientific, reasonable, and suitable for multiple regression analysis.

The goodness of fit of the Zhuhai model was 0.699, and the F-value was 127.569, indicating that the linear correlation was significant. In the model, "financial support" was not significantly correlated with the business environment when it was correlated with other variables. It was not detected in the model, and the other factors were 0.000 in the regression. Based on this, the multiple regression model of Zhuhai is derived:

$$Ln(DB) = 1.555 + 0.263\ \ln(PS) + 0.179\ \ln(TG) + 0.86\ \ln(MS) + 0.228\ \ln(CS). \tag{2}$$

Convert it to the Cobb-*Douglas* function as $DB = 4.735PS^{0.263}TG^{0.179}MS^{0.186}CS^{0.228}$

Similarly, "talent guarantee" did *not* enter the Macao model test, and the Cobb-Douglas function of the Macau model was $DB = 2.62PS^{0.183}MS^{0.321}FS^{0.158}CS^{0.228}$

Further, Table 9 performs the Coefficient Test and Regression Estimation of the Cobb-Douglas function model for common data of Zhuhai and Macao, and the Cobb-Douglas function of Zhuhai and Macao can be obtained as follows:

$$DB = 4PS^{0.227}TG^{0.147}MS^{0.231}FS^{0.055}CS^{0.234}. \tag{3}$$

From the above three Cobb-Douglas functions, it can be compared that (1) the financial support has not been combined with other factors to affect the business environment in Zhuhai. This further reflects the uneven and insufficient situation of Zhuhai's overall financial industry, and the problem of incongruity with the development of the real economy is more prominent. When the other four factors jointly act on Zhuhai's business environment, the flexibility coefficient of policy support is the highest, and the rest are cultural promotion, market supervision, and talent protection. (2) The failure of talent security to have a joint effect with other factors affecting Macao's business environment is related to Macao's talent dilemma, the shortage of population supply, and the single skill structure, and the introduction of mainland talents has been in a "contradictory" situation for a long time. When the other four factors are combined to act on Macao's business environment, the elasticity coefficient of market supervision is the highest, and the rest are cultural promotion, policy support, and financial support. (3) When the five factors jointly act on the business environment of Zhuhai and Macao, they can produce significant correlations, and the elasticity coefficient of Chinese promotion is the highest, and the rest are policy support, market supervision, talent security, and financial support.

6. Conclusions and Recommendations

In order to explore the influencing factors of the regional business environment, this paper focuses on the five aspects of policy support, talent security, market supervision, financial support, and cultural promotion, and it takes Zhuhai and Macao registered enterprises for empirical analysis. The following conclusions are drawn: first, five factors in different categories have different degrees of significant impact on the regional business environment, among which the industry type has the greatest impact (both significant). In addition to cultural promotion, personal position also has a significant impact. The registered city of enterprises does not significantly affect the business environment, but it has the complementary effect of influencing factors overall. The significant impact of business exchanges between Zhuhai and Macao on the business environment is reflected in the policy support and market supervision. The nature and scale of the enterprise are not significantly affected by some factors. Apart from cultural promotion, the duration of registration does not significantly affect the business environment. Second, there is a significant positive correlation between the six evaluation dimensions of Zhuhai and Macao. There is no significant difference in the correlation degree of most evaluation dimensions. However, the correlation degree of policy support and other dimensions in Zhuhai is higher than that of Macao, and the correlation degree of market regulation and other dimensions in Macao is higher than that of Zhuhai. In the joint effect, financial support failed to have a joint effect with other factors to affect the business environment in Zhuhai, and talent security failed to combine with other factors to affect the business environment in Macao. Thirdly, the five factors have a significant impact on the regional circulation business environment of Zhuhai and Macao, among which the biggest impact of Zhuhai is policy support (the largest elasticity coefficient), the smallest impact is financial support (no significant correlation), the largest impact of Macao is market supervision (the largest elasticity coefficient), and the smallest impact is talent security (no significant correlation). The integration of Zhuhai and Macao can produce a significant correlation. The greatest impact is cultural promotion (the largest elasticity coefficient), and the smallest impact is financial support (the smallest elasticity coefficient).

Based on this, this paper puts forward the following suggestions: (1) according to the industrial characteristics

and enterprise types of the important node cities in Guangdong, Hong Kong, and Macao, this paper proposes political measures for different factors affecting the region's business environment, especially paying attention to the specific needs of different industry types, and comprehensively optimizes the regional business environment from the perspectives of policy, talent, market, finance, and culture to ensure the sustainable and high-quality development of the Greater Bay Area. (2) Objectively evaluate and introduce the element resource differences of important node cities in Guangdong-Hong-Kong and Macao Great Bay Area, build a fusion platform for regional business environment through multiparty cooperation, launch a "one-to-one," "one to many," or even "many to many" communication and coordination mechanism, and implement a new path of binding development of regional economy. (3) Seek the complementary effect of resources between the important node cities in Guangdong-Hong-Kong and Macao Great Bay Area, build a multiagent policy cooperation operation mechanism, enrich the new connotation of talent attraction and cultivation among cities, promote the construction of joint guarantee market mechanism, carry out a new model of multinode financial coordinated development, and work together to enhance the cultural soft power of the important node cities in Guangdong-Hong Kong-Macao Bay area, so as to achieve the sustainable and high-quality development of Guangdong-Hong Kong-Macao Bay area.

The research was made based on two cities, Zhuhai and Macao, and we hope to have more data on more cities in Guangdong-Hong Kong-Macao Bay area to make the analysis more accurate and adaptable [7–11].

Data Availability

Data could be accessed by request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The paper was supported by 2020 Guangdong Innovation and School Strengthening Project (Provincial Key Platform and Major Scientific Research Project): Research on the Path of Zhuhai Macao Collaborative Optimization of Business Environment (2020WQNCX098).

References

[1] J. Yoon and S. Joung, "Environmental self-identity and purchasing ecofriendly products," *Journal of Logistics, Informatics and Service Science*, vol. 8, no. 1, pp. 82–99, 2021.

[2] T. Yang, "Research on the construction of business environment assessment index system -- Based on the comparative analysis of Shandong, Jiangsu, Zhejiang and Guangdong," *Business economics research*, vol. 13, pp. 110–112, 2015.

[3] L. Wu and G. Zhang, "Construction of business environment assessment framework based on subjective perception of market subjects -- Comments on the business environment assessment model of the world bank," *Contemporary Economic Management*, vol. 40, no. 6, pp. 91–95, 2018.

[4] X. Peng and R. Ma, *Optimization of government business environment and construction of its evaluation index system*, vol. 11, pp. 96–99, Academic research, Shanghai, 2018.

[5] Z. Yan, *Study on Satisfaction and Influencing Factors of Business Environment in Districts and Counties -- Based on the Practice of Xiangshan County*, pp. 17–30, Dissertation of Zhejiang University, Ningbo, 2019.

[6] D. Peng, Bo Chen, and Z. Liu, "Construction and application of regional business environment assessment index system -- Taking the Yangtze River economic belt as an example," *Finance and Economics*, vol. 05, pp. 35–45, 2019.

[7] H. Rachidi and M. El Mohajir, "Improving SMEs' performance using innovative knowledge and financial system designed from the Moroccan business environment," *African Journal of Science, Technology, Innovation and Development*, vol. 13, no. 1, pp. 15–30, 2021.

[8] K. Li, "Speech at the National Teleconference on Deepening the Reform of "deregulation, Management and Service" and Optimizing the Business Environment," *People's daily*, pp. 09–30, 2020.

[9] R. E. Rasi and D. Hatami, "Environmental risk and innovation in supply chain: analysis of influence of supply chain agility," *Journal of System and Management Sciences*, vol. 9, no. 3, pp. 1–25, 2019.

[10] Q. Sun and H. Chen, "Determinants, impact effects and evaluation indexes of China's regional business environment -- A study based on mimic model," *Financial Research*, vol. 6, pp. 22–37, 2020.

[11] J. Wang, Z. Li, and X. Sun, "Empirical analysis on the influence of business environment on foreign direct investment inflow based on the panel data on 26 countries," *International Journal of Sustainable Development and Planning*, vol. 15, no. 8, pp. 1223–1230, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8188395, 10 pages
https://doi.org/10.1155/2022/8188395

Research Article

The Landscape of *Robinson Crusoe* in China: A Bibliometric Analysis

Zhihua Liao [1] **and Joan Qionglin Tan** [1,2]

[1] *School of Humanities, Shanghai University of Finance and Economics, Shanghai 200433, China*
[2] *School of Foreign Studies, Shanghai University of Finance and Economics, Shanghai 200433, China*

Correspondence should be addressed to Joan Qionglin Tan; tan.qionglin@mail.shufe.edu.cn

Received 31 May 2022; Accepted 10 July 2022; Published 8 August 2022

Academic Editor: Lele Qin

Daniel Defoe's novel *The Life and Strange Surprising Adventures of Robinson Crusoe* has an everlasting impact in China since its first entrance in Cantonese in 1902. Now, it has become a Robinson Crusoe industry in the publishing sector. This paper attempts to give quantitative evidence from bibliometrics to examine its popularity in China. The data collected are based on all articles published in authoritative CSSCI journals from its inception (1999) to January 2021. We also retrieved *Robinson Crusoe* results from the National Library Reference Alliance and e-commerce China Dangdang to identify its popular Chinese versions. Five themes are concerned with this novel: comparative literature, economic analysis, translation studies, communication, and philosophical thinking. The study has articulated that *Robinson Crusoe*'s publications in China have increased significantly since the novel was designated as a topic related to China's National College Entrance Examination in 2018. Hence, rewriting *Robinson Crusoe* for teenagers has been a driver for a wide readership, which accordingly makes its translation much embraced in the Chinese world due to the recent statistics.

1. Introduction

The year 2019 marks the 300th anniversary of the publication of Daniel Defoe's *The Life and Strange Surprising Adventures of Robinson Crusoe* (hereinafter *Robinson Crusoe*), a travelogue of seemingly real incidents about the castaway mariner Robinson Crusoe, who lived alone in an uninhabited island for 28 years [1]. Credited as "the first English novel" [2], *Robinson Crusoe* has been stirring both the literary and media world since its publication due to a variety of editions, translations, movies, and other spin-off TV series for all levels of readers in different countries. It is recorded that by the end of the 19th century, at least 700 alternative versions, translations, and imitations had appeared, including children's versions with pictures, pantomimes, and operas [3]. In 1902, French film artist and magician Georges Méliès first exploited "the medium of film as a means of personal expression" [4] to produce *Robinson Crusoe*, which brought out a revolution of adapting this novel into screen versions. To date, there are more than 100 adapted films, including silent drama films, science fiction films, and animated cartoons since the first decade of the twentieth century [5]. Undoubtedly, either the abbreviated title of the novel "*Robinson Crusoe*" or the name of the protagonist "*Robinson Crusoe*" has now become a household word throughout the world, though Defoe's other two sequels are less known: *The Farther Adventures of Robinson Crusoe* (1719, hereinafter *Farther*) and *Serious Reflections of Robinson Crusoe* (1720, hereinafter *Serious Reflections*). As a well-received global publication phenomenon, *Robinson Crusoe* also experienced its own story in China in the past century. Although translated into many languages, including Inuktitut, Coptic, and Maltese, Chinese readers did not know Daniel Defoe (1660–1731) and his adventurous story *Robinson Crusoe* until 1902, 171 years after his death in London in 1731. The documentary survey demonstrates that Defoe's debut in China is indebted to William C. Burns (1815–1868), a Western Christian missionary, who helped to

translate the novel *Robinson Crusoe* into Cantonese, a widely spoken dialect in South China but condensed the original title with rich connotations *The Life and Strange Surprising Adventures of Robinson Crusoe* into *Gusu Licheng*, a simple Chinese title with typical Chinese four characters, meaning "Robinson Crusoe's experience" [6, 7]. Since then, *Robinson Crusoe* has had an everlasting impact on Chinese readers. For example, President Xi Jinping, in his 2015 diplomatic visit to the United Kingdom, mentioned *Robinson Crusoe* in his memory of the United Kingdom's literary works [8]. In 2017, the Chinese version of *Robinson Crusoe* was listed as the Top 3 largest borrowing volumes by Hunan Library [9]. To date, a tremendous literature related to *Robinson Crusoe* in China has been made, which turns out to be a Robison Crusoe industry. Numerous versions, whether full, abridged, or adapted, have been issued by a variety of Chinese publishing sectors, including some well-known publishing houses, such as the Commercial Press, the People's Literature Publishing House, and the Higher Education Press. Here, in our paper, by the italicized "*Robinson Crusoe*," we mean the novel and its derivatives or paratexts. Although the Crusoe story remains very popular in China, how this novel has been accepted lacks an empirical description. No specific data show how Chinese scholars interpreted the novel and how many Chinese versions were issued. This paper attempts to give a bibliometric review on the reception and translation of this extraordinary novel in China, identifying potential, yet convincing reasons that contribute to its popularity through the retrievable data in Mainland China, Hong Kong, Macau, and Taiwan. Hence, to have a thorough, yet scientific study of its acceptance in China, five aspects are examined via the bibliometric analysis: comparative literature, economic analysis, translation studies, communication, and philosophical thinking. Three contributions are made via this method: (1) the reliable statistics help identify popular versions of *Robinson Crusoe*; (2) the research gives a review of how Chinese scholars interpret *Robinson Crusoe*; and (3) the review covers a broader collection of data comparing with the existing study, which makes it more comprehensive.

2. Materials and Methods

In relating to *Robinson Crusoe,* journals, Master's theses and PhD dissertations, funds, and library collections are applied to retrieve the book. The data sources come from CNKI (China Journal Full-Text Database), Wanfang Data, the National Library Reference Alliance, and Dangdang. We select those data sets because they provide users with representative periodicals, theses, and authors.

CNKI, launched by Tsinghua University in 1999, is the largest Chinese journals database, which provides all MA theses, doctoral dissertations, newspapers, and journal articles. In this respect, CNKI stands for the Chinese scholars' research about *Robinson Crusoe*, from which their perspectives of the novel can be examined. "The National Library Reference Alliance" is the largest digital resource platform that offers an online reference service and documents remote transmission service for its users. While Dangdang is one of China's top booksellers, we can still find ordinary readers of the book. Beyond the data from Mainland China, papers from Hongkong, Macau in HKMO, and the HKU Scholars Hub are retrieved as well. Moreover, for the data in Taiwan, the National Digital Library of Theses and Dissertations in Taiwan and the Taiwan Academic Literature Database are selected. On the whole, the selected data in this paper possess the credibility of *Robinson Crusoe* studies in China.

To date, with "Robinson Crusoe," both italicized and nonitalicized, as the keyword on January 23, 2021, the results in CNKI demonstrate that there are a total of 779 journal papers, 107 theses (3 PhDs, 104 MAs), 15 conference papers, and 33 newspapers reviews, among which 88 articles are issued in authoritative CSSCI journals. Since CSSCI (Chinese Social Sciences Citation Index) is a database representing an indicator of evaluating a Chinese scholar's published journals and promotion, an analysis of articles on "*Robinson Crusoe*" from the CSSCI journals will help researchers get the current, yet full picture of the topic. Here, we use the Chinese characters "*Robinson Crusoe*" as a keyword to indicate two forms in English: both the novel *Robinson Crusoe* and the protagonist Robinson Crusoe, for there is no distinction between the writing forms of the italicized and the nonitalicized in Chinese. To make the search results more inclusive, the following search items are used:

Topic = "*Robinson Crusoe*"

Language: English and Chinese

Indexes = CSSCI Timespan = All year

Search results: 107 records date last updated: January 23, 2021

To make the results more accurate, those authors who just mention "*Robinson Crusoe*" without any analysis of the book are removed. Then 88 results are selected through manual work. Each record from CSSCI contains the title, author, keywords, institution, journal, and publication year. On the other hand, retrievable MA theses and PhD dissertations can also be found through CNKI and Wanfang Data. Then 103 MA theses and 3 PhD dissertations are identified. The library collection, especially Duxiu (Knowledge Search Database) and the National Library can trace Chinese versions of *Robinson Crusoe* with a higher number, thus identifying which one is popular.

"The National Library Reference Alliance" provides users with the largest number of Chinese books, making it the right place to figure out the number of Chinese versions of *Robinson Crusoe*. The search results can be conducted as follows:

Title = "*Robinson Crusoe*" with different forms due to homophones

Language = Chinese

Timespan = All year

Match = exact matching

In China, "Robinson" is rendered as different Chinese written characters for its similar pronunciation "bin" and "son," while "Crusoe" is translated as different titles, indicating a travelogue without any destination. In other words, they form different types of translation versions. The results will be shown in different ways with the combination of translation retrieved from the National Library Reference Alliance.

Major booksellers in China can also prove the popularity of the novel. E-commerce China Dangdang Inc., known as Dangdang, one of China's top booksellers, contains ordinary readers' comments of *Robinson Crusoe*, through which the bestsellers can be found based on its sales rankings of Dangdang till January 26, 2021.

With results retrieved from CNKI, CSSCI, HKMO, the HKU Scholars Hub, National Digital Library of Theses and Dissertations in Taiwan, and Taiwan Academic Literature Database, we removed duplicates of the data. Based on the texts from CSSCI, the first part of this article uses CiteSpace (version 5.7R3) developed by Chen Chaomei and his team to analyze the authors, journal sources, keywords, and institutions of the text. Given that CiteSpace cannot produce an English version of maps when the source text is Chinese, 365 Excel is applied to make "*Robinson Crusoe*" data tables. The data are then conducted with the VOSviewer software tool (version 1.6.15) developed by Eck and Waltman of the University of Leiden of the Netherland. VOSviewer has the function of removing the synonyms of *Robinson Crusoe*. For Dangdang, it provides users with its own sales rankings based on buyers' comments. Then those data are conducted through 365 Excel of Microsoft.

3. Results and Discussion

3.1. Translation Versions. The translation versions of *Robinson Crusoe* with different Chinese written characters (namely, homophones) can be identified through the search results of the National Library Reference Alliance. It is noted that there are many translation versions ranging from the full, abridged, adapted, bilingual to the illustrated children's version. Interestingly, the popular Chinese translation title indicates that the eponymous hero's "drifting" story appears to be much more received than his "adventurous" story, which might be caused by Chinese readers' longing for mysterious sea story. From the data observed, the former includes seven versions with homophones, which tops the rankings with 1598 results, whereas the latter with 12 results. The statistics demonstrate that there are altogether 50 versions published alone in 2018 with the translation title containing the reliant, resourceful man's "drifting" story (see Figure 1).

3.2. Active Authors and Institutions. Table 1 exhibits CSSCI authors' demonstration, without considering results from Macau, Hongkong, and Taiwan. The top-ranked item by citation counts is Ren Haiyan, with citation counts of four. The second one is Luo Fukai, with citation counts of three. The third is Hui Haifeng, with citation counts of three. The rest ranks the fourth with citation counts of two. From the table, we can see that Ren Haiyan is the biggest provider relating to *Robinson Crusoe* in those papers. What merits attention is that her 2009 doctoral dissertation "A Modern Myth and Its Revisions: A Study of Robinson Crusoe, Friday and Foe" was later published by Peter Lang in 2014 entitled *Différance in Signifying Robinson Crusoe: Defoe, Tournier, Coetzee and Deconstructive Re-visions of a Myth*. In her book, Ren argues that deconstructive rewritings belong to the category of revisions by engaging *Robinson Crusoe* in tandem with two of its revisions, Michel Tournier's *Friday* and J. M. Coetzee's *Foe*, from the perspective of the Enlightenment ideology. At present, Ren is also doing some research on "*Robinson Crusoe* and Its Rewriting" supported by the Social Science Fund Project of Huan Province.

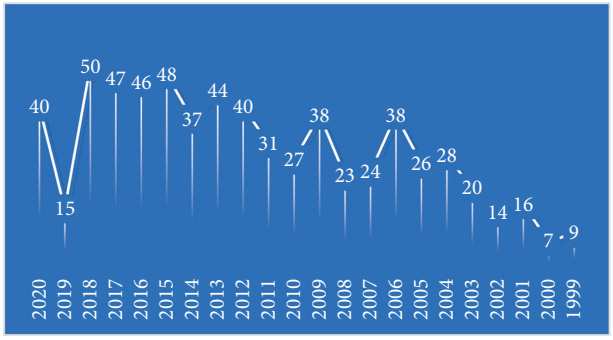


Figure 1: Publications of *Robinson Crusoe* with the title indicating the hero's drifting story.

Table 1: Active authors of *Robinson Crusoe*.

Freq	Degree	Sigma	Author	Year
4	0	1	Ren Haiyan	2009
3	1	1	Luo Fukai	2009
3	1	1	Hui Haifeng	2011
2	1	1	Niu Hongying	2007
2	0	1	Song Xiaochuan	2003
2	0	1	Wang Xiaoxiong	2017
2	0	1	Li Jin	2009
2	0	1	Zeng Yan	2017
2	2	1	Yang Yang	2018
2	0	1	Xu Weizi	2019
2	1	1	Shen Fuying	2011

Like Dr. Ren, Cui Wendong from the City University of Hong Kong has contributed four periodical papers, two MA theses, and one doctoral dissertation related to *Robinson Crusoe*. Unlike Ren's study of comparing *Robinson Crusoe* with *Friday* and *Foe*, Dr. Cui examines *Robinson Crusoe* by placing it at the background of the Late Qing Dynasty (1840–1912) and combining it with these two works within the framework of Chinese literature. Thus, Cui collected earlier Chinese translation versions of *Robinson Crusoe*, identifying the translators' ethical selections. At the same time, Hui attempts to explore *Robinson Crusoe* from the perspective of children's literature and has already issued three English articles [10–12] and three Chinese ones [13–15]. He deals with how Robison Crusoe changes its

image in China to gain its popularity in the Chinese textbook, contending that the Chinese edition aims more at how the Crusoe story should be understood primarily as a material for drawing traditional moral lessons.

If we classify the aforementioned three young scholars as the paradigm of literary studies, Luo Fukai examines the economic activities that Robinson Crusoe represents. According to Luo [16], Robinson Crusoe is an ideal economic model that signifies how an individual works in an uninhabited island. Thus, Luo uses "*Robinson Crusoe*" as a figure to discuss the accumulation of wealth through collaboration, factors of production, financial capital, and value. In this sense, Robinson Crusoe has nothing to do with literary studies but as an economic analysis tool.

3.3. Publication Source. The novel's publication source can be summarized in two ways: periodicals and publishing houses. As indicated in Table 2, Hunan Normal University tops the publications, reflecting that the university has outreached others in CSSCI papers in *Robinson Crusoe* research.

Table 2 shows the top 9 institutions based on publications. Hunan Normal University is the largest Robinson Crusoe provider with six papers listed on the CSSCI journals.

Table 3 is the top 10 cited articles based on CNKI. It displays that those three articles examined from economic perspectives are second to the other seven articles in literary studies.

Table 4 demonstrates four PhD dissertations related to Robinson Crusoe from Mainland China, Hongkong, and Taiwan. In terms of language, Ren Haiyan's dissertation is written in English, while Cui Wendong and Yang Zonghua in Chinese, and Zheng Li in French. Ren's and Yang's studies focus on the comparative literature of Robinson Crusoe. In comparison, Cui and Zheng concentrate on the translation of the novel.

Table 5 shows that 103 MA theses related to *Robinson Crusoe* in Mainland China are higher than that of Hongkong, Taiwan, and Macau until February 6, 2021.

Table 6 displays the data from Dangdang about *Robinson Crusoe*, up to February 18, 2021. It shows the Commercial Press provides two popular versions, especially the version from Wen Zhong with great impact on readers. Those bestselling books are important indicators of the increasing readership. What they share is that they are all rewriting for Chinese children at the age of 10 with a guided reading from renowned Chinese teachers. For example, Wen Zhong's and Liu Rongyue's editions make the book easier, for the target readers are Year 6 students in China. Predictably, the number of comments will continue to grow dramatically in the near future.

3.4. Co-Occurrence Keywords and Burst Keywords Analysis. Co-occurrence keywords in CiteSpace can be used for identifying research topics. The network is divided into 12 co-citation clusters, which are labelled by index terms from their own citers. The largest four clusters are summarized, with "Friday," "colonialism," "subjectivity," and "social ecology" as keywords.

Table 2: Top 9 institutions based on publications.

Rank	Institution	Publications
1	Hunan Normal University	6
2	Peking University	2
3	Wuhan University	2
4	Nankai University	2
5	Nanjing University	2
6	Shandong University	2
7	Huazhong University of Science and Technology	2
8	Hezhou University	2
9	Chinese Marine University	2

Table 7 demonstrates the largest four clusters. The first largest cluster (#0) has 32 members and a silhouette value of 0.879. The most active citer is Sun Tingting, whose article "A Study of the Relationship among Robinson, Friday and Island in Tournier's Fiction" was issued in the journal of *Foreign Literature* in 2010.

The second-largest cluster (#1) has 23 members and a silhouette value of 0.968. The most active citer to the cluster is Shen Fuying, who published her article "On the Metamorphosis of the Images of 'the Other' in British Novels" in *Foreign Literature* in 2015. Niu Hongying and Xue Fengyan are also labelled as the most active citers, who co-authored "Robinson Crusoe and the State of Nature Theories in the West" in the *Journal of Northeast Normal University* (Philosophy and Social Sciences) in 2010.

The third-largest cluster (#2) has 20 members and a silhouette value of 0.938. The most active citer to the cluster is Bai Chunsu, whose article "Destruction and Reconstruction: On the Changes of Philosophical Connotations in Desert Island Fictions," appeared in the *Journal of East China Normal University* (Humanities and Social Sciences) in 2015; and Ren Haiyan's article "Foe's Rewriting of the Robinson Crusoe Myth," was issued in *Foreign Literature* in 2009.

The fourth largest cluster (#3) has 18 members and a silhouette value of 0.986. The most active citer to the cluster is Luo Yalin, who published her article "The Complex Genealogy of the 'New Man' and the Shaping of Continuity: On Lu Yao's 'Reform' Writing," in *Literary and Artistic Theory and Criticism* in 2017.

By comparison, the burst of keywords in the CiteSpace are applied to make sure burst keywords. Chen Chaomei contends that the citation burst is not only an indicator of a most active area of the research, but also a detection of a burst event, which can last for many years as well as a single year [17]. In some sense, CiteSpace supports the citation bursts. From Figure 2, we can identify the keywords are "orientalism," "colonialism," "anthropocentrism," "rewrite," "Robinson," "Defoe," "modernity," "desire," and "colonial narrative." These keywords articulate how colonialism and ecocriticism influence each other, and modernity is one of the keywords of colonialism.

Table 3: The Top 10 cited articles.

Author	Title	Source	Year
Luo Fukai	Enterprise's essential factor capital research	*The Theory and Practice of Finance and Economics*	2009
Zhang Deming	Narrative, modern subject and empire politics: reinterpretation of the adventure of Robinson Crusoe	*Foreign Literature*	2007
Ren Haiyan	Foe's rewriting of the Robinson Crusoe myth	*Foreign Literature*	2009
Niu Hongying	Robinson Crusoe and utopian thought of the West	*Foreign Literature Studies*	2007
Liu Ge	Defoe and Swift's "Barbarians"	*Foreign Literature Review*	2007
Zhang Yong	Colonial canon and rewriting of the canon: an analysis of postcolonial rewriting of Robinson in J. M. Coetzee's Foe	*Foreign Literature*	2011
Zhao Yina	The epitome of colonization: a post-colonial reading of Robinson Crusoe	*Foreign Literature*	2004
Song Xiaochuan	A disequilibrium economic dynamic Model	*Economic Research Journal*	2003
Wang Wenhua	On the image of Robinson from the perspective of modernity	*Foreign Literature Studies*	2004
Liu Lian	The existence of "the others" and the trouble in Search for "root," reading of "Vendredi" and "Robinson Crusoe"	*Comparative Literature in China*	2003
Hui Haifeng, Shen Dan	Individualism, religion and marginalization of family a reinterpretation of Robinson Crusoe	*Foreign Language and Literature*	2011
Wang Jinchao, Fan Jinxue	Economic explanation of participants' decision-making behavior in repeated games	*Seeker*	2005

Table 4: Ph.D. Dissertations related to *Robinson Crusoe*.

Author	Institution	Title	Year	Supervisor
Ren Haiyan	Nanjing University	A modern myth and its revisions: a study of Robinson Crusoe, Friday and Foe	2009	Wang Shouren
Cui Wendong	The Chinese University of Hongkong	A study of translated biographies of heroes in late Qing Dynasty	2015	Chen Pingyuan
Yang Zonghua	Taiwan Normal University	An ecological Turn in the contemporary Robinsonade: Haushofer, Tournier, Ballard, Martel	2018	Chen Chunyan, Zeng Sixu
Zheng Li	Shanghai International Studies University	Traductions, adaptations et reecritures approches du traitement et de la diffusion de Robinson Crusoe en occident et dans le monde chinois	2018	Qian Peixin

Table 5: MA theses related to *Robinson Crusoe*.

Place	Number
Mainland China	103
Hongkong	2
Taiwan	7
Macau	0

A degree is an algorithm in the CiteSpace that is used to identify major keywords. Table 8 illustrates that the top-ranked item by degree is "Robinson," with degree of 41. Others are shown clearly on the table.

Table 9 identifies the centrality. Centrality metrics provide a computational method for finding pivotal points between different specialties or tipping points in an evolving network [18].

Table 10 suggests that the top-ranked item by citation counts is "Robinson," with citation counts of 26. Readers may easily discern that the second one is "*Robinson Crusoe*" with citation counts of 16, whereas the 9th is the same "*Robinson Crusoe*" with citation counts of 3. This phenomenon is caused by two different Chinese written characters with the same pronunciation "piao," in which the former one is visualized as "water," while the latter is visually connected with "the wind." It indicates that most translators prefer to the character with the meaning of "drifting or flowing in the water" because the Crusoe story happens at sea. "Foe" and "Defoe" are marked with the same citation counts of six, while "Tournier," "colonialism," "modernity," and "rewriting," are with the same citation counts of four. The 10th is "subjectivity," with citation counts of three.

4. Discussion

4.1. Popular Translations and Published Source. From the aforementioned statistics, we can safely infer that the popular translations of *Robinson Crusoe* can be attributed to three reasons. First, *Robinson Crusoe* is an exciting adventurous book that fits both the old and the young. To the Chinese mind, it has become one of the representative literary works of English literature. Second, the copyright of *Robinson Crusoe* has been due for many years. It is part of the novel's essential component for China's popularity. To make profits, publishers will do what they can to survey which version fits the market. Thus, Chinese publishers can make full use of the book's intellectual property. Third, the research shows that the top three versions target teenagers who are required to read the novel designated by the education administrators. The reception and translation of *Robinson Crusoe* are highly relevant to China's College Entrance Examination after the year 2000; hence, rewriting for the

Table 6: Bestseller of *Robinson Crusoe* in Dangdang.

Complier/translator	Publisher	Comments	Year
Wen Zhong	The Commercial Press	232,400	2012
Wang Jinhua	Zhejiang Gongshang University press	105,051	2017
Lu Jin	The Commercial Press	99,334	2017
Liu Rongyue	Jiangsu Literature and Art Publishing House	91,992	2017
Zuo Ruke	The Yilin Press	70,518	2010
Wen Zhong	The Commercial Press	51,271	2017

Table 7: Summary of the largest four clusters.

Cluster ID	Size	Silhouette	Average (year)	Keywords
#0	32	0.879	2010	Friday
#1	23	0.968	2014	Colonialism
#2	20	0.938	2012	Subjectivity
#3	18	0.986	2012	Social ecology

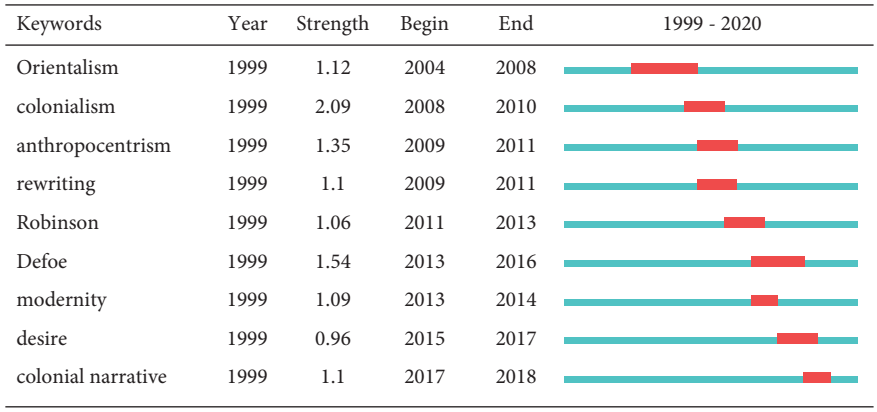


Figure 2: Top 9 keywords with the strongest citation bursts. Notes: the keywords with the most robust citation bursts (the bars mean some keywords cited).

Table 8: Top 10 keywords by degree.

degree	References
41	Robinson
35	Robinson Crusoe
16	Defoe
13	Foe
12	Subjectivity
11	Tournier
11	Modernity
11	Rewriting
9	Colonialism
9	Ecocriticism

Table 9: Top 10 keywords by the centrality.

Centrality	References
0.44	Robinson
0.32	Robinson Crusoe
0.10	Defoe
0.08	Foe
0.06	Modernity
0.06	Anthropocentrism
0.05	Subjectivity
0.05	Rewriting
0.04	Colonialism
0.04	Subject

young generation has been a driver for the increasing readership. The statistics indicate that *Robinson Crusoe* sells well when it is made available for the youngsters as Supplementary Material for textbooks, with the cooperation among translators, publishers, literary experts, and patrons. The protagonist Robinson is remoulded as an icon for self-reliance and confidence to overcome difficulties. This situation is coupled with labour which officially becomes the course for the primary and secondary school students required by the Ministry of Education of the People's Republic of China. This suggests that the educational function has been a primary factor for Chinese readers, which turns out to be an essential source of popularity. During this process, translators exercise their power over the original work to make the novel suit their target readers. In this respect, the popularity of *Robinson Crusoe* is the result of the joint efforts made by translators, publishers, advertisers, and patrons.

Table 10: Top 10 keywords by citation counts.

Citation counts	References
26	Robinson
16	Robinson Crusoe[1]
6	Foe
6	Defoe
4	Tournier
4	Colonialism
4	Modernity
4	Rewriting
3	Robinson crusoe[2]
3	Subjectivity

The most popular translation version is done by the Commercial Press due to its reputation, a time-honoured brand in China. Historically, the press published several versions of *Robinson Crusoe* during the Republic of China (1912–1948). As one of the top publishing houses, this can be evidenced by its everlasting impact on translation versions, particularly those translated by Xu Xiacun, Gao Xisheng, Li Lei, and Wang Wenhua. To some extent, the publication of *Robison Crusoe* in China reflects a short history of the Commercial Press. For example, Xu Xiacun's version of *Robinson Crusoe* was published by the Commercial Press in 1930. In the preface, Xu gave a detailed explanation of Defoe, stating that his translation was based on William Peterfield Trent's research. Unlike previous versions, Xu made it very clear in the preface that he spent a year translating this novel and tried to keep the style of the original work. He also pointed out that most translators were based on the excerpts instead of the full version of the novel. Their texts, to some extent, were paraphrased [19]. In 1959, Xu Xiacun's version of *Robison Crusoe* was reprinted by the People's Literature Press (PRC), partly because Xu's translation is faithful to the original work and has been considered one of the most successful versions. Now, 23 versions can be retrieved in Duxiu, one of which was published in the name of Fang Yuan rather than Xu Xiacun, though it was translated by Xu Xiacun himself. According to Xu, daughter of Mr. Xu Xiachun, her father was classed as the rightist against the revolutionary government. In order to avoid censorship and publish *Robinson Crusoe*, the publisher had to change Xu Xiacun's name into Fang Yuan, a penname selected by Xu Xiacun [20]. In these special days, to use a pseudonym is to prevent political persecution.

Table 11 shows the top 10 major journals and their impact factors. It articulates that *Foreign Literature Studies* ranks first in *Robinson Crusoe* with 11 articles and then *Foreign Literature* with 8. In other words, *Robinson Crusoe* in China is studied from the literary analysis, but literary periodicals have less influence than sociological periodicals and periodicals on humanities and social sciences run by universities.

4.2. Analysis and Characteristics of the Papers. The interpretation of *Robinson Crusoe* can be classified as five topics in China. The first is to interpret it from the perspective of comparative literature, especially comparing Robinson Crusoe with Foe and Friday, represented by Gu et al. They argue that Robinson Crusoe is a typical person of enlightenment and a rational economic man who signifies the earlier colonial conquer of the Great Britain [21–27]. *Foe* and *Friday* are important rewritings aiming at destructing the image of colonialism and puritanism, thus the universality, inevitability, and permanency of language colonization are clearly revealed [28].

The second is to interpret the novel from the perspective of Chinese translation, represented by Song Lihua, Cui Wendong, and Li Jin. They contend that the translation of *Robinson Crusoe* in China experienced the ethical dilemma between the Western value and the traditional Chinese value, especially the longstanding dominant Confucianism which gives priority to family members. Therefore, the Chinese translators in the Late Qing revised the original value to cater to the traditional piety value. For example, Lin Shu (1852–1924), one of the prominent translators of *Robinson Crusoe*, who applied traditional Chinese ethical codes to reinterpret his ideas, was criticized by vernacular literature advocates such as Qian Xuantong and Liu Bannong. In Cui's opinion, Lin Shu realized that Robinson was a pioneer of colonialism, inspiring Westerners to take risks to colonize and invade China, but it was a shame that 400 million Chinese could not resist [29]. While translating this novel, Lin wanted to use Robinson to criticize the idea of royalty represented by Confucianism.

The third is from the perspective of communication, which focuses on the Chinese image in Defoe's *The Farther Adventures of Robinson Crusoe*. Recent years have witnessed the tremendous growth of how the image of China is acculturated in other nations, which can be identified through the keywords "the image of China" in the National Social Science Fund Project (NSCFP) database, and then 40 funded projects from 2014 to 2019 were found. As one of the most important indicators for the academic promotion for Chinese scholars, particularly on Mainland China, NCSFP provides opportunities to find what other cultures think of the nation in literary works. In this sense, theories of orientalism and colonialism are much applied in literary analysis. As Zhang and Yang argue, the book is full of discrimination, prejudice, and arrogance against China. To their mind, the superiority of Eurocentrism makes Defoe despise China's spiritual and material wealth; his orientalist perspective makes him gaze at the East with his contemptuous eyes, constructs the image of China at will, thus coveting to dominate China; and the colonialist's vision drives him to seek theoretical grounds for colonizing China in spiritual and material terms [30].

The fourth is beyond the novel's literary studies. Robinson Crusoe becomes a figure for economic discussion. In this circumstance, Robinson Crusoe provides scholars with a perfect model to deal with how wealth accumulation happens. Luo Fukai contends that production factors in the modern economy include not only human resources, financial resources, material, and equipment resources, but also technology, information, and knowledge, which can be analyzed through Robinson Crusoe (3). Robinson Crusoe economy is of great value in the study of the history of

Table 11: Top 10 major journals and impact factor.

Rank	Publications	Journals	Impact factor (2020)
1	11	*Foreign Literature Studies*	0.576
2	8	*Foreign Literature*	0.498
3	3	*Foreign Literature Review*	0.527
4	3	*Seeker*	1.407
5	2	*Literary Review*	1.407
6	2	*Comparative Literature in China*	0.4
7	2	*Humanities & Social Sciences Journal of Hainan University*	0.851
8	2	*Journal of Henan University (Social Science)*	1.481
9	2	*Journal of Social Science of Hunan Normal University*	1.389
10	2	*Chinese Journal of Sociology*	4.484

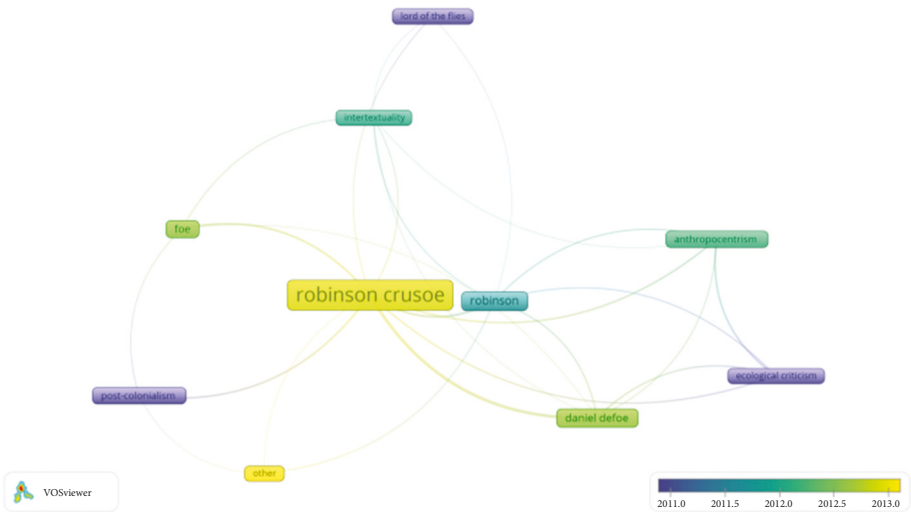


Figure 3: Evolution of the network of keywords based on co-occurrence.

economic thought, because it is closely related to the development of Western economics, especially in the evolution from political economy to economics, both illustrative and defensive.

The fifth is from the perspective of the philosophical interpretation of the novel. Wang and Ren contend that the foundation of the 18th British realistic literature is based on Locke's philosophy [31]. Through the construction of the self and the destruction of the authority, Crusoe disobeys his father and leaves home for the sea, which echoes Locke's idea of the patriarch and self-decision. Niu and Xue maintain that Defoe was much influenced by the state of nature theories advocated by well-known philosophers Thomas Hobbes (1588–1679) and Jean-Jacques Rousseau (1712–1778), but Defoe's depiction in his novel *Robinson Crusoe* makes both the author and the protagonist shift from a Hobbesian anti-utopia natural man to a Rousseau's utopia natural man. Defoe's contradictory ideas presented in his novel, to some extent, build an intellectual bridge from Hobbes to Rousseau, though Rousseau intentionally misread the novel [32]. Fan and Wei take Robinson Crusoe as an example to describe the individualist MaGinn and collectivist Bloor's view of whether an isolated Robinson can follow the rules based on Wittgenstein's theory of the rule of following [33].

Based on the distribution of the periodicals, the statistics show that the research of the novel mainly focuses on literary studies (66), translation studies (5), philosophical studies (7), and economic studies (8). Most of these periodicals are from the literary circle. They interpret the novel from the perspectives of modernity, colonialism, orientalism, post-colonialism, ecocriticism, and anthropocentrism. The translation studies focus on the rewriting of earlier Chinese translation versions. In comparison, the philosophical studies and economic studies concentrate on how Robinson Crusoe becomes a right or suitable person for philosophical and economic discussions.

4.3. Analysis of Keywords. For the keywords of *Robinson Crusoe*, different algorithms result in different answers. Whether from sigma or degree or centrality, all of them share such keywords as "modernity," "Foe," "rewriting," and "colonialism," indicating that the novel is often interpreted from the perspective of literature.

Figure 3 reveals the evolution of each keyword cluster according to 103 MA theses. The graphic makes a clear map of the important keywords over time that they appear. The colour indicates the terms they have arisen from the papers. It shows that all these terms arose before 2013, in which they form three clusters. Cluster 1 includes "Foe," "Other," "postcolonialism," and "Robinson Crusoe;" Cluster 2 has "anthropocentrism," "Daniel Defoe;" and Cluster 3 "intertextuality," "Lord of the

Flies," and "Robinson." From the co-occurrence of these keywords, we can discern that the comparative studies of the novel are the mainstream of MA theses in China. It is observed that those theses share the same keywords with periodicals listed within CSSCI journals. As a matter of fact, some periodical papers are based on MA theses, which are showcased by Cui Wendong with two MA degrees in English whose work is related to *Robinson Crusoe*.

5. Conclusions

This article offers a visual and systematic bibliometric review of how the study of *Robinson Crusoe* in China is progressed in academia. There are four doctoral dissertations and 112 MA theses gathered from Mainland China, Hongkong, Macao, and Taiwan. The research analyzed 88 CSSCI papers on *Robinson Crusoe* from CNKI during the period 1999 to 2021. The number of publications in *Robison Crusoe* has dramatically increased since 2009. According to the statistics, scholars in China research *Robinson Crusoe* mainly from the perspectives of colonialism, Orientalism, and ecocriticism.

Compared with other novel rewritings, including *Foe* and *Friday*, the early Chinese translation of *Robinson Crusoe* has attracted some researchers who specialize in Chinese literature. They tend to analyze the novel with the then literary norms and prefer to rewrite the original story to make the translation suitable for the traditional codes of Confucianism. This situation was much improved with the coming of Xu Xiacun's version published by the Commercial Press in 1930, marking a classical translation due to its loyalty to the original works. The statistics indicate that among a variety of *Robinson Crusoe* versions, the Chinese title with homophones related to the hero's "drifting" story is the most popular translation versions. It is recorded that since the year 2000, at least 15 versions are published each year with the title name related to Robinson's "drifting" story. On the other hand, its popularity is highly relevant to the children's extracurricular readings in the compulsory education period, which requires *Robinson Crusoe* to be an essential book for educational purposes. In this connection, publishers introduce educators, translators, and editors to work together to make *Robison Crusoe* a booming industry. Among the bestsellers of *Robinson Crusoe* in Dangdang, the top 3 versions are all designated for kids with more than 100,000 comments. The biggest supplier is the Commercial Press with two versions, in which Wen Zhong's edition reached 228,303 comments by January 26, 2021. This popularity demonstrates the increasing readership of children during the 9-year compulsory education. By analyzing 103 MA theses, the study states that "Foe," "Other," "postcolonialism," "Robinson Crusoe," "anthropocentrism," "Daniel Defoe," "intertextuality," "Lord of the Flies," and "Robinson" are co-occurrence keywords. In terms of active authors, Ren Haiyan from Hunan Normal University and Cui Wendong from the City University of Hong Kong are the top two providers, both of whom are based on their previous studies to pursue their master's and doctoral degrees.

Of course, this study has its own limitations, which can be served for further research. One of the limitations is that the master's and doctoral theses cannot be updated timely. On one hand, it is hard for one to find research articles related to *Robinson Crusoe* before 1999. Some translation versions of the book in the Late Qing Dynasty and the Republic of China are difficult to be identified. On the other hand, some articles are not listed in the CSSCI journals, which may make some papers omitted in this analysis.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] D. Defoe, *The Life and Strange Surprising Adventures of Robinson Crusoe*, William Taylor, New Mexico, USA, 1719.

[2] M. Drabble, *The Oxford Companion to English Literature*, Oxford University Press, Oxford, UK, 6th ed edition, 2000.

[3] I. Watt, "*Robinson Crusoe* as a myth," *Essays in Criticism*, vol. I, no. 2, pp. 95–119, 1951.

[4] B. T. Lupack, *Nineteenth-Century Women at the Movies: Adapting Classic Women's Fiction to Film*, T. L. Barbara, Ed., Bowling Green State University Popular Press, New York, NY, USA, 1999.

[5] R. Mayer, "Robinson Crusoe in the Screen Age," in *The Cambridge Companion To Robinson Crusoe*, R. John, Ed., Cambridge University Press, Cambridge, USA, pp. 221–233, 2018.

[6] L. H. Song, "A study of the early Cantonese translation of *Robinson Crusoe*," *The Literary Review*, vol. 4, pp. 64–72, 2012.

[7] D. D. Yao, "*Robinson Crusoe* in late-Qing translation: protestant ethic and obsession with China," *Research of Chinese Literature*, vol. 1, pp. 19–23, 2012.

[8] H. Ni, "Xi jinping revisits Britain after 21 years," 2015, http://m.news.cntv.cn/2015/10/22/ARTI1445471903804576.shtml.

[9] M. F. Deng, "Hunan released reading big data," Xinhua Net, 2018, http://m.xinhuanet.com/hn/2018-04/23/c_1122724921.htm.

[10] H. F. Hui, "Appropriating *Robinson Crusoe* in Chinese primary school after-class compulsory reading: applauding a kind-hearted Crusoe," *History of Education & Children's Literature*, vol. 9, no. 1, pp. 693–708, 2014.

[11] H. F. Hui, "Curricular requirements, critical traditions, and adaptation in the paratext of Chinese and American school editions of Robinson Crusoe," *CLCWeb: Comparative Literature and Culture*, vol. 19, no. 3, pp. 1–9, 2017.

[12] H. F. Hui, "Appropriating Robinson Crusoe to be a good boy: literary adaptation in *the New Robinson Crusoe* at the end of the 18th century," *History of Education & Children's Literature*, vol. 13, no. 1, pp. 445–459, 2018.

[13] H. F. Hui and D. Shen, "Individualism, religion and marginalization of family: a reinterpretation of *Robinson Crusoe*," *Foreign Languages*, vol. 27, no. 4, pp. 14–19, 2011.

[14] H. F. Hui, "Adaption of the children's edition of *Robinson Crusoe*: Robinson Crusoe of each era," *Foreign Literature Review*, vol. 3, pp. 229–239, 2012.
[15] H. F. Hui, "Society, Novel and the cover: historical changes of children's editions of *Robinson Crusoe*," *Foreign Literatures*, vol. 5, pp. 58–67+158, 2013.
[16] F. K. Luo, "Enterprise's essential factor capital research," *The Theory and Practice of Finance and Economics*, vol. 30, no. 1, pp. 3–8, 2009.
[17] C. C. Chen, "The CiteSpace manual (version 1.01)," vol. 19, 2014, http://cluster.ischool.drexel.edu/%7Ecchen/citespace/CiteSpaceManual.pdf CiteSpace Mannual.
[18] C. C. Chen, "CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature," *Journal of the American Society for Information Science and Technology*, vol. 57, no. 3, pp. 359–377, 2006.
[19] D. Defoe, *Robinson Crusoe*, China Intercontinental Press, Beijing, China, 1930.
[20] X. Y. Xu, "Xu Xiacun in his daughter's eye," *Historical Materials of New Literature*, vol. 4, pp. 153–190, 1994.
[21] H. L. Gu and X. S. Zheng, "Spatial representation of power — spatial image and power game in Coetzee's *Foe*," *Foreign Language Research*, vol. 36, no. 4, pp. 92–96, 2019.
[22] F. Yue and J. P. Kong, "Space-time reconstruction of classical colonial narrative — reading notes of *Robinson Crusoe* and *Foe*," *Chinese Comparative Literature*, vol. 1, pp. 185–196, 2018.
[23] Y. J. Zhang, "Reading Elizabeth Bishop's Brazil-related travel poems in the light of colonialism, post-colonialism and internal colonialism," *Foreign Language and Literature*, vol. 4, pp. 27–35, 2017.
[24] Y. N. Zhao, "The epitome of colonization: reading *Robinson Crusoe* from the post-colonial perspective," *Foreign Literatures*, vol. 3, pp. 73–78, 2004.
[25] H. Huang, "Foe: a reconstruction of imperial literary canon," *Foreign Literature Studies*, vol. 32, no. 3, pp. 155–160, 2010.
[26] H. Y. Ren, "Foe's rewriting of the Robinson Crusoe myth," *Foreign Literatures*, vol. 3, pp. 81–88+127, 2009.
[27] H. Y. Ren and C. Robinson, "A myth of the enlightenment revisited," *Foreign Literatures*, vol. 5, pp. 74–81+158, 2012.
[28] C. Y. Wang, "On the language strategy of Foe," *Foreign Literature Studies*, vol. 5, p. 160, 2008.
[29] W. D. Cui, "Translating national character: taking the late Qing Chinese translations of *Robinson Crusoe* for an example," *Chinese Translators Journal*, vol. 31, no. 5, p. 23, 2010.
[30] X. H. Zhang and Q. Yang, "On orientalism in *the farther Adventures of Robinson Crusoe* and *serious Reflections of Robinson Crusoe*," *See*, vol. 1, p. 198, 2008.
[31] A. J. Wang and X. J. Ren, "Construction of the self: Locke's philosophy and Robinson Crusoe," *Foreign Literature Studies*, vol. 34, no. 5, p. 57, 2012.
[32] H. Y. Niu and F. Y. Xue, "Robinson Crusoe and the state of nature theories in the west," *Journal of Northeast Normal University*, vol. 2, pp. 118–121, 2010.
[33] Y. H. Fan and Y. D. Wei, "Can Robinson Crusoe follow rules? The dispute of settlement between individualist and collectivist," *Journal of Dialectics of Nature*, vol. 33, no. 2, p. 66, 2011.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9730564, 13 pages
https://doi.org/10.1155/2022/9730564

Research Article

Utilization of Rural Resource Assets: Time-Space Estimate on the Total Factor Productivity

Lan Wang and Cong Li

School of Economics and Finance of Xi'an Jiaotong University, Shaanxi, Xi'an 710000, China

Correspondence should be addressed to Lan Wang; elaine8023@stu.xjtu.edu.cn

Received 20 April 2022; Revised 30 June 2022; Accepted 4 July 2022; Published 4 August 2022

Academic Editor: Lele Qin

The utilization efficiency of China's rural collective resource assets has always been at a low level, and excessive energy consumption and input have become the main limiting factor, which seriously affects the overall improvement of agricultural modernization and rural people's livelihood. In this paper, time measure and space measurement are adopted alternatively, and spatiotemporal vertical-horizontal progressive deduction is built with the improved model, so as to set up a perfect spatiotemporal dynamic effect evaluation system: First of all, improve the U-HDM-GML index model, study on the improvement strategy for input redundancy and unexpected output redundancy in the utilization efficiency of rural collective resources assets in various provinces of China, as well as the equilibrium rupture relation between the two from the perspective of global space and time, and at the same time of fulfilment of time measurement and estimation, provide support for better expressing the spatial effect in terms of improving approach and strategy; secondly, measure the improvement strategy of the total factor productivity of research samples with the spatial expletory ESDA test method, and it is also applicable to global spatial effect evaluation system; finally, apply FE-SDM to further analyze the difference of spatial effect of total factor productivity in rural resource asset utilization. Through analysis of the significant difference characteristics of the research samples with different geographical and spatial characteristics, the strategy deficiency in terms of difference discrimination is made up. *Conclusions*. This paper carries out the time and spatial effect measurement of total factor productivity for the performance of pilot strategies in various provinces of China in the last ten years and puts forward a more beneficial improved strategy and mechanism, preferentially selected according to the direction indicated by good research indicators, gets the redevelopment strategy for improving the utilization efficiency of areas at a low level of resources utilization currently, and indicates the direction for tapping the full potential of existing rural resources according to the practical conditions at local places, in the hope of establishing the trans-provincial cooperation supply and demand system based on the new rural collective economic organizations (cooperatives) after the reform experimentation and optimizing the spatial spillovers of rural resources assets, so as to make a breakthrough in the barrier due to growth of technical efficiency.

1. Introduction

Since the 19th China national Congress of the CPC, the development of China's rural collective economy has created a new historic achievement for the all-round construction of a modern socialist country. As the prosperous rural industries are rooted in the promotion of collective resource utilization efficiency, the vital basis for the development of rural collective economy in the next century lies in the innovation in the ways of rural collective resources utilization, the establishment of cross-provincial rural resources benefit coupling, the exploration into the coordination between resource ecology and resource-based economy, and green sharing and balance-broken relation (boundary-limiting relationship between balance and imbalance). Especially China's rural collective resources assets have gone through extensive development for a very long time, which has caused the problems of insufficient vitality of production factors, short chain of cross-provincial resource utilization, multiple financial dilemmas of agriculture, rural

areas, and rural residents [1]. Therefore, how to effectively utilize the characteristics of rural spatial patterns and improve the utilization efficiency, quality, and economic results in the society of rural collective resources by improving the influencing factors of spatial effect is extremely urgent.

Utilization efficiency of resource assets is an important indicator to measure the improvement of total factor productivity (hereinafter TFP) under the interaction of multiple systems, such as rural collective asset ownership confirmation, resource utilization management, and ecological civilization construction. It comprehensively reflects the transfer and transformation of matter energy and the acting forces between internal elements of urban and rural economies and between internal elements and the external environment [2].

There are many gaps in the existing studies literature. Such as, the studies focus on the multiple dimensions of the effectiveness of land reform, resources utilization, and bioenvironment balance. However, there is a lack of innovation in the selection of research samples, with the average data of cities being chosen as most of the research samples, while it was impossible for the original administrative regions to reform rapidly to achieve the research objectives. For example, the studies conducted the quantitative evaluation of the security of rural collective land use from the perspectives of five asset types for households' livelihood [3], of which the results lack universal practical significance because such analysis has a requirement for the research sample, requiring the research sample to have typical research characteristics. The studies analyzed the shortcomings of the profit-making strategy of resource management of independent members exit from the collective at the structural level of the secondary market of rural collective land from the perspective of land management [4, 5], but they neglected that there lacks a clear legal relationship protection mechanism between the rural collective organizations and members, the long-term livelihood guarantee for peasants with high mobility as provided by a dynamic management and income distribution, and a perfect design for people at the bottom of the society.

Given our objectives, we draw on the existing studies and summarize the gaps in existing literature, and then present innovations as follows: Firstly, study the innovation of the samples selected. Take the China National Development New Area in provinces that have successfully completed the integrated use of urban and rural land and have the obvious advantage of the joint office system of various functional institutions as examples to study on the rapid urbanization; secondly, combined with the resource endowment and spatial differences of geographical information of each province, provide data support for effectively realizing the development and interindustry aggregation on supply chain of idle resource assets in rural areas, so as to improve the current situation of rural population migration; Thirdly, enhance the promotion of the construction of interprovincial Internet of Things platform for rural collective to provide services for the secondary and tertiary industries, and further improve the current situation of hollow villages, providing the policy basis and theoretical data support for improving the level of economical and intensive utilization of urban and rural resources in China.

2. Literature Review

Drawing on a comprehensive review of prior literature on empirical model analysis, for example, the Naive Bayes-based distance classification approach is applied to the Online HDM in the existing literature [6], which is stable, contributes through combining known algorithms, and offers satisfactory accuracy while carrying out the classification tasks including distance, effective in terms of time and memory complexity. In the literature, a distance measurement approach based on HDM combined with a dimension reduction is proposed [7], which follows a similar deformation and allows a clustering into local structures over time. This study focuses on breaking the general constraints of traditional DEA models limited by radial and nonradial distance function models.

Although the characteristics and differences of urban construction land use efficiency within each province were measured based on DDF-GML improved index model, the improved scheme was based on the assumption of constantly expanding desirable output and constantly decreasing undesirable output [8]. As a result, the changes in land use efficiency in high efficiency areas and extensive areas are very similar, which shows the limitations of the method requiring specific control assumptions, so we must consider the efficiency reform and improvement scheme under the condition of undesirable output in this study.

In the paper, a model that is adaptable to the special features of unconventional output is defined [9]. To seek robustness, the author used an enhanced version of the Malmquist-Luenberger productivity index to overcome some of the drawbacks suffered from the original approach. Due to the technical regression experienced during my study, this regression method was cited here for improving the limitations of the single Malmquist index model, exploring the ways and strategies to improve the utilization efficiency of rural collective resources assets in each province of China, and discussing whether the spatial effect can be better expressed.

[10, 11] are intended to provide an overview of the developments that have taken place in the field of ESDA, with emphasis on tools that are now available for spatial data exploration [10, 11]. The former's point is an introduction to ESDA (including the temporal dimension as ESTDA), presents the web-based tools that are currently available for the early developments in ESDA/ESTDA, and reflects on the future. The latter's point aims to study urban planners and require an understanding of the composition as well as the spatial distribution and the spatial dependency to design policies for various wards of a city. His result owns to the statistics used (i.e., global Moran index), which is an average statistic that captures the overall spatial autocorrelation of the data and does not capture variability on a local scale.

[12] used the superundesirable-SBM to thoroughly measure and evaluate the dynamic characteristics of environmental space of TFP and improvement conditions of

environmental regulation under the comprehensive consideration of undesirable output [12]. However, there is a lack of the equilibrium rupture relation evaluation for slack variables' redundancy rates of input and undesirable output, respectively, under the premise of maximizing the desirable output, so it is impossible for the research to obtain the optimal evaluation of the strategy.

Based on the research results of existing literature, possible innovations in this study include the adoption of improved models. Comprehensively use the advantages of U-HDM with a global time-space perspective and Malmquist index model with global technology to complete the measurement in the dimension of time and then use FE-SDM to complete the evaluation system of spatial dynamic effect, thus better evaluating the performance at different stages of resource assets regulation reform strategy in China in the past decade, so as to provide a strategic basis for the next stage of revitalizing the management strategy of provincial rural collective resource assets, constructing the dynamic management system of time-space effects, and improving the average technical efficiency per capita and per land area.

3. Conditional Hypothesis and Improved Models Development

3.1. Measurement Method of Improved U-HDM. The Hybrid Distance model is selected in this study, which integrates the advantages of the radial BCC model and nonradial SBM distance function models together, and effectively avoids the problem of losing the original proportion information of factors in the efficiency frontier in traditional performance model studies [13]. It improved the single evaluation target of economic benefits in the past and assumed the ideal state of taking the improvement strategy of purely relying on the infinite decrease in input and increase in desirable output. During socioeconomic development, the destruction of resource assets is nonrevertible. Therefore, the researches based on the improved equilibrium rupture relation of undesirable output redundancy and input redundancy have practical significance. Therefore, the U-HDM with undesirable hybrid distance function including slack variables was adopted, and the objective function and constraint conditions are designed as follows:

$$\begin{aligned}
&\mathrm{Min}\rho = \frac{\theta - \varepsilon 1/\sum_{i=1}^{m} w_i^- \sum_{i=1}^{m} w_i^- s_i^- / x_o}{\varphi + \varepsilon 1/\sum_{r=1}^{s} w_r^+ \sum_{r=1}^{s} w_r^+ s_r^+ / y_o},\\
&\text{subject to } \sum_{\substack{j=1\\ j\neq o}}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{io}, \quad i = 1,\ldots,m,\\
&\sum_{\substack{j=1\\ j\neq o}}^{n} y_{rj}^g \lambda_j - s_r^{g+} = \varphi y_{ro}^g, \quad r = 1,\ldots,s,\\
&\sum_{\substack{j=1\\ j\neq o}}^{n} y_{rj}^b \lambda_j + s_r^{b-} = \varphi y_{ro}^b, \; r = 1,\ldots,s, \lambda_j, s_i^-, s_r^{g+}, s_r^{b-} \geq 0,
\end{aligned} \tag{1}$$

where ρ is the evaluation index of resources assets efficiency, x_o is the input vector, yg/o and yb/o are, respectively, desirable output vector and undesirable output vector. The slack variables $s_i^-, s_r^{g+}, s_r^{b-}$ represent input redundancy, desirable output redundancy, and undesirable output redundancy. DUM weight in each designed area is set as λ, and $\varepsilon \in [0,1]$ is the key parameter.

3.2. Calculation of TFP Change Index Based on Global Technology. Based on the research results of U-HDM of the previous stage, Global Malmquist Luenberger (GML) index was used for the measuring and calculating method of TFP change of global technology, which solved the problem of no solution to nontransitivity and no feasible solution to linear programming in the circularly cumulative data statistics. The direction vector was set as $g = (-g_x, g_y)$, where g_y includes desirable output and undesirable output. Import in the hybrid direction distance function to get $\overrightarrow{D}(x, y; g_y) = \sup\{\beta\colon (y + \beta g_y) \in P(x)\}$, so the expression of U HDM-GML (2) is as follows:

$$GML_{HDM} = \frac{1 + D^G\left(x^t, y^t; y^t\right)}{1 + D^G\left(x^{t+1}, y^{t+1}; y^{t+1}\right)}. \tag{2}$$

According to its influencing factors, the HDM-GML index can be decomposed into two indexes: EFFCH and TECH, which can measure the differential treatment for technical progress and technical efficiency in TFP change, where the technical progress is used to measure the moving characteristics of efficiency frontier during two periods, and technical efficiency change is used to measure whether the land utilization efficiency in sampling areas is more approximate to the efficiency frontier [14].

The specific decomposition is shown as follows:

$$\begin{aligned} GML_{HDM} &= \left(\frac{1 + D^t\left(x^t, y^t; y^t\right)}{1 + D_v^{t+1}\left(x^{t+1}, y^{t+1}; y^{t+1}\right)} \times \frac{1 + D_C^G\left(x^t, y^t; y^t\right)/1 + D_v^G\left(x^t, y^t; y^t\right)}{1 + D_C^G\left(x^{t+1}, y^{t+1}; y^{t+1}\right)/1 + D_v^G\left(x^{t+1}, y^{t+1}; y^{t+1}\right)} \right) \\ &\quad \times \frac{1 + D_v^G\left(x^t, y^t; y^t\right)/1 + D_v^t\left(x^t, y^t; y^t\right)}{1 + D_v^G\left(x^{t+1}, y^{t+1}; y^{t+1}\right)/1 + D_v^{t+1}\left(x^{t+1}, y^{t+1}; y^{t+1}\right)} \\ &= \text{EFFCH} \times \text{TECH}. \end{aligned} \tag{3}$$

3.3. Exploratory ESDA Test Method. According to the results of time measurement, select the global Moran index in ESDA so as to further identify whether the spatial measurement was more suitable to be applied for the research samples and be used to measure the autocorrelation and aggregated effect of the improved strategy of TFP in global spatial analysis.

The global Moran index is calculated as follows:

$$I = \frac{\sum_{i=1}^{n} \sum_{j \neq 1}^{n} \omega ij \left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} \omega ij}. \tag{4}$$

According to the design, n is the total number of areas researched; ω_{ij} is the spatial weight matrix, x_i and x_j are, respectively, the total factor productivities of area i and area j, where $\overline{x} = 1/n \sum_{i=1}^{n} x_i$, $s^2 = 1/n \sum_i (x_i - \overline{x})^2$; first Rook contiguity is adopted for calculation, and the value range of the index is set as [−1, 1], and the absolute values could explain the strong or weak relationship of spatial correlation [10].

3.4. Fixed Effects-Spatial Durbin Model. Rural collective resource assets at different geographic locations in China boast prominent differences. The improved models combine FE-SDM with fixed effect, which could be helpful to make up for the shortcomings of spatial calculation and measurement method in terms of spatial measurement and differentiation discrimination, and thus better solve the problem of improving the TFP of rural resource assets in terms of spatial effect.

First Rook contiguity matrix method is used for model calculation. According to the design, ω_{ij} is the spatial weight matrix; the explained variable GML_{it} represents the logarithm of total productivity efficiency of the province i during the period of the explained variables, respectively: economic development level (GDP_{it}), the level of the secondary industrial structure (IND_{it}), the level of border economic cooperation ($BECit$), urbanization level (URB_{it}), and financing level ($FINit$). The FE-SDM is expressed as follows:

$$\begin{aligned} \ln GML_{it} &= \beta_0 + \rho \sum_{j=1}^{n} \omega_{ij} \ln GML_{it} + \alpha \ln GDP_{it} + \beta \ln IND_{it} + \\ &\quad \psi \ln BEC_{it} + \tau \ln URB_{it} + \varphi \ln FIN_{it} + \alpha' \sum_{j=1}^{n} \omega_{ij} \ln GDP_{it} + \beta' \sum_{j=1}^{n} \omega_{ij} \ln IND_{it} + \psi' \sum_{j=1}^{n} \omega_{ij} \ln BEC_{it} + \\ &\quad \tau' \sum_{j=1}^{n} \omega_{ij} \ln URB_{it} + \varphi' \sum_{j=1}^{n} \omega_{ij} \ln FIN_{it} + \mu_i + \varepsilon_{it}. \end{aligned} \tag{5}$$

4. Research Methodology

This study is to improve the conceptual framework of sampling and develop the measures. We began the scale development process by investigating the relevant existing literature as far as possible for validated scales that could be used in this study. Although we did not find the complete direct sample scales that were suitable for this study, we were able to identify several time or spatial measurement models and scale fragments to find an excellent selection of sample indicators since insufficient coverage of the technical barriers was deemed an issue. Based on the research objectives, the data and indicators in this study were selected in two stages: The first stage of the study is that the majority of the governance system transformation was adopted from the rural collective

resource assets management project but modified slightly for the time measure models context. The second stage of the study is that the majority of the global spatial autocorrelation was adopted from the China National Economic and Technological Development New Area. Some new indicators were self-developed based on the definitions provided by making innovations for the spatial measure models in context.

4.1. Sampling Administration of Time Measurement Models. The first stage: time measurement and analysis, the data of 30 provincial areas of China (except Tibet) from 2009 to 2019 were selected, mainly from the China Statistical Yearbook, the annual statistics of each province, city and county, and each department, China Energy Statistical Yearbook, China Rural Statistical Yearbook, and China Agricultural Statistics Yearbook. Selection of input indicators: The capital stock of collective economic organizations, the number of available workers in rural areas except for the primary industry, energy consumption, and the capital, labor, and energy input used as rural collective resource assets, and the capital stock is estimated by the perpetual inventory method [15]. Selection of desirable output indicators: Rural GDP, the added value of the rural secondary industry, the proportion of newly developed land area and newly cultivated land area; selection of undesirable output indicators: Negative externalities measured by urban and rural sewage discharge. Go into the input and undesirable output redundancy in resource utilization of each provincial areas, analyze the true characteristics of the tendencies and changes, and explore whether it is more effective to use space to improve the analysis path.

4.2. Measurement Indicators Development of Spatial Measure Models. The second stage: spatial measurement and analysis. Based on the research results from the first stage, derived from building spatial measurement and analysis for strategy system evaluation by performance. According to the structure and layout of the leading industry, land use structure and ecological endowment, and future potential factors in rural areas of China, it can position the successful research samples for the accelerated urbanization process more accurately [16]. In the spatial benefit model, the China national economic and technological Development New Area in each province were selected as the research samples. The indicators of social and economic levels, secondary industry structure adjustment level, border economic cooperation level, urbanization level, and financing level were selected to decompose the influencing factors of TFP. The logarithm of per capita GDP, the proportion of the added value of the secondary industry in GDP, trade of agricultural and forestry products and the total amount of border tourism, urbanization rate, and increase of loans guaranteed by financing for agriculture, rural areas, and farmers were used in measuring, respectively. Data are from China Rural Statistical Yearbook, China Land and Resources Statistical Yearbook, the Report on Development of State-level Economic and Technological Development New Area, Notification on the Evaluation about Intensive Land Use of State-level Economic and Technological Development New Area, The Third national Agricultural Census of China, and so on. The spillover effect of TFP was analyzed by spatial measurement method in order to provide data support and strategy reference for China's rural revitalization strategy research.

5. Data Analysis and Results

5.1. Slack Variables Analysis with U-HDM. As the completion year of China's resource assets management project and the year of rural collective economic governance system transformation, 2016 plays a historic role in comprehensively initiating the task of deepening supply-side reform for the 13th Five-Year Plan. This study takes the data of 2016 as a typical example and uses U-HDM to measure the slack variables of provincial input index and undesirable output index under the assumption of constant returns to scale. Take the redundancy rate of each province when it realizes validity for measurement, the input redundancy rate when output remains unchanged represents that invalid provinces become valid, and how much the proportion of investment that can be decreased should be. The undesirable output's redundancy rate when input remains unchanged represents how much the proportional share that can be reduced from the current level under the premise of ensuring validity may possibly be, as shown in Table 1.

From the analysis of each area, the utilization efficiency of China's rural collective resource assets is still at a medium and low level, and the undesirable output of sewage discharge has reduced the resource utilization efficiency by more than 20%. In terms of the geographical spatial location of each area and each province, the utilization efficiency gradually decreases from the eastern provinces to the western provinces. In the process of adjusting and optimizing the distribution of resource structure and improving the comprehensive carrying capacity of the land, the redundancy rate of energy consumption throughout China exceeds 25%, and the redundancy rate of sewage discharge exceeds 34%. However, as seen from the differences of each province classified by region, there are still 4 provinces in eastern China—Hebei, Fujian, Guangxi, and Hainan—with a redundancy rate higher than the national average. Because of the particularity of geographical distribution and industrial distribution, the redundancy rate in northeast China is the most unbalanced. The stock redundancy of collective economic organizations in Henan Province in central China, which obviously lags behind other provinces in implementing the reform strategy of the rural collective property rights system, is more than twice the local and national average level. Qinghai Province in western China has the highest redundancy rate among other provinces in China, especially in energy waste.

Eastern regions are economically developed on the whole and are more mature with respect to resources assets utilization, especially the utilization of land resources. There

Table 1: Input and undesired output redundancy rates of rural collective resource assets in China in 2016.

Area		Input redundancy			Undesirable output redundancy
		Collective economic organization capital stock (%)	Employable persons in rural areas except primary industry (%)	Energy consumption (%)	Sewage discharge (%)
East	Beijing	0.00	0.00	0.00	0.00
	Tianjin	4.73	9.73	17.14	22.32
	Hebei	19.51	35.78	46.49	50.06
	Shanghai	0.00	0.00	0.00	0.00
	Jiangsu	6.50	12.34	2.42	17.69
	Zhejiang	5.62	31.38	2.60	9.94
	Fujian	15.75	30.22	5.68	16.38
	Shandong	9.82	11.07	19.97	53.33
	Guangdong	0.00	0.00	0.00	0.00
	Guangxi	19.23	19.23	19.23	31.79
	Hainan	20.32	38.34	19.29	50.89
	East area	9.23	17.10	12.07	22.95
North east	Inner Mongolia	45.32	1.36	58.74	76.09
	Liaoning	0.36	0.42	11.76	31.24
	Jilin	29.85	7.25	22.54	62.70
	Heilongjiang	1.37	1.74	23.31	46.21
	North east area	19.23	2.69	29.09	54.06
Central	Shanxi	14.03	14.03	64.23	83.21
	Anhui	0.00	39.89	13.16	39.79
	Jiangxi	0.00	4.73	2.60	17.69
	Henan	32.60	49.58	21.69	36.09
	Hubei	9.73	9.73	21.14	24.72
	Hunan	14.03	39.59	23.33	19.90
	Central area	11.73	26.26	24.36	36.90
West	Chongqing	7.21	22.55	24.72	7.21
	Sichuan	0.23	30.16	33.59	4.23
	Guizhou	14.17	14.17	44.98	60.07
	Yunnan	29.48	29.48	35.88	33.88
	Shaanxi	27.03	8.93	32.32	63.31
	Gansu	2.83	13.69	47.86	58.79
	Qinghai	56.91	36.57	68.33	41.28
	Ningxia	6.50	13.49	20.86	28.79
	Xinjiang	9.28	0.00	49.68	56.00
	West area	17.07	18.78	39.80	39.28
National		13.41	17.52	25.12	34.65

are significant effects of the general checkup on the collective fixed assets in rural areas and relatively reasonable layout of industrial structure. In particular, Beijing, Shanghai, Guangdong, Tianjin, and Jiangsu have effectively reduced energy consumption and improved the sewage treatment effect when they steadily pushed forward the process of integration in urban and rural areas; however, in Shandong, Hebei, Hainan, and Guangxi, energies are utilized extensively, and at the same time, the policies, measures, and hardware support for pollution control lag far behind the process of industrial structure layout. Northeast China shows the characteristics of uneven industrial structure, the dominance of heavy industry in the early stage, good resource endowment, and a complex natural environment. The rural collective economic organization has a certain foundation, but it still needs to introduce advanced technology in energy consumption reduction and wastewater and biomass treatment to explore a path of substantial improvement. The utilization rate of input factors in the central region is on the rise, but there is too much personnel redundancy, so it is encouraged to transfer the labor force to the central and western regions.

In western regions, the rural collective economy is backward. Generally, there are more mountainous and deserts which cannot be developed, the villages are dispersed, not concentrated and, more importantly, in the core areas of ecological restoration, there are backward supporting infrastructures, insufficient innovation mechanism, less emerging industries and technology industry layout, prevailing labor-intensive industries, and serious hollow village phenomenon, the labor forces go out for work for more than 6 months in a year, property rights system reform

is not implemented effectively and has poor performance, energy utilization is extensive, as manifested by the high input, high consumption, high emission and low output. In recent years, with the policy support of the state, western regions have increased the investment in large-scale fixed assets; however, the effective layout of industrial structure and the policies on technology and talent introduction are still lacking, and the conversion rate of investment assets is not high. It should accelerate to improve the rural collective organization system, stabilize the membership of economic organizations, better the general checkup on the fixed assets, rationally plan the development paths, and strengthen land consolidation and intensive use.

5.2. Evolution Tendency and Characteristic Analysis. Based on the longitudinal evolution trend analysis on the time scale, the TFP of rural resources asset utilization in 30 provinces of China from 2009 to 2019 was decomposed. Taking 1 as the critical point, the TFP of resource utilization and its decomposition value were divided into three types: Increase (index >1), stagnation (index = 1), and regression (index <1). The number of provinces under various results is shown in Table 2:

The growth of the TFP change index of the rural collective resources assets mainly depends on the improvement of the technical level. From the analysis of Table 2, it can be known that, from the overall average of 10 years, there are 11 provinces that can basically realize the constant increase of TFP utilization rate of collective resources asset with the average increase rate of about 36%, and 19 provinces regressed with the average regression rate of about 64%; during the investigation period, Beijing, Shanghai, Guangdong, and other first-tier provinces have the technical efficiency value of 1, which have reached the efficiency frontier and the change index stagnates. Among the provinces that have achieved technological progress, 40% have sustained growth, 13% have stagnated, and 47% have regressed. On average, 13 provinces can achieve a technological efficiency increase, accounting for 43% of the total, and the regression rate is 57%, which is high. It can be seen from the comprehensive analysis that the TFP utilization rate of rural collective resources assets in most provinces of China is in a state of regression, but the regression speed is in a downward trend, indicating that there is still a large space for resource planning and improvement and technological level improvement, especially since 2016. The number of provinces gradually shows a rising trend with the strengthening of the national reform of the rural collective property rights system during the "13th Five-Year Plan" period. The overall utilization efficiency trend is getting better, but it still needs to be reinforced and increase improvement planning during the "14th Five-year Plan" period.

Horizontal analysis by spatial scale differences is shown in Table 3:

From Table 3, through the spatial horizontal analysis from the TFP of rural resource asset utilization in various regions on the same time axis, it can be seen that the overall national average is still less than 1 after over 10 years of reform and rectification, while all indicators showed varying degrees of increase; in terms of technical indicators, the EFFCH change index and the TECH progress index showed the opposite situation in different regions as a whole. The global GML index can be divided into two stages. The first stage is before 2015, and the overall growth rate is slow and below 0.98. The change difference among technical indicators is small, and the growth rate of technical efficiency is relatively higher than the technological progress. In the second stage, from 2015 to 2019, the growth rate of the GML index is accelerated, increased to more than 0.99 on the whole, and is greater than 1 in 2018-2019 (the growth rate reached 0.9%). The growth rate of technical efficiency was significantly accelerated, and the performance was greater than 1 in three periods, while the change of technological progress showed an opposite trend, showing a large regression from 2015 to 2017 (by 4.8% and 7.4%, respectively).

From the regional differences in total factor productivity (hereinafter TFP), the average TFP of the eastern, northeast, central, and western regions were 1.004, 0.981, 0.972, and 0.981, respectively. The eastern region has seen faster growth of its TFP and achieved positive growth in 2012–2019 (GML index >1), but the growth rate slowed down gradually after 2016; the central region has seen slower growth and increase in its TFP, indicating the lack of effective improvement measures and technologies; the western region showed a strong fluctuation before 2015, while the overall improvement was relatively average after 2015 but still showed an overall growth trend. The EFFCH index of the four regions is larger than its TECH index, and the effectiveness of technical efficiency improvement is obvious, which shows that there is still much room for improving the TFP of resource utilization in each region in terms of TECH index. Different regions show different growth, which is obviously influenced by regional differences. The profound economic basis and superior geographical location of the eastern region make the public infrastructure form a linkage system as a whole, which can supply internal and internal and external circulation demand. The rational industrial distribution in the eastern region has been able to achieve the agglomeration effect of advantageous industries. Besides, the first and second stages of relatively complete land remediation projects in the eastern region have been fully completed, and the implementation rules of various natural resources management and environmental ecological restoration and management systems have been built, which has formed a more reasonable and complete overall mode in the strategic layout of rural collective resource assets. The northeast region has complex resource attributes and the initial completion of the rural collective economic organization. Compared with other provinces in China, the northeast region has the largest floating population base and is difficult to manage, and the basic facilities in the vast territory still need greater improvement. It is necessary to take the idea of continuing to introduce new technology industries, attracting and retaining talents as the core of structural layout transformation. Rural collective organizations in the central and western regions have a relatively disorganized system, weak overall strength, poor collective economic foundation, and supporting

Table 2: Decomposition value and evolution trend of total factor productivity of rural resource assets utilization.

Particular year	UHDM-GML			UHDM-EFFCH			UHDM-TECH		
	Increase	Stagnate	Backwards	Increase	Stagnate	Backwards	Increase	Stagnate	Backwards
2009-2010	8	0	22	9	5	16	8	0	22
2010-2011	8	0	22	12	5	13	8	0	22
2011-2012	5	0	25	3	5	22	19	0	11
2012-2013	13	0	17	18	4	8	5	0	25
2013-2014	12	0	18	4	3	23	20	0	10
2014-2015	16	0	14	14	3	13	17	0	13
2015-2016	10	0	20	23	4	3	6	0	24
2016-2017	15	0	15	12	6	12	13	0	17
2017-2018	12	0	18	12	6	12	13	0	17
2018-2019	19	0	11	14	3	13	17	0	13
Mean	11	0	19	12	4	14	13	0	17

infrastructure, which needs to be improved. Due to the lack of attractiveness of financing, long-term "credit dilemma," low level of industrial structure, and waste of resources, it is difficult to achieve a strong industrial agglomeration effect. Moreover, the slow progress of technology is not enough to significantly curb pollution discharge, resulting in the overall resources being idle or exploited at will, as well as the relatively extensive and low-level resource management. However, with the "Belt and Road Initiative," the development speed of the western region has been greatly improved since 2012 with strong potential. The western region should strive to tap the superiority of geographical resources, develop characteristic industries according to local conditions, adjust the transformation and allocation of economic structure in a timely manner, and enhance the cross-provincial and cross-border cooperation mode, especially in northwest mountainous areas and minority areas. In addition, it should accelerate the establishment of the IoT (Internet of Things) service platform to more effectively improve the TFP of rural collective resource assets utilization, retain organization members to work and start businesses in rural areas, and vigorously support rural micro and small enterprises, and complete the last step of financial services such as collective organizations and local governments jointly guarantee and exploitable resources mortgage loans.

5.3. Test by the Spatial Econometric Models

5.3.1. Establish the Spatial Weight Matrix. The model calculates the global Moran's I index of national development of the new area in each province from 2010 to 2019, as shown in Table 4, by using the global Rook first-order adjacency criterion to study the spatial aggregation degree and spatial dependence of global spatial autocorrelation for the TFP of integrated land use in Development New Area in each province.

The results showed that the global Moran's I index increased from 0.303 to 0.357 from 2010 to 2019, and all passed the significance test at the 1% level, indicating that the development of land use is linked to increase and decrease in each province in China has achieved initial results. Taking the data of China National Development New Area as a typical example, it can be found that the TFP of land utilization in the rapid urban-rural integration region has a significant spatial agglomeration and gradually increases as a whole.

5.3.2. Statistics and Inspection Management. In order to determine the applicability of the spatial econometric model, Wald statistics and LR statistics were used to test the performance of data in spatial lag and spatial error in the spatial model. The results show that statistical results all passed the significance test at the 1% level, and then the Hausman test was used and confirmed that the inspection result is 39.52, which also passed the significance test at the 1% level, indicating that SDM with fixed effect is most appropriate to achieve the research target. Import the statistical data to the FE-SDM to conduct econometric regression statistics on TFP of resource asset utilization in China National Development New Area in provinces, and the results are as shown in Table 5:

It can be seen from Table 5 that the value R^2 of the spatiotemporal two-way fixed effects is the maximum, reaching 0.883, and also passed the significance test at the 1% level, indicating that the model has the highest goodness of fit and good explanatory power. Using partial differential equations to decompose the SDM of time-space two-way fixed effects, the spatial effects of explanatory variables are manifested as direct spatial effects and indirect spatial effects. Among them, the indirect effect is manifested as a spatial spillover effect. That is, each explained variable is affected by the double influence effect of other explained variables and explanatory variables across provinces, as shown in Table 6.

From the analysis in Table 6, it can be seen that the direct effect and indirect effect of TFP on urban and rural resource utilization in each provincial, national development zone, based on the comprehensive analysis of five level indicators GDP_{it}, IND_{it}, $BECit$, $URB_{it,}$ and $FINit$, are all positive numbers; except for the urbanization level indicator, all the others have passed the significance test at the 1% level, and there are significant spatial spillover effects among the indicators across provinces. The establishment and development of the China National Development New Area have

Table 3: Decomposition value and evolution trend of total factor productivity of resource assets in each region.

Year	GML					EFFCH					TECH				
	National	East	North east	Central	West	National	East	North east	Central	West	National	East	North east	Central	West
2009-2010	0.965	0.956	0.960	0.951	0.986	0.994	0.954	0.992	0.963	1.060	0.971	1.002	0.973	0.987	0.929
2010-2011	0.972	0.990	0.967	0.964	0.960	1.000	1.009	0.999	0.989	0.999	0.972	0.982	0.973	0.975	0.961
2011-2012	0.961	0.978	0.958	0.978	0.932	0.953	0.967	0.955	0.969	0.928	1.008	1.011	1.008	1.010	1.004
2012-2013	0.995	1.006	0.988	0.970	1.003	1.045	1.053	1.043	1.017	1.058	0.952	0.955	0.952	0.954	0.948
2013-2014	0.990	1.003	0.983	0.967	0.995	0.970	0.965	0.969	0.960	0.981	1.021	1.039	1.020	1.008	1.014
2014-2015	0.997	1.032	0.991	0.978	0.977	1.081	1.063	1.079	1.109	1.066	0.926	0.970	0.923	0.882	0.917
2015-2016	1.009	1.049	1.003	0.985	0.989	1.008	1.032	1.006	0.985	1.002	1.001	1.016	1.001	1.000	0.986
2016-2017	0.992	1.007	0.986	0.976	0.990	0.992	0.991	0.991	0.979	1.004	1.000	1.016	1.000	0.998	0.986
2017-2018	0.994	1.007	0.982	0.978	0.977	1.079	1.024	1.065	1.066	1.106	0.990	1.001	0.990	0.982	0.988
2018-2019	1.006	1.009	0.989	0.975	0.998	1.039	1.031	1.025	0.979	1.064	1.005	1.011	0.997	0.968	1.012
Mean	0.988	1.004	0.981	0.972	0.981	1.016	1.009	1.012	1.002	1.027	0.985	1.000	0.984	0.976	0.975

Table 4: Global Moran's I value of land use in China national development new area of China from 2010 to 2019.

Particular year	Moran's I index	Z-statistics	P value
2010	0.303	3.502	0.010
2011	0.340	3.583	0.005
2012	0.341	3.641	0.004
2013	0.343	3.784	0.001
2014	0.343	3.694	0.004
2015	0.368	5.473	0.000
2016	0.326	3.544	0.008
2017	0.337	3.570	0.005
2018	0.322	3.519	0.008
2019	0.357	4.589	0.000

Table 5: Estimation results of SDM.

	No fixed effects		Period fixed		Space fixed		Space-time double fixation	
	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
$\ln GDP$	0.325^{***}	7.418	0.332^{***}	7.507	0.576^{**}	6.992	0.532^{***}	7.139
$\ln IND$	0.298^{**}	2.051	0.151^{**}	2.364	0.351^{**}	2.319	0.251^{**}	2.842
$\ln BEC$	0.243^{**}	4.109	0.208^{**}	4.357	-0.219^{**}	−4.083	0.119^{**}	4.039
$\ln URB$	0.176	0.851	0.196	0.673	0.153	0.837	0.028	0.984
$\ln FIN$	0.312^{**}	2.256	-0.293^{**}	−2.253	0.293^{**}	2.241	0.293^{***}	2.241
$\omega \times \ln GDP$	0.211	1.039	0.320^{**}	2.049	0.374^{*}	1.938	0.493	0.983
$\omega \times \ln IND$	0.412^{***}	2.983	0.438^{**}	2.382	0.527^{***}	6.938	-0.402^{**}	−2.038
$\omega \times \ln BEC$	−0.031	0.893	0.532	1.099	0.034^{***}	4.982	0.183^{***}	4.092
$\omega \times \ln URB$	0.209^{***}	3.984	0.201^{***}	3.083	0.184^{***}	3.948	0.302^{**}	2.093
$\omega \times \ln FIN$	-0.109^{***}	5.932	0.037^{***}	−4.983	-0.231^{**}	2.342	0.409^{***}	3.984
ρ	0.536^{***}	11.083	0.484^{***}	8.975	0.652^{***}	7.938	0.746^{***}	10.338
Cons	0.832^{***}	5.931	0.922^{***}	7.392	0.326^{***}	8.478	0.532^{***}	5.624
R^2	0.573		0.71		0.806		0.883	
Wald_spatial_lag	—		92.084^{***}		23.253^{***}		43.265^{***}	
LR_spatial_lag	—		—		—		55.643^{***}	
Wald_spatial_error	—		90.835^{***}		22.321^{***}		43.537^{***}	
LR_spatial_error	—		—		—		54.804^{***}	

EX: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$.

Table 6: Decomposition of spatial Dubin model based on temporal and spatial double fixed effects.

Variable	Direct effect		Indirect effect		Total effect	
	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
$\ln GDP$	0.504^{***}	7.507	0.319^{**}	5.732	0.826^{***}	4.932
$\ln IND$	0.237^{**}	2.064	0.163^{**}	1.998	0.401^{***}	3.023
$\ln BEC$	0.116^{***}	4.357	0.089^{***}	3.736	0.195^{***}	2.986
$\ln URB$	0.036	0.773	0.083	0.893	0.118	1.023
$\ln FIN$	0.289^{**}	2.753	0.092^{***}	3.062	0.381^{***}	3.248

EX: $^{*}p < 10\%$, $^{**}p < 5\%$, $^{***}p < 1\%$.

not only improved the TFP of resource asset utilization in the province but also have had a positive impact on the neighboring provinces.

6. Discussion and Practice

Based on the time axis, spatial evolution, and time-space effects, this study measures the TFP of resource asset utilization and its improvement and decomposition in provinces of China in the recent decade and draws the following conclusions: (1) There are ineffective improvements in the utilization of rural collective resource assets in all provinces and regions of China, and the unbalanced industrial layout leads to a low utilization intensity of resource assets on the whole, except that the first-tier provinces in eastern China have a higher overall level of intensive utilization of resources and the input redundancy rate is 0. The other ineffective provinces all have high redundancy of human resources, energy, and sewage discharge, and the effect of resource income stagnates and presents a declining trend. Since 2015, the regression speed in northeastern China and the western regions has decreased significantly year by year,

whereas, under the impact of a large number of resource assets, authentic right and population migration, social problems, such as aging and hollow village, are still the relatively serious problems restricting the development of rural collective economy in the region. However, thanks to technological progress and larger improvement room for resource utilization efficiency, the advantages of population relocation in western China to develop the characteristic industries have made the TFP improve significantly and show a steady growth trend; the results of the comprehensive analysis of the central region are the least satisfactory. From the perspective of input-output benefits, the input intensity accounts for about 80% of that in the eastern region but with an output per land of only 40%, and the redundancy of sewage discharge is even1.6 times the average in the eastern region. The overall growth rate of all provinces is very slow and small, and it needs to be improved in all aspects of deepening the reform and implementation. (2) Dual management of spatial evaluation and time-space effect is a favorable evaluation system for the effectiveness of constructing strategies for improvement of TFP of rural collective resources asset utilization in China. There are natural attributes of resource utilization, including force majeure, inseparability, and unpredictable dynamics, so that enhancing monitoring its nonlinear dynamics and the emerging characteristic changes shall be considered as the core of spatial dynamic management evaluation. This study selected the state-level Development New Area as crack policy, financing, project implementation level, personnel, supplies, and other barriers to collaboration between the various functional departments, which is typical and practically significant. Statistical results confirmed in decomposition that the indicators of China National Development New Area in improving the TFP of rural collective resources asset utilization have a significant positive spatial correlation, and the spatial agglomeration and spatial spillover effects are increasing year by year; in terms of the improvement of urbanization migration defects, upstream and downstream industry service clusters that break geographical limitations can be built through the internal competition of the spatial benefits of the original rural collective resource assets, gathering and enhancing the strength of characteristic industries to guide collective organization members to relocate, and improving industrial technical efficiency and service level, so as to form a more optimized and complete improvement strategy.

6.1. Implications for Practice. The National Development New Area as a very special organization in China is bearing part of the government's economic and technical industry management functions. While being different from the administrative management functions of the traditional regional government, it focuses on solving the problem of the low spatial and temporal effect of TFP due to the unfair distribution of resource endowments in the original administrative division. Since 1986, various provinces have been successively establishing the China National Development Zones, which has laid a good foundation for the provinces to explore the development strategy of optimizing the layout of modern industrial structures dominated by emerging and high-tech. China National Development New Area is planned to be distributed in the transportation hub areas (a kind of connection) of various provinces, municipalities, and autonomous regions, undertaking important responsibilities such as urban-rural integrated development, opening-up layout, high-tech localization transformation, deepening supply-side reform pilots, and leading the rural revitalization strategies.

Analyzing the standard of economic development, the establishment of Development New Area has promoted the sharing of resources, information, and technology between urban and rural areas, especially increasing the Supporting infrastructure for ensuring people's wellbeing and the public service facilities. Some qualified Development New Area has begun to drive the surrounding villages and towns with conditions to transform into urban, comprehensive functional service areas and construct and improve the "satellite city" (medium and small cities around the big city) belt clusters with improved management mechanisms and development strategies. The improvement of the integration of the rural collective industrial structure in the original area has begun to take shape, which effectively intensifies the use efficiency of land for construction, with the supply volume reaching as high as 87%. At the same time, areas with higher index levels bring a positive spatial spillover effect to more surrounding areas through spatial agglomeration effect and realize the radiation, diffusion, and collaborative sharing level of capital, technology, and other factors.

Analyzing the industrial estate structure, Set 2016, for example, among the research targets, only the total revenue of the high-tech industry exceeded RMB 9.9 trillion. The optimization and upgrading of industrial structure effectively accelerated the optimal and reasonable allocation and flow of resource factors. Scientific and technological progress and the innovation of management mode of resource assets by TFP had a significantly positive influence, which has improved the land factor output level brought by mismatching of information chain and supply chain.

Analyzing economic cooperation, Taking Guangxi and Inner Mongolia as examples, border economies have become the development core of the industrial layout of the rural collective economy in this region, the improvement of trade in agricultural and forestry products and border tourism is conducive to the exchange and improvement of technology, which utilized characteristic business operation to have revitalized the transformation of idle, unused resource assets to useable operational assets.

6.2. Implications for Theory. Especially in the developed regions, the establishment of an integrated public supporting linkage system in the form of urban and rural opening has basically been completed. This "New Area" setup and the development have not only improved the TFP of resource asset utilization across provinces, but also have had a positive impact on the neighboring provinces.

Analyzing the Urbanization process, spatial effects were positive but have not passed the significance test, indicating that a surge of China National Development New Area can effectively promote the rapid urbanization rate, while the population migration and industrial agglomeration thus resulted have high mobility, instability, and unsustainability, and the real and stable agglomeration of manpower and capital cannot be immediately manifested in the early stage of urbanized transformation, which is mainly based on attracting people to migrate for short-term employment. In order to realize the agglomeration of industrial structure optimization with human capital and the positive correlation of it with energy consumption structure, the core of truly improving TFP of resource utilization lies in providing improving guarantee mechanisms. We will effectively solve the problem that the negative effects of energy consumption and pollution increase in the labor importing areas and the economic income dominating the consumption still remain in the original household registration place. The positive spatial spillover benefits can only be generated by simultaneously improving technological progress and technological efficiency.

Analyzing the loan openness of financing guarantee for agriculture, rural areas, and rural residents, in order to effectively avoid the risk of social capital encroachment on the contracted management rights of rural collective land, China's laws have clearly prohibited the establishment of right to mortgage the rural land since the mid-1990s, which has greatly restricted the development of agricultural land financialization and finance for agriculture, rural areas, and rural residents. Since the full implementation of rural collective property and capital verification and land rights confirmation in 2016, financial services have once again entered the countryside and farmland. The provincial finance departments all provided "agriculture, rural areas, and rural residents" with financing guarantee platforms and policy support for medium-small- microsized enterprises, solving the credit dilemma of rural areas and peasants gradually and orderly promoting the impact of farmer's credit access from farmland mortgages on regional economic structure adjustment and the scale expansion of farmland management, to improve the scale preference of rural industrial layout.

7. Improvement Strategies

Based on the analysis of the results of the study, the following improvement strategies are proposed: First, the Local governments should unite with the National Development New Area to build a strategic layout of urban-rural integration such as establishing living quarters along the traffic lines and integrating the layout of administrative villages and natural villages in axial clustering; giving preference to public infrastructure in rural land use; coordinating the development of equal access to public services in urban and rural areas so as to complete the last step of the intangible transformation; balancing the income between urban and rural areas; improving the utilization efficiency of newly added cultivated land and develop large-scale agricultural operations with distinctive features to increase farmers' incomes.

Second, strengthen the effectiveness of the dynamic evaluation system of time-space control and attract the clustering of cross-provincial industry chain service platforms. The government should provide preferential policies and encourage additional social capital investment opportunities for the intensive transformation of special industries. Revitalize the centralized management of industrial land index adjustment in contiguous villages and support the construction of scale-oriented credit systems that do not depend on traditional farmland collateral, such as farmland management credit scoring system, industrial cluster loans, financial supply chain, etc., so as to reduce the potential credit guarantee risk or compensation undertaken by local governments in the pilot reform of farmland mortgage and effectively alleviate the scale preference constraints of small-scale farmers in credit access.

Finally, the government should strengthen the differential control measures of border rural economy. Support the differentiated development of borderland use, make overall plans for policies supporting special use of land, and put an end to the one-size-fits-all border construction land supply policy. Besides, scientifically guide the improvement of socioeconomic supply implementation rules for border security and development according to the progress of local urban function, so that border farmers can participate in the operation and development of foreign cultural value-added services to drive the economic development of the nearby regions.

8. Limitations

Additionally, we should mention some limitations of our study. First, we have not taken into available data about the negative numerical value and zero numerical value into potential contextual factors affecting the units in our measures of performance; thus, a potential extension of the current research could entail the use of a particular model that works with particular data, not using alternative methodological approaches that allow us to include this information such as the Parallel system models proposed. Second, we cannot interpret our results in a single dimension way since it would entail neglecting the potential presence of interactivity in times and space measure (e.g., arising from the sample times selection bias, reversed space causality, or unobserved heterogeneity). It is worth mentioning that we have developed methods to address the issue of unobserved times-heterogeneity and space-endogeneity in our next studies. However, these possibilities exceed the scope of the present paper.

Data Availability

Data used in this study could be accessed by request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This paper was supported by the National Natural Science Foundation of China Outstanding Youth Science Fund Project: "Evaluation and Management of Sustainable Development Policy in Ecologically Fragile Areas," No. 72022014; General Project of the National Natural Science Foundation of China: "A Study on Poverty Alleviation Pattern, Risk of Returning to Poverty and Sustainable Development Policy Innovation of Relocated People from Inplaces from the Perspective of Livelihood Resilience" No. 71973104.

References

[1] N. Zhou, Y. Y. Xu, J. J. Liu, and L. Y. Zhang, "Farmland titling, farmland mortgage and availability of Farmers'Credit-evidence from rural reform experimental areas," *Chinese Rural Economy*, vol. 30 November, 2018.

[2] Z. H. Ji and P. Zhang, "Spatial difference and driving mechanism of urban land use efficiency under the environmental constraints-based on 285 cities in China," *China Land Science*, vol. 34, no. 08, pp. 72–79, 2020.

[3] H. Q. Qiang, X. L. Liu, W. D. Qiao, and W. S. Cheng, "Quantitative evaluation of land ecological security in minqin based on farmer livehood assets," *Journal of Desert Research*, no. 04, pp. 1182–1208, 2016.

[4] J. Liu, "The new law clarifies the secondary market structure of collectively-owned commercial construction land," *Land Science Developments*, no. 6, pp. 48–51, 2019.

[5] P. Xiao, "A brief analysis on the system of paid withdrawal of the right to use homestea," *Land Science Developments*, no. 6, pp. 52–55, 2019.

[6] J. Jędrzejowicz and P. Jędrzejowicz, "A hybrid distance-based and naive bayes online classifier computational," *Collective Intelligence*, vol. 24, 2015.

[7] P. J. Schneider and U. Soergel, "Clustering persistent scatterer points based on a hybrid distance metric," *DAGM German Conference on Pattern Recognition*, no. 13 January, pp. 621–632, 2022.

[8] L. Yue and W. B. Li, "Typical urban land use efficiency in China under environmental constraints based on DDF-Global Malmquist-Luenberger index modeling," *Resources Science*, vol. 39, no. 04, pp. 597–607, 2017.

[9] J. Aparicio, J. M. Cordero, and C. Díaz-Caro, "Efficiency and productivity change of regional tax offices in Spain: an empirical study using Malmquist–Luenberger and Luenberger indices," *Empirical Economics*, vol. 59, no. 3, pp. 1403–1434, 2020.

[10] J. E. H. Percival, N. Tsutsumida, D. Murakami, T. Yoshida, and T. Nakaya, "Exploratory spatial data analysis with gwpcorMapper: an interactive mapping tool for geographically weighted correlation and partial correlation," *Journal of Geovisualization and Spatial Analysis*, vol. 6, no. 1, 2022.

[11] H. Cheniti, M. Cheniti, and K. Brahamia, "Use of GIS and Moran's I to support residential solid waste recycling in the city of Annaba, Algeria," *Environmental Science and Pollution Research*, vol. 28, no. 26, pp. 34027–34041, 2021.

[12] G. S. Luo and T. Li, "Dynamic change and driving factors of land use efficiency differences affected by carbon emissions at the provincial level in China," *Acta Ecologica Sinica*, vol. 39, no. 13, pp. 4751–4760, 2019.

[13] L. Li and Z. Yang, "Estimation of fixed effects spatial dynamic panel data models with small T and unknown heteroskedasticity," *Regional Science and Urban Economics*, vol. 81, p. 103520, 2020.

[14] M. Wu, *Research on the Input Efficiency of Provincial Public Capital in China"*, Chongqing University, Chongqing China, 2016.

[15] S. C. Liu, Y. M. Ye, and W. Xiao, "Spatial-temporal differentiation of urban land-use efficiency in China based on stochastic frontier analysis," *China Land Science*, vol. 34, no. 01, pp. 61–69, 2020.

[16] L. T. Liang, Y. J. Yong, and G. Chen, "Measurement of urban land green use efficiency and its spatial differentiation characteristics an empirical study based on 284 cities," *China Land Science*, vol. 33, no. 06, pp. 80–87, 2019.

[17] J. Bai, S. Li, N. Wang, J. Shi, and X. Li, "Spatial spillover effect of new energy development on economic growth in developing areas of China—an empirical test based on the spatial Dubin model," *Sustainability*, vol. 12, no. 8, 2020.

[18] N. Shan-dong, F. Bin, C. Cui, and H. Shi-hui, "The spatial temporal pattern and path of cultivated land use transition from the perspective of rural revitalization:Taking Huaihai Economic Zone as an example," *Journal of Natural Resources*, vol. 35, no. 8, p. 1908, 2020.

[19] J. Xu, "Exploring land use innovation to help the development of border areas-A summary of the academic seminar on border land use and rural revitalization in the new era," *Southern Land and Resources Magazine*, no. 1, pp. 47–50, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 3013289, 14 pages
https://doi.org/10.1155/2022/3013289

Research Article

Game Analysis of Supply Chain Enterprises' Choice of Carbon Emission Reduction Behavior under Environmental Regulation and Consumers' Low Carbon Preference

Huanhuan Huo,[1] **Haiyan Liu**,[1] **Xinzhong Bao**,[2] **and Wei Cui**[1]

[1]*School of Economics and Management, China University of Geosciences (Beijing), Beijing 100083, China*
[2]*Management College, Beijing Union University, Beijing 100101, China*

Correspondence should be addressed to Haiyan Liu; liuhy@cugb.edu.cn

Received 18 March 2022; Revised 6 May 2022; Accepted 25 May 2022; Published 3 August 2022

Academic Editor: Lele Qin

Under the background of low-carbon economy, in order to explore the internal mechanism of enterprises implementing carbon emission reduction behavior, this paper uses evolutionary game theory and numerical simulation method to study the evolutionary stability strategy and its influencing factors of carbon emission reduction behavior of supply chain enterprises in a two-level supply chain composed of a single supplier and a single manufacturer from a dynamic perspective, considering environmental regulation and consumers' preference for low carbon emission. The results show that there are certain conditions that make supply chain enterprises converge to carbon emission reduction investment behavior under the effect of command-and-control environmental regulation and consumer low-carbon preference, and converge to cooperative carbon emission reduction behavior under the effect of market-based environmental regulation and consumer low-carbon preference. On this basis, the factors significantly influence the carbon emission reduction investment behavior of supply chain enterprises are the carbon emission reward and punishment coefficient and the low carbon preference coefficient of consumers. Increasing the carbon tax rate, carbon emission trading price and the proportion of cost subsidies, as well as encouraging consumers to consume low-carbon products will help promote the realization of cooperative carbon emission reduction.

1. Introduction

One of the characteristics of the 21st century is the excessive use of the atmosphere as a greenhouse gas disposal space [1]. In 2021, global carbon dioxide emissions from the global energy sector reached 36.3 billion tonnes, a 6% increase year-on-year, surpassing the level before the outbreak of the COVID-19 and setting an all-time record [2]. The 2021 Emission Gap Report issued by the United Nations Environment Programme pointed out that in order to control global warming below 1.5°C by the end of this century and achieve the ideal goal of the Paris Agreement, the world needs to halve its annual greenhouse gas emissions in the next 8 years. Enterprises are the main body of carbon emission, the total carbon dioxide emissions of the 100 listed companies mentioned in the "China Listed Company Carbon Emissions Ranking (2021)" totaled 4.424 billion tons, accounting for about 44.7% of the national total and 13.7% of the global total. However, due to the large cost of implementing carbon emission reduction investment, enterprises will face a lot of financial pressure, which makes enterprises lack enthusiasm and initiative in environmental protection investment. The behavior of enterprises is often a response to the government's environmental protection regulatory policies [3], governments of various countries have formulated carbon emission reduction targets and issued environmental regulatory policies (such as total emission control, emission standard control, and carbon emission trading, etc.) to regulate high-carbon emission industries.

While the government has stepped up efforts to promote emission reduction, consumers' low carbon awareness is also gradually increasing. Shuai et al. found that with the improvement of education level and income level, Chinese residents are more and more willing to pay more for low-carbon products [4]. According to Toluna's 2019 sustainability report, more than one-third (37%) of the 1000 U.S. consumers surveyed said they sought and were willing to pay 5% more for environmentally friendly products. It can be seen that in addition to the functional value of the commodity itself, consumers are gradually paying attention to the low-carbon attribute of the commodity, that is, consumers' low-carbon preference. Liu et al. and Wu et al. pointed out that the greater consumers' preference for low carbon, the more beneficial it is to supply chain enterprises [5, 6]. Therefore, the influence of consumers' low carbon preference should also be considered in the decision-making of enterprises' carbon emission reduction behavior.

The operation mode of enterprises is changing with the progress of science and technology, upstream and downstream enterprises gradually consider to form a community of interests from a link in the supply chain, which makes the decision of carbon emission reduction behavior closely related to the decision of upstream and downstream enterprises. Therefore, by analyzing the possible carbon emission reduction behavior response of enterprises in the supply chain (composed of a single supplier and a single manufacturer) under the dual effects of environmental regulation and consumers' low-carbon preference, this paper discusses what equilibrium state will be produced in the process of strategic interaction between enterprises? what conditions need to be met to achieve the ideal equilibrium state? And what factors affect these equilibrium states? Through the analysis of the above problems, it provides a theoretical basis for supply chain enterprises to implement carbon emission reduction behavior decision-making, and provides a reference for government environmental policy-making.

2. Literature Review

The profit-seeking nature of an enterprise determines that the choice of corporate behavior is based on cost and benefit. In the actual operation process, the cost and benefit of an enterprise are affected by many factors such as government policies and public preferences [7]. Environmental regulation is a necessary response to the problem of environmental impact [8], which is generated to solve the negative externality of environmental pollution, and it continues to expand with the development of ecological environment and people's demands for environmental improvement. According to the mechanisms, means and methods of functioning, environmental regulation policies can be divided into command-and-control policies, market-based policies, voluntary agreement policies and information tool policies [9].

The impact of environmental regulation policy on enterprise carbon emission reduction decision. Xu et al. investigated the impact of environmental penalties on enterprises' emission reduction decisions through the data of Chinese listed industrial companies, and found that China's environmental penalties did not have a substantial impact on enterprises' emission reduction decisions, but only reduced the absolute emission level of enterprises [10]. Han et al. studied the mechanism of environmental regulation driven emission reduction and found that the total amount of constrained pollutants has a significant emission reduction effect at the enterprise level, and it will drive enterprises to adopt cleaner production and end-of-line treatment to reduce pollutant emissions [11]. Huang et al. used the difference-in-difference method to find that environmental regulation has a positive impact on R&D spending [12]. However, since carbon tax will generate additional tax costs, it will also have a negative impact on corporate investment decisions [13]. Cheng and Sun divided environmental regulation into two categories: mandatory and incentive, and divided low-carbon manufacturing practice into five dimensions: supply chain enterprise cooperation, internal management support, production process management, low-carbon product design and environmental standard implementation, using structural equation model to explore the relationship between environmental regulation and low-carbon manufacturing practice. The results show that environmental regulation has a significant role in promoting low-carbon manufacturing practice, and the impact of mandatory and incentive environmental regulation on each dimension of low-carbon manufacturing practice is different. Mandatory environmental regulation has a significant positive impact on internal management support, low-carbon product design and implementation of environmental standards; incentive environmental regulation has a significant positive impact on supply chain enterprise cooperation and production process management [14]. However, there are also studie believe that environmental regulation cannot promote the practice of supply chain extension under carbon emission reduction targets [15]. Existing literature mainly studies the effects of single environmental regulation measures such as carbon tax and carbon emission right trading, and finds that different types of environmental regulation provide different constraints or incentive conditions for enterprises' carbon emission reduction behaviors, and enterprises may show different attitudes and behavior choices.

The environmental value function of low-carbon products can enhance the utility of consumers [16], making consumers more inclined to consume low-carbon products. Some scholars have studied the impact of consumers' low-carbon preference on enterprise decision-making. Du et al. studied the impact of carbon footprint and low carbon preference on the production decisions of emissions-dependent firms in the total amount control and trading system and found that low-carbon processing has no economic cost advantage for manufacturers who only consider total amount control and trading, when consumers have a strong low carbon preference, manufacturers will choose it [17]. Wen et al. used a duopoly game model to study the carbon emission reduction and pricing strategies of enterprises facing the dual pressures of emissions trading prices

and consumers' carbon awareness in a competitive market. The results show that carbon price and consumer awareness have cumulative effects on the company's emission reduction efforts [18]. Sun et al. constructed a Stackelberg game model (dominated by manufacturers) to analyze the transfer and emission reduction of carbon emissions among enterprises in the supply chain. The results shows that the lag time of emission reduction technologies and consumers' low carbon preference has a positive effect on the carbon emission transfer level of manufacturers [19]. Liu et al. incorporated the change of consumer preference into the theoretical model and evaluated the impact of carbon emission reduction cost sharing on supply chain profits. The research shows that while achieving the carbon emission reduction target, consumers' preference for low-carbon products is beneficial to both supply chain enterprises [5]. To sum up, considering that consumers, as rational people, have a preference for low-carbon products, in addition to government environmental policies, enterprises' carbon emission reduction behavior strategies will also be affected by consumers' purchase intentions.

Therefore, in the context of low-carbon economic environment, how does the dual role of environmental regulation measures and consumers' low-carbon preference affect the choice of carbon emission reduction behavior and its long-term relationship of supply chain subjects? Evolutionary game theory originated from the application of game theory to the evolving population of life forms in biology. By introducing biological fitness function, variation mechanism and selection mechanism, the dynamic replicator equation is constructed, which can well reflect the process of observation, imitation and mutual learning experienced by enterprises in the decision-making process [20]. It has been proved to be an effective analytical tool to study the relationship between government behavior or carbon reduction strategy of supply chain enterprises. Zhao et al. constructed an evolutionary game model to analyze the possible responses of enterprises to incentive policies related to the implementation of carbon emission reduction labeling program, and found that relevant incentive policies have a positive impact on the implementation of carbon emission reduction labeling program [21]. Zhang et al. established an evolutionary game model between the government and manufacturers, and analyzed the influence of government policies (static carbon trading price and dynamic carbon trading price) on manufacturers' decisions and the dynamic trend of total cap trading market [22].

From the above literature review, it can be seen that previous studies mainly consider the relationship between single regulation policy and enterprise operation decision-making. The results show that enterprises show different attitudes and behaviors under the action of different types of environmental regulation. In addition to environmental regulation, corporate carbon emission reduction behavior strategy will also be affected by consumers' low-carbon preference. The innovation of this paper is that different environmental regulation policies have different soft and hard constraints on operation decisions, and enterprises can choose different carbon emission reduction behaviors. Considering the dual effects of comprehensive environmental regulation strategy constraints or incentive conditions and consumers' low-carbon preference, this paper explores the decision-making mechanism of enterprises' carbon emission reduction behavior. Therefore, this paper constructs a game model of a two-level supply chain composed of a single supplier and a single manufacturer, considering the impact of environmental regulation and consumers' low-carbon preference, market-oriented environmental regulation and consumers' low-carbon preference respectively, studying the strategic stability, the interactive relationship of strategic selection and the evolution path of dynamic decision-making of carbon emission reduction behavior of supply chain enterprises from a dynamic perspective. The influence of different parameters on the behavior decision of supply chain enterprises is analyzed by numerical simulation.

3. Analysis of Supply Chain Enterprises' Carbon Emission Reduction Investment Behavior under Command-and-Control Regulation and Consumers' Low-Carbon Preference

3.1. Problem Description and Model Assumptions. Command-and-control environmental regulation refers to the formulation of laws, regulations, policies and systems by the legislative and administrative departments in order to prevent individuals and enterprises from doing actions that are not conducive to environmental protection. Including setting emission standards, limiting pollution emissions, shutting down and transferring, etc. [23]. The main feature of this regulatory model is that polluters have almost no right to choose. In order to satisfy the law of the minimum environment requirements, companies will take the necessary adjustment measures, such as compliance costs, and increase the environmental investment, stimulate the enterprise to the environmentally friendly production technology innovation, to achieve reductions [24]. Or some enterprises, after comparing the cost of violation with the cost of compliance costs, choose to violate environmental laws and regulations and pay more pollution charges instead of reducing carbon emissions [25]. Therefore, it is assumed that in the face of such a policy environment, supply chain enterprises with supply-demand relationship can choose implementing carbon emission reduction investment or not.

In the stage of command-and-control environmental regulation, this paper focuses on the impact of emission standard policy on carbon emission reduction behavior strategy of supply chain enterprises. In order to more clearly analyze and describe this problem, this paper makes the following assumptions:

(1) Assume that the costs of carbon abatement investments by suppliers and manufacturers are C_S and C_M respectively. Referring to the research of Jones and Mendelson [26], the manufacturer's emission reduction investment cost is $C_M = 1/2\mu_M\lambda_M^2$, where $\lambda_M\,(0 < \lambda_M < 1)$ is the manufacturer's emission

reduction effort at the moment, and μ_M ($\mu_M > 0$) is the manufacturer's emission reduction cost coefficient. Similarly, the supplier's carbon emission reduction investment cost is $C_S = 1/2\mu_S\lambda_S^2$, make $\mu_M = \mu_S = \mu$.

(2) Referring to the research of Jiang et al. [27], the emission reduction of final products depends on the emission reduction efforts of manufacturers and suppliers. Assuming that β_S represents the impact coefficient of suppliers' emission reduction efforts on product emission reduction and the impact coefficient of β_M represents manufacturers' emission reduction efforts on product emission reduction. Then the change of product emission reduction is $\rho = \beta_i\lambda_i\,(i = M, S)$i $= M, S$ is the same in below. ρ_{0M} and ρ_{0S} are the carbon emissions (emission concentration) generated in the process of using raw materials to produce unit products before implementing carbon emission reduction behavior strategies for manufacturers and suppliers respectively. The amount of carbon emissions generated after the implementation of carbon emission reduction investment behavior is $\rho_{Li} = \rho_{0i} - \rho$. ρ_{LMS} or ρ_{LSM} represent the carbon emissions after both have made carbon reduction investments. ρ_{LM} (ρ_{LS}) represents the carbon emissions of the product after the manufacturer (supplier) has invested in carbon reduction.

(3) The market demand is $D(\rho) = \alpha$, which α is the potential market demand without carbon emission reduction investment. When the carbon content of products changes, the changes of market demand refer to the research of Jiang et al. [27], $D(\rho) = \alpha + \delta\rho$, $\delta > 0$ is the impact factor of carbon emission reduction of manufacturers and suppliers on the market demand, that is, the low-carbon preference coefficient of consumers. $\overline{\rho}_i$ ($\rho_L < \overline{\rho} < \rho_0$) is the upper limit of carbon emission concentration per unit product of manufacturers and suppliers set by the government. k ($k > 0$) is reward and punishment coefficient for exceeding the standard of carbon emission per unit product formulated by the government.

(4) The marginal revenues of supply chain companies remain unchanged, and they are all the positive constants, which can be predicted from the actual financial data of the company, denoted by v_M and v_S respectively. v_S is the remaining part of the supplier's unit whole sale price minus the unit average cost excluding low-carbon investment expenses, v_M is the remaining part of the manufacturer's unit whole sale price minus the unit average cost excluding low-carbon investment expenses.

(5) Suppose the profits of manufacturers and suppliers are π_M and π_S respectively. The superscript N indicates that both manufacturers and suppliers do not take carbon emission reduction investment; the superscript U indicates that manufacturers take emission reduction investment but suppliers do not; the superscript D indicates that suppliers make emission reduction investment but manufacturers do not make emission reduction investment; the superscript B indicates that both manufacturers and suppliers take emission reduction investment.

(6) When an enterprise chooses to adopt the carbon emission reduction investment strategy, considering the external positive effect of carbon emission reduction investment in the supply chain, the other enterprise can adopt the behavior of "free-riding." In this case, the government will give certain punishment measures to the free-riding enterprise, the punishment intensity is F.

Assuming that both manufacturers and suppliers are bounded rational decision makers, x ($0 < x < 1$) is the proportion of manufacturers adopting carbon emission reduction investment behavior strategy, then $1 - x$ is the proportion of non carbon emission reduction investment behavior strategy; y is the proportion of suppliers adopting carbon emission reduction investment behavior strategy, and $1 - y$ is the proportion of suppliers not adopting carbon emission reduction investment behavior strategy. The game payment matrix of carbon emission reduction behavior choice of supply chain enterprises under imperative environmental regulation and low-carbon preference of consumers is shown in Table 1.

3.2. Model Construction and Solution. Based on the above discussion, the evolutionary stability of emission reduction investment behavior strategy of upstream and downstream enterprises is analyzed by using the method of evolutionary game theory. Then the expected return of the manufacturer implementing the carbon emission reduction investment behavior strategy is u_M^{x1}, and the expected return of not implementing the carbon emission reduction investment behavior is u_M^{x0}:

$$u_M^{x1} = \pi_M^U + y\delta\beta_S\lambda_S v_M + y\beta_S\lambda_S k\{(\alpha + \delta\beta_M\lambda_M) + \delta[\overline{\rho}_M - (\rho_{0M} - \beta_M\lambda_M - \beta_S\lambda_S)]\}, \tag{1}$$

$$u_M^{x0} = \pi_M^N + y\delta\beta_S\lambda_S[v_M - k(\rho_{OM} - \overline{\rho}_M)] - yF. \tag{2}$$

Similarly, we can get the expected return (u_S^{y1}) of suppliers choosing to implement carbon emission reduction investment behavior and not implementing carbon emission reduction investment behavior strategy (u_S^{y0}).

In evolutionary game theory, replicator dynamics, as a method to study strategy selection, guides decision-makers to make dynamic decisions and promotes decision-makers' strategy selection to converge towards a stable state until it reaches a stable state.

The manufacturer's replicator dynamics equation obtained by formulas (1) and (2) is:

Table 1: Payment matrix of both parties in the game of carbon emission reduction investment behavior of supply chain enterprises.

Supplier	Manufacturer	
	Adopt carbon emission reduction investment x	Non adopt carbon emission reduction investment $1-x$
Adopt carbon emission reduction investment y	$\pi_M^B = v_M D(\rho) + k(\overline{\rho}_M - \rho_{LMS})D(\rho) - C_M(\lambda)$ $\pi_S^B = v_S D(\rho) + k(\overline{\rho}_S - \rho_{LMS})D(\rho) - C_S(\lambda)$ $D(\rho) = \alpha + \delta(\beta_M\lambda_M + \beta_S\lambda_S)$	$\pi_M^D = v_M D(\rho) - k(\rho_{0M} - \overline{\rho}_M)D(\rho) - F$ $\pi_S^D = v_S D(\rho) + k(\overline{\rho}_S - \rho_{LS})D(\rho) - C_S(\lambda)$ $D(\rho) = \alpha + \delta\beta_S\lambda_S$
Non adopt carbon emission reduction investment $1-y$	$\pi_M^U = v_M D(\rho) + k(\overline{\rho}_M - \rho_{LM})D(\rho) - C_M(\lambda)$ $\pi_S^U = v_S D(\rho) - k(\rho_{0S} - \overline{\rho}_S)D(\rho) - F$ $D(\rho) = \alpha + \delta\beta_M\lambda_M$	$\pi_M^N = v_M D(\rho) - k(\rho_{0M} - \overline{\rho}_M)D(\rho)$ $\pi_S^N = v_S D(\rho) - k(\rho_{0S} - \overline{\rho}_S)D(\rho)$ $D(\rho) = \alpha$

$$f(x) = \frac{dx}{dt} = x(1-x)\left(u_M^{x1} - u_M^{x0}\right) = x(1-x)\left[\pi_M^U - \pi_M^N + y\beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + yF\right]. \tag{3}$$

In the same way, the supplier's repliction dynamic equation can be obtained as:

$$f(y) = \frac{dy}{dt} = y(1-y)\left(u_S^{y1} - u_S^{y0}\right) = y(1-y)\left[\pi_S^D - \pi_S^N + x\beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + xF\right]. \tag{4}$$

Make $f(x) = dx/dt = 0$ and $f(y) = dy/dt = 0$, The equilibrium point of the dynamic process of evolutionary game can be generated, including $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, $E_5(P^*, q^*)$. Where $E_5(P^*, q^*)$ is the equilibrium point of hybrid strategy.

The equilibrium point obtained from the replicated dynamic equation is not necessarily the evolutionary stability strategy (ESS) of the system. According to the method proposed by Friedman [28], the asymptotic stability of the equilibrium point is determined by Lyapunov discriminant method (indirect method). Take the first partial derivatives of f (x) and f (y) with respect to x and y respectively, then the Jacobian matrix of the system is as follows:

$$J = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} = \begin{bmatrix} df(x)/dx & df(x)/dy \\ df(y)/dx & df(y)/dy \end{bmatrix} = \begin{pmatrix} (1-2x)\left[\pi_M^U - \pi_M^N + y\beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + yF\right] & x(1-x)\left[\beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + F\right] \\ y(1-y)\left[\beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + F\right] & (1-2y)\left[\pi_S^D - \pi_S^N + x\beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + xF\right] \end{pmatrix}. \tag{5}$$

Based on the local stability analysis of Jacobian matrix, the stability of the equilibrium point of the system is analyzed. For Jacobian matrix (J), the stable state satisfying the determinant of the matrix $\det(J) > 0$ and the trace time of the matrix $\mathrm{tr}(J) < 0$ is the evolutionary stability strategy.

In evolutionary game theory, evolutionary stable strategy (ESS), as a judgment method to judge whether the system reaches equilibrium, plays an important role in the process of game evolution. By solving the determinant of Jacobian matrix and the sign of trace of two-dimensional differential dynamic equations, the evolutionary stability strategy of the system can be determined. It can be calculated from Table 2 that at the equilibrium point $(x = p^*, y = q^*)$, $C_{11} = C_{12} = 0$ is not satisfied $C_{11} + C_{12} < 0$. So $(x = p^*, y = q^*)$ is not an ESS, it's just a non-asymptotically stable state. So we only need to talk about the stability of the other four equilibrium points.

(1) When $\pi_M^U - \pi_M^N < 0$, and $\pi_S^D - \pi_S^N < 0$, it can be concluded that $(0,0)$ is the evolutionary stable point of the system, i.e. (manufacturers do not take emission reduction investment measures and suppliers do not take emission reduction investment). In addition, $(1,0)$ and $(0,1)$ are unstable points, (P^*, q^*) is a saddle point, and $(1,1)$ is uncertain.

(2) When $\pi_M^U - \pi_M^N + \beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + F < 0$, and $\pi_S^D - \pi_S^N > 0$, it can be concluded that $(0,1)$ is the evolutionary stable point of the system, i.e. (manufacturers do not take emission reduction investment measures and suppliers take emission reduction investment). Similarly, when $\pi_M^U - \pi_M^N > 0$, $\pi_S^D - \pi_S^N + \beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + F < 0$, $(1,0)$ is the evolutionary stable point of the system, i.e. (manufacturers take emission reduction investment measures and suppliers do not take emission reduction investment). See Figures 1(a) and 1(b).

(3) When $\pi U/M - \pi N/M < 0$, $\pi D/S - \pi N/S < 0$, and $\pi_M^U - \pi_M^N + \beta_S \lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + F > 0$, $\pi_S^D - \pi_S^N + \beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + \mathrm{F} > 0$, $(0,0)$ and $(1,1)$ is the evolutionary stable point of the system, that is (manufacturer's do not take carbon emission reduction investment, suppliers's do not take carbon emission reduction investment) and (manufacturer's carbon emission reduction investment, suppliers's carbon emission reduction investment). At this point, the dynamic phase diagram under this condition can be obtained as shown in Figure 1(c).

3.3. Simulation Analysis of Evolutionary Stability. Based on the above theoretical analysis, with the help of constraints and replication dynamic equations, this paper uses Matlab tool to simulate the evolution process of carbon emission reduction behavior of supply chain enterprises. Suppose that the parameter values in the game payment matrix are as follows: $\nu_M = 50$, $a = 40$, $\delta = 0.2$, $\beta_M = 0.3$, $\beta_S = 0.2$, $\lambda_M = 20$, $\mathrm{K} = 2$, $\overline{\rho}_M = 15$, $\rho_{0M} = 20$, $\lambda_s = 20$, $\mu = 0.1$, $F = 10$, $\nu_S = 50$, $\overline{\rho}_s = 13$, $\rho_{0s} = 16$.

Figures 2(a)–2(d) respectively show the influence of consumers' low carbon preference coefficient, enterprises' upper limit of carbon emission concentration, incentive and punishment coefficients for exceeding carbon emission per unit product, and free-rider penalty intensity on the change of supply chain enterprises' behavioral strategy choice after the expansion of the same multiple. The results show that with the learning and imitation behavior of both parties, the carbon emission reduction behavior strategies of supply chain enterprises ultimately evolve in the direction of (carbon emission reduction investment, carbon emission reduction investment). Among all kinds of influencing factors, the carbon emission incentive and punishment coefficient has the most obvious influence, the consumer's low-carbon product preference coefficient has the middle influence, the enterprise emission concentration ceiling and the government's punishment intensity have no significant effect.

The introduction of command-and-control environmental regulations will put some pressure on the development of enterprises. For example, the EU stipulates that the average emission of new cars sold by 2021 should not exceed 95 grams of CO_2 equivalent. The implementation of such policies will make enterprises weigh the punishment of violation with the investment of emission reduction, so as to make the carbon emission reduction behavior choice strategy. The larger the reward and punishment coefficient of carbon emission per unit product exceeds the standard, the greater the loss the enterprise will bear when it does not take emission reduction measures. Therefore, the enterprise will be more willing to take carbon emission reduction investment behavior, and finally stabilize the carbon emission reduction investment behavior.

At the same time, corporate environmental responsibility will increase the attractiveness of a company's products or services to customers in the industrial market [29], which will then be transformed into consumers' intention to purchase corporate products [30]. In order to maintain certain market competitiveness, enterprises will also be influenced by consumers' low-carbon preference when making carbon emission reduction behavior decisions, as shown in Figure 2(a).

4. Analysis of Carbon Emission Reduction Cooperation Behavior of Supply Chain Enterprises under Market-Based Environmental Regulation and Consumers' Low-Carbon Preference

4.1. Problem Description and Model Assumptions. Under command-based environmental regulations, enterprises pay attention to whether their carbon emissions in each link of production meet the requirements of laws and regulations from their own perspective [14]. Different from the compulsion in the implementation of command-and-control environmental regulations, market-based environmental regulations are formulated by the government according to the operation mechanism of the market [31], which uses the signal mechanism of the market to guide enterprises to conduct pollution control. The main feature is that it provides enterprises with options, and polluters can choose the most effective way to maximize their own interests. Studies have found that incentive environmental regulation has an impact on cooperation and production process management of supply chain enterprises [14], and the model of supply chain enterprise cooperation will lead to the simultaneous increase of product greenness, supply chain profit and consumer surplus [32]. At the same time, with the promotion of the "dual carbon" strategic goal, low-carbon life such as shared travel and recyclable online shopping packaging has gradually become a new trend in society, and consumers' low-carbon demand preference plays an important role in the carbon reduction decision of supply chain enterprises. Therefore, how to realize supply chain coordination under the influence of environmental regulations and consumers' low-carbon preference has become a key direction. This paper assumes that in this environment, the behavioral strategy space of supply chain enterprises is (cooperative carbon emission reduction, non-cooperative carbon emission reduction).

Under the premise of carbon emission reduction investment cooperation consensus, there are two cooperation modes of revenue sharing and cost sharing among enterprises. Liu et al. proposed that cost-sharing contracts for carbon emission reduction can promote and coordinate the development of supply chains in the context of consumers' preference for low-carbon products [5]. In this paper, cost-sharing contract is considered to study the cooperative carbon emission reduction behavior of supply chain enterprises. At the same time, based on Kem's [33] classification of the current macro environmental policies to

Table 2: The value of $C_{11}C_{12}C_{21}C_{22}$ at local equilibrium.

Equilibrium	C_{11}	C_{12}	C_{21}	C_{22}
$x = 0, y = 0$	$\pi_M^U - \pi_M^N$	0	0	$\pi_S^D - \pi_S^N$
$x = 0, y = 1$	$\pi_M^U - \pi_M^N + \beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + F$	0	0	$-(\pi_S^D - \pi_S^N)$
$x = 1, y = 0$	$-(\pi_M^U - \pi_M^N)$	0	0	$\pi_S^D - \pi_S^N + \beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + F$
$x = 1, y = 1$	$-[\pi_M^U - \pi_M^N + \beta_S\lambda_S k(\alpha + 2\delta\beta_M\lambda_M + \delta\beta_S\lambda_S) + F]$	0	0	$-[\pi_S^D - \pi_S^N + \beta_M\lambda_M k(\alpha + 2\delta\beta_S\lambda_S + \delta\beta_M\lambda_M) + F]$
$(x = p^*, y = q^*)$	0	*	*	0

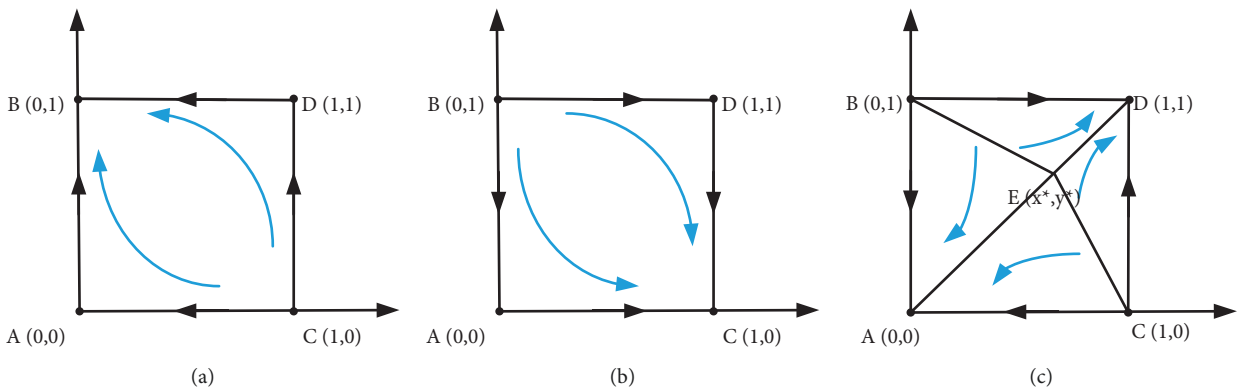


Figure 1: Dynamic phase diagram.

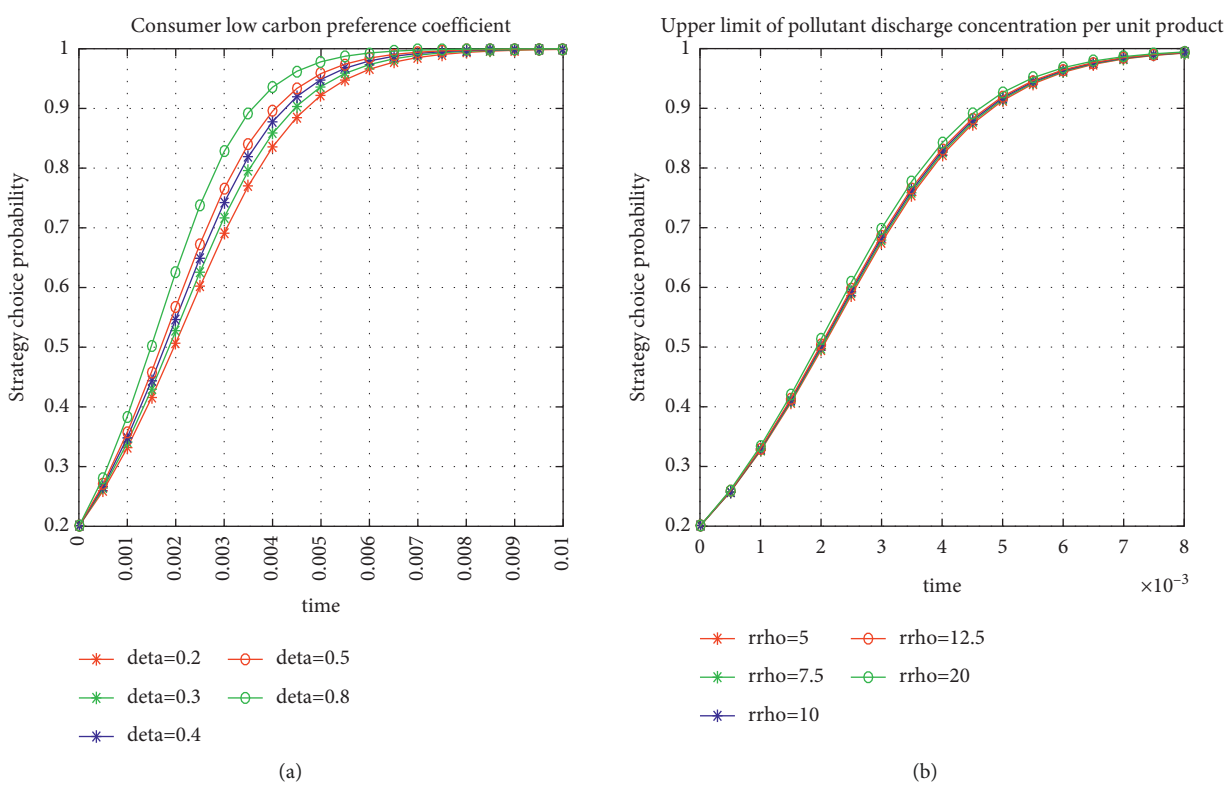


Figure 2: Continued.

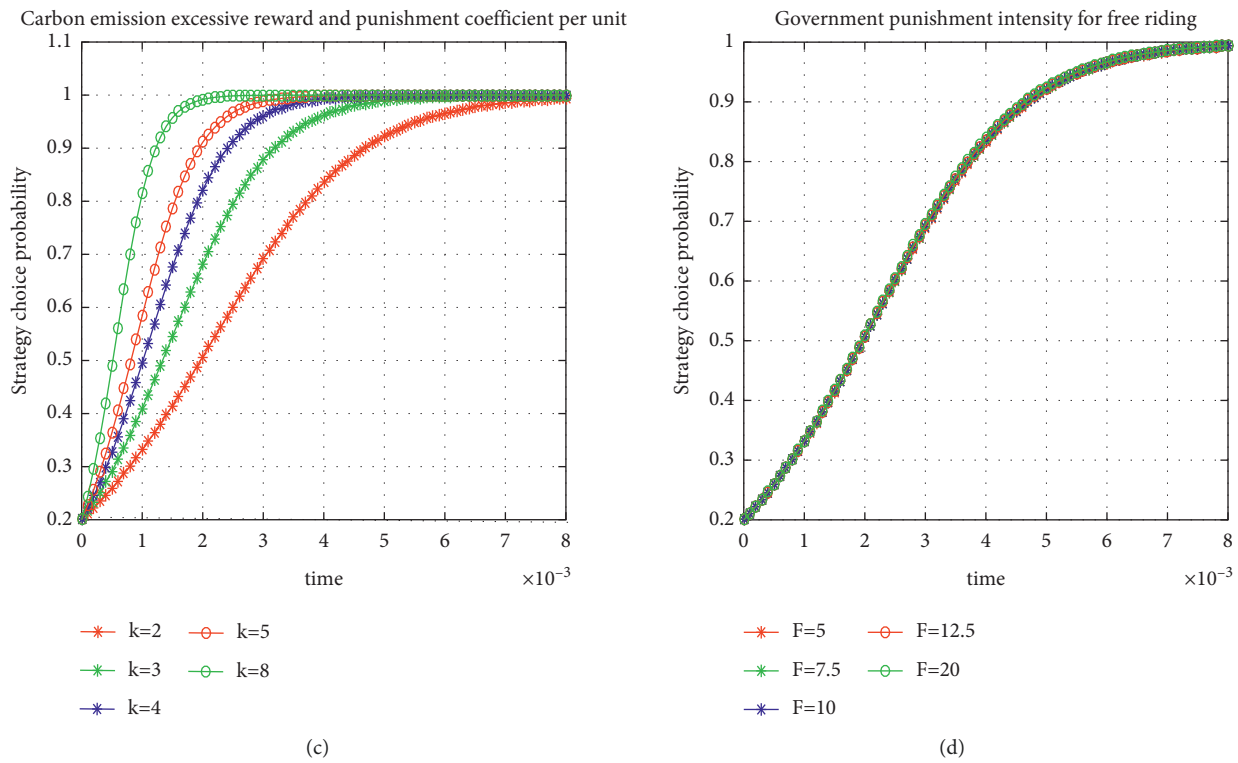


Figure 2: Impact of different parameter changes on carbon emission reduction investment behavior of supply chain enterprises.

encourage enterprises to reduce carbon emissions, and referring to Wang et al.'s research [34], this paper focuses on the impact of three different market-oriented environmental regulation policies, namely, carbon tax, emission trading and cost subsidy, on the cooperative carbon emission reduction behavior of supply chain enterprises. In order to analyze and describe this problem more clearly, this paper makes the following assumptions:

(1) When supply chain enterprises all choose cooperative carbon emission reduction behavior strategy, we can define it as joint emission reduction [35]. In order to promote cooperation behavior between enterprises, it is assumed that one party will bear part of the cost θ_i $(i = M, S)$ of the other party. For example, the proportion of cooperative carbon emission reduction cost borne by the manufacturer is θ_M, and the proportion of cooperative carbon emission reduction investment cost borne by the supplier is θ_S. Carbon emission reduction behaviors of both parties through cooperation will have an impact on market demand.

(2) As can be seen from the previous section, the market demand for carbon emission reduction investment by both parties is $\mathrm{D}(\rho) = \alpha + \delta\rho$. Enterprise cooperation in carbon emission reduction is a manifestation of enterprises actively fulfilling their social responsibilities. Existing research results show that corporate social responsibility has a positive impact on the brand evaluation of entrepreneurs and consumers [36]. This paper assumes that when enterprises choose cooperative carbon emission reduction behavior, the market demand is $D(\rho) = \alpha + \delta\rho + \varphi\mathrm{CCo}$, CCo is the change in brand image of products under cooperative carbon emission reduction behavior, and φ is the influence factor of brand image between manufacturers and suppliers on market demand. $\mathrm{CCo} = \eta_\mathrm{S}\mathrm{Co}_\mathrm{S} + \eta_\mathrm{M}\mathrm{Co}_\mathrm{M}$, η_S and η_M respectively represent the influence coefficient of the supplier's and manufacturer's cooperative carbon emission reduction efforts on the product's brand image; Co_S and Co_M respectively collaborative carbon reduction efforts of suppliers and manufacturers. Based on the hypothesis of the investment cost of carbon emission reduction in 3.1 (1), this part assumes the co-emission reduction cost coefficient is equal to 1, then the value of cooperation emission reduction cost of supply chain enterprises is $1/2\mathrm{Co}_i^2$.

(3) In order to reduce carbon emissions and stimulate enterprises to produce and promote low-carbon products, the government will formulate environmental regulations policies based on the carbon emissions of products. In this model, it is assumed that manufacturers and suppliers obtain a specific initial carbon quota from the government, and that

the maximum carbon emission standards of manufacturer and supplier in the supply chain by the government are $\overline{W_M}$ and $\overline{W_S}$. When the company adopts the carbon emission reduction investment behavior model alone, the carbon emissions generated by the manufacturer and the supplier are $W_M = \rho_{LM} D(\lambda)$ and $W_S = \rho_{LS} D(\lambda)$, $(W_M > \overline{W}_M, W_S > \overline{W}_S)$ respectively. When both companies adopt cooperative carbon emission reduction actions, the carbon emissions generated by the manufacturer and supplier are W_{MC} and $W_{SC}(W_{MC} < \overline{W}_M, W_{SC} < \overline{W}_S)$ respectively. When the actual carbon emissions are greater than the initial carbon quato, the enterprise needs to buy the difference in the carbon emission trading market. On the contrary, the enterprise can sell the difference in the carbon emission trading market. The unit price of carbon emission trading is ε.

(4) The government will also give a certain degree of subsidy to enterprises actively participating in cooperative carbon cooperative emission reduction according to the size of cooperative emission reduction, and the subsidy coefficient is μ. According to the "China Carbon Tax System Design," the government imposes a specific carbon tax on the carbon dioxide emitted by manufacturing companies, and the carbon tax rate is $t = (10–40)$ RMB/t.

(5) Punishment mechanisms have been shown to motivate firms to engage in long-term cooperation [37]. In order to promote the realization of joint emission reduction mode among enterprises, it is assumed that the government will punish enterprises that do not actively participate in cooperative carbon emission reduction to a certain extent, and the intensity of punishment is set as $F\prime\,(F\prime \rangle 0)$. For other parameters, see 3.1 Model.

(6) Suppose the profits of manufacturers and suppliers are π_M' and π_S' respectively. The superscript $N\prime$ indicates that neither manufacturers nor supplier are working together to reduce carbon emissions; the superscript $U\prime$ indicates that manufacturers cooperate in emission reduction while suppliers do not; the superscript $D\prime$ indicates that suppliers cooperate in emission reduction while manufacturers do not; the superscript $B\prime$ indicates that both manufacturers and suppliers adopt cooperative carbon emission reduction behavior.

Assuming that both manufacturers and suppliers are bounded rational decision makers, x $(0\langle x\langle 1)$ is the proportion of manufacturers adopting carbon emission reduction cooperative behavior strategy; y is the proportion of suppliers adopting carbon emission reduction cooperative behavior strategy. The game payment matrix of carbon emission reduction behavior choice of supply chain enterprises under imperative environmental regulation and low-carbon preference of consumers is shown in Table 3.

4.2. Model Construction and Solution. Suppose that the expected return of manufacturers choosing cooperative carbon emission reduction strategy is u_M^{X1}, and the expected return of non cooperative carbon emission reduction is u_M^{X0}:

$$u_M^{x1} = \pi_M^{U'} + y\left[v_M\,\varphi\,\eta_S \mathrm{Co}_S + (1-\mu)\theta_S \frac{1}{2}\mathrm{Co}_M^2\right], \tag{6}$$

$$u_M^{x0} = \pi_M^{N'} + y\left[v_M\,\varphi\,\eta_S \mathrm{Co}_S + (1-\mu)\theta_s \frac{1}{2}\mathrm{Co}_M^2 - F'\right]. \tag{7}$$

Similarly, the expected benefits of supplier cooperative carbon emission reduction and non cooperative carbon emission reduction behavior strategies can be obtained.

The manufacturer's replicated dynamic equation obtained from equations (6) and (7) is:

$$f(x) = \frac{dx}{dt} = x(1-x)\left(u_M^{x1} - u_M^{x0}\right) = x(1-x)\left(\pi_M^{U'} - \pi_M^{N'} + yF'\right). \tag{8}$$

Similarly, the supplier's replication dynamic equation can be obtained as follows:

$$\begin{aligned} f(y) &= \frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y)\left(u_S^{y1} - u_S^{y0}\right) \\ &= y(1-y)\left(\pi_S^{D'} - \pi_S^{N'} + xF'\right). \end{aligned} \tag{9}$$

Make $f(x) = \mathrm{dx/dt} = 0$, $\mathrm{f(y) = dy/dt} = 0$, it can produce the equilibrium point of the dynamic process of evolutionary game, include $E_1'(0,0), E_2'(0,1), E_3'(1,0), E_4'(1,1), E_5'(p^*q^*)$. Where $E_5'(p^*q^*)$ is the equilibrium points of the hybrid strategy. The Jacobi matrix is:

$$J = \begin{bmatrix} df(x)/dx & df(x)/dy \\ df(y)/dx & df(y)/dy \end{bmatrix} = \begin{pmatrix} (1-2x)*\left(\pi_M^{U'} - \pi_M^{N'} + yF'\right) & x*(1-x)F' \\ y*(1-y)*F' & (1-2y)\left(\pi_S^{D'} - \pi_S^{N'} + xF'\right) \end{pmatrix}. \tag{10}$$

Based on the local stability analysis of Jacobian matrix, the equilibrium point of the system is analyzed. The results are shown in Table 4:

The evolutionary stability strategy of the system can be determined by the determinant and the sign of trace of Jacobian matrix. As mentioned in 3.2, the equilibrium point $(x = p^*, y = q^*)$ is not an ESS, it is only a non-asymptotically stable state.

It can be calculated from Table 4 that when $\pi_M^{U'} - \pi_M^{N'} < 0$, $\pi_S^{D'} - \pi_S^{N'} < 0$, $(0,0)$ is the evolutionary

Table 3: Payment matrix of both parties in the game of carbon emission reduction cooperation of supply chain enterprises.

Supplier	Manufacturer: Adopt cooperative measures to reduce carbon emission x	Manufacturer: Adopt non cooperative carbon emission reduction measures $1-x$
Adopt cooperative measures to reduce carbon emission y	$\pi_M^{\acute{B}} = \upsilon_M D(Co) - tW_{MC} - (1-\mu)\left[\begin{array}{c}(1-\theta_S)1/2Co_M^2 \\ +\theta_M 1/2Co_S^2\end{array}\right] + \varepsilon(\overline{W}_M - W_{MC})$	$\pi_M^{\acute{D}} = \upsilon_M D(Co) - tW_M - (1-\mu)[(1 - \theta_S) * 1/2Co_M^2] - \varepsilon(W_M - \overline{W}_M) - F\prime$
	$\pi_S^{\acute{B}} = \upsilon_S D(Co) - tW_{SC} - (1-\mu)\left[\begin{array}{c}(1-\theta_M)1/2Co_S^2 \\ +\theta_S 1/2Co_M^2\end{array}\right] + \varepsilon(\overline{W}_S - W_{SC})$	$\pi_S^{\acute{D}} = \upsilon_S D(Co) - tW_{SC} - (1-\mu)(1/2Co_S^2 + \theta_S * 1/2Co_M^2) + \varepsilon(\overline{W}_S - W_{SC})$
	$D(Co) = \alpha + \delta\rho + \varphi(\eta_M Co_M + \eta_s Co_s)$	$D(Co) = \alpha + \delta\rho + \varphi\eta_s Co_s$
Adopt non cooperative carbon emission reduction measures 1-y	$\pi_M^{\acute{U}} = \upsilon_M D(Co) - tW_{MC} - (1-\mu)(1/2Co_M^2 + 1/2\theta_M Co_S^2) + \varepsilon(\overline{W}_M - W_{MC})$	$\pi_M^{\acute{N}} = \upsilon_M D(Co) - tW_M - (1-\mu)1/2Co_M^2 - \varepsilon(W_M - \overline{W}_M)$
	$\pi_S^{\acute{U}} = \upsilon_S D(Co) - tW_S - (1-\mu)[(1 - \theta_M) * 1/2Co_S^2] - \varepsilon(W_S - \overline{W}_S) - F\prime$	$\pi_S^{\acute{N}} = \upsilon_S D(Co) - tW_S - (1-\mu)1/2Co_S^2 - \varepsilon(W_S - \overline{W}_S)$
	$D(Co) = \alpha + \delta\rho + \varphi\eta_M Co_M$	$D(Co) = \alpha + \delta\rho$

Table 4: The value at the $C_{11}C_{12}C_{21}C_{22}$ local equilibrium.

Equilibrium	C_{11}	C_{12}	C_{21}	C_{22}
$(x = 0, y = 0)$	$\pi_M^{U'} - \pi_M^{N'}$	0	0	$\pi_S^{D'} - \pi_S^{N'}$
$(x = 0, y = 1)$	$\pi_M^{U'} - \pi_M^{N'} + F'$	0	0	$-(\pi_S^{D'} - \pi_S^{N'})$
$(x = 1, y = 0)$	$-(\pi_M^{U'} - \pi_M^{N'})$	0	0	$\pi_S^{D'} - \pi_S^{N'} + F'$
$(x = 1, y = 1)$	$-(\pi_M^{U'} - \pi_M^{N'} + F')$	0	0	$-(\pi_S^{D'} - \pi_S^{N'} + F\prime)$
$(x = p^*, y = q^*)$	0	*	*	0

stability point of the system, that is (manufacturers do not cooperate in emission reduction measures, suppliers do not cooperate in carbon emission reduction). $(1, 0)$ and $(0, 1)$ are unstable points, and $(1, 1)$ is uncertain.

When $-F' < \pi_M^{U'} - \pi_M^{N'} < 0$, $-F' < \pi_S^{D'} - \pi_S^{N'} < 0$, $(0, 0)$ and $(1, 1)$ is the evolutionary stability point of the system, that are (manufacturers do not take cooperative emission reduction measures and suppliers do not take cooperative emission reduction measures) and (manufacturers take cooperative emission reduction measures and suppliers take cooperative emission reduction measures). In addition, $(1, 0)$ and $(0, 1)$ are the unstable points, as shown in Figure 3.

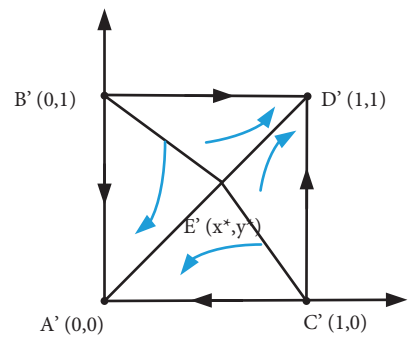


Figure 3: Dynamic phase diagram.

4.3. Simulation Analysis of Evolutionary Stability. Based on the above theoretical analysis, with the help of constraints and replication dynamic equations, Matlab is used to simulate the evolution process of cooperative carbon emission reduction behavior among supply chain enterprises.

Suppose that in the game payment matrix, the parameter values are as follows: $\nu_M = 50$, $a = 40$, $\delta = 0.2$, $\varphi = 0.2$, $\eta_M = 0.3$, $Co_M = 30$, $t0 = 10$, $W_M = 30$, $\mu = 0.2$, $\theta_M = 0.5$, $Co_s = 30$, $\varepsilon = 8$, $\overline{W}_M = 20$, $\eta_S = 0.2$, $W_{MC} = 15$, $F' = 10$, $\nu_S = 40$, $W_S = 25$, $\theta_S = 0.2$, $\overline{W}_S = 18$, $W_{SC} = 12$, $\beta_M = 0.3$, $\lambda_s = 20$, $\lambda_M = 20$, $\beta_S = 0.2$, $W_{MS} = 10$.

Figures 4(a)–4(d)show the impact of input subsidy coefficient, unit carbon emission transaction price, carbon tax rate and low-carbon preference of consumers on corporate carbon reduction cooperative behavior strategy. The results show that the system eventually evolves in the direction of (cooperative emission reduction investment, cooperative emission reduction investment). The convergence rate of cooperative carbon emission reduction behavior strategy of supply chain enterprises is relatively fast under the influence of carbon tax rate, the convergence rate is in the middle under the influence of carbon emission trading price.

Under fiscal policies, governments of various countries often levy taxes or provide subsidies according to the energy consumption of different products, so as to drive enterprises in the supply chain to realize product substitution and low-carbonization while maximizing profits [38]. In the cooperative emission reduction investment mode, this paper considers the influence of subsidies when investing in carbon emission reduction. However, the input subsidy coefficient is reflected in the two-way cost mutual sharing, and the cost sharing accounts for a small proportion in the total cost. Therefore, the expansion of the input subsidy coefficient by the same factor in Figure 4(a) has a smaller impact on the cooperative carbon emission reduction behavior than other variables. In terms of environmental regulation policies, carbon tax will increase the tax burden of enterprises, while subsidies will reduce the production cost of enterprises. Therefore, we can consider to combining the two to achieve the regulation of enterprises' carbon emission reduction behavior.

Figure 4(b) shows the impact of unit carbon trading price on emission reduction behavior strategy under different scenarios. It is found that the larger the unit carbon trading price is, the faster the convergence rate of cooperative carbon emission reduction behavior strategy is. It shows that carbon trading price can effectively promote the cooperative carbon emission reduction behavior of supply chain enterprises. This is mainly because under the carbon regulatory policy, if the carbon emission level is lower than the initial carbon quota, suppliers and manufacturers can sell the remaining quota in the carbon trading market to obtain additional profits, and the increase of the carbon trading price leads to the increase of additional profits. The carbon trading price is determined by the carbon emission trading market [34]. Therefore, the carbon emission trading market can stimulate the supply chain to reduce carbon emissions by regulating the carbon trading price.

Carbon tax policy is implemented by the government, which is an effective means of carbon emission control by directly taxing enterprises that emit carbon dioxide [39]. Figure 4(c) shows the results of corporate behavior strategy selection under different carbon tax rates. It can be seen that the change of carbon tax rate has a significant impact on the convergence rate of corporate cooperative carbon emission reduction behavior strategy. The implementation of carbon tax policy in supply chain enterprises has a certain incentive effect on carbon emission reduction in manufacturing industry, and encourages manufacturers to increase investment in carbon emission reduction, so as to obtain environmental and economic benefits.

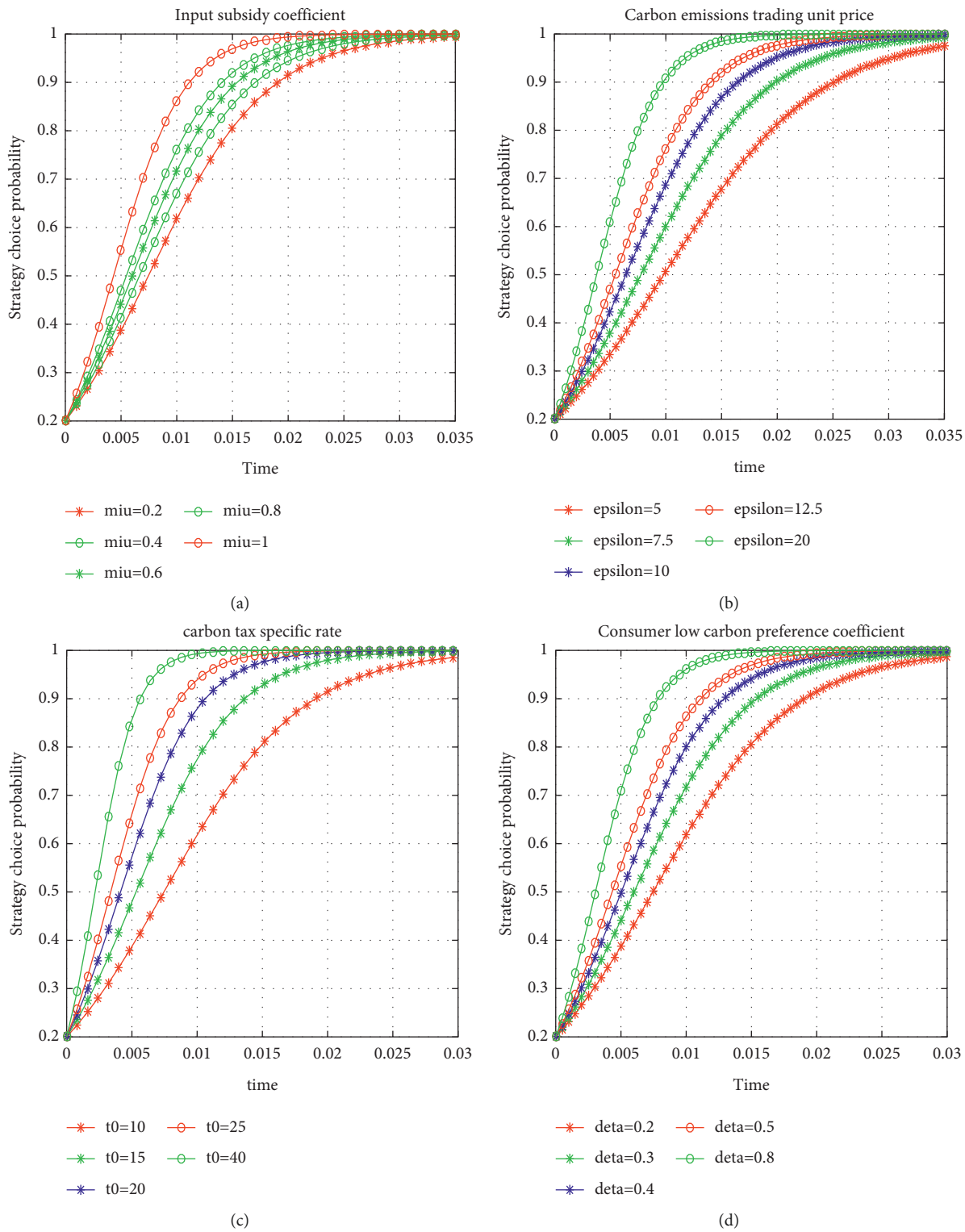


Figure 4: Enterprise behavior strategy under different parameter changes.

Figure 4(d) shows the results of corporate behavior strategy selection under the effect of low-carbon consumption preference. It can be seen that the higner the consumer's low-carbon preference coefficient is, the faster the convergence rate of corporate cooperative carbon emission reduction behavior selection probability will be. Some studies has also confirmed that consumers are more willing to choose environmentally friendly products and services [29]. Therefore, with the further improvement of consumers' awareness of environmental protection, it has become a key factor influencing enterprises' choice of carbon emission reduction behavior.

5. Conclusions and Prospects

This paper first obtains the respective profits of supply chain enterprises under different strategy combinations, and then obtains the evolutionary stability strategy of carbon emission reduction investment behavior and cooperative carbon emission reduction behavior by using evolutionary game theory. Finally, numerical simulation is used to analyze the low-carbon decision-making behavior of supply chain enterprises under different circumstances. It can be found that: (1) In the strategy of choosing whether to implement carbon emission reduction investment behavior, when the profit difference between the two sides of the enterprise does not participate in carbon emission reduction investment behavior and only one side chooses to participate in carbon emission reduction behavior is less than a certain threshold value, and the difference between the two is greater than 0, enterprises will evolve towards the trend of (carbon emission reduction investment, carbon emission reduction investment) in a long time. Through numerical simulation, it is found that the preference coefficient of consumers' low-carbon products and the incentive and punishment coefficient of carbon emissions significantly promote enterprises' carbon emission reduction investment behavior, the upper limit of enterprises' emission concentration and the government's punishment intensity have no significant effect; (2) Under the influence of market-based environmental regulation and consumers' low-carbon preference, when the profit difference between the only one party choosing cooperative carbon emission reduction and two parties' not participating in cooperative carbon emission reduction investment is more than a certain threshold value, the two parties' enterprises will evolve towards the trend of (cooperative carbon emission reduction investment, cooperative carbon emission reduction investment) in a long time. Carbon tax rate, input subsidy cost, unit carbon emission trading price and consumers' preference for low-carbon demand are important factors influencing the cooperative carbon emission reduction behavior among supply chain enterprises.

This paper puts forward the following suggestions: first of all, as the key force in supply chain emission reduction, manufacture can adopt improved emission reduction technology to reduce the carbon content of products, and the suppliers' investment in carbon emission reduction can help promote consumers' consumption of low-carbon products. Considering the long-term development, both parties can consider actively seeking cooperation opportunities through two-way cost sharing, so as to achieve coordinated development in the supply chain and achieve the emission reduction goal; Secondly, the government's environmental regulation policy has a great impact on the carbon reduction decision of supply chain enterprises. Therefore, the government can promote supply chain enterprises to reduce carbon emissions by regulating the upper limit of emission concentration, carbon emission reward and punishment coefficient of carbon emissions, input subsidy coefficient, etc. For example, by drawing on the experience of Sweden, France and other countries and combining China's national conditions and industry characteristics, the carbon tax rate is formulated to achieve the purpose of stimulating emission reduction through carbon tax; Finally, supply chain members and governments can promote consumers' awareness of low-carbon consumption through advertising and other strategies. At the same time, they should also timely collect and feedback consumers' information about low-carbon products to help manufacturers improve their products, so as to increase product sales.

This paper deduces and reveals the dynamic mechanism of carbon emission reduction investment behavior and cooperative carbon emission reduction behavior among supply chain enterprises, which provides a certain reference basis for the choice of carbon emission reduction behavior strategy of supply chain enterprises and the formulation of government environmental regulation measures. However, the current research only stays at the level of theoretical deduction, and further research can be carried out based on the collection of actual data in the later stage. In addition, the supply chain composed of one manufacturer and one supplier is considered in our study, and the case of multiple suppliers and multiple manufacturers can be considered in future research.

Data Availability

All data used in this study can be accessed by request.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] F. Max, L. Kai, J. Michael, S. J. Christoph, and E. Ottmar, "Mobilizing domestic resources for the agenda 2030 via carbon pricing," *Nature Sustainability*, vol. 1, no. 7, pp. 350–357, 2018.

[2] International Energy Agency, "Global Energy Review: CO2 Emissions in 2021," 2022, https://www.iea.org/data-and-statistics/data-product/global-energy-review-co2-emissions-in-2021.

[3] S. F. Zhang and M. L. Bu, "Environmental regulation, environmental protection investment and productivity: an empirical study based on questionnaire of enterprises in China," *Nankai Economic Studies*, no. 02, pp. 129–146, 2011.

[4] C.-M. Shuai, L.-P. Ding, Y.-K. Zhang, Q. Guo, and J. Shuai, "How consumers are willing to pay for low-carbon products? - results from a carbon-labeling scenario experiment in China," *Journal of Cleaner Production*, vol. 83, pp. 366–373, 2014.

[5] M.-l. Liu, Z.-h. Li, S. Anwar, and Y. Zhang, "Supply chain carbon emission reductions and coordination when consumers have a strong preference for low-carbon products," *Environmental Science and Pollution Research*, vol. 28, no. 16, pp. 19969–19983, 2021.

[6] D. Wu and Y. X. Yang, "Study on the differential game model for supply chain with consumers'Low carbon preference," *Chinese Journal of Management Science*, vol. 29, no. 04, pp. 126–137, 2021.

[7] G. H. Qu, L. Yang, W. H. Qu, and Q. M. Li, "Game model to analyze strategy options between government regulation and public supervision under in the third party international

environmental audit," *Chinese Journal of Management Science*, vol. 29, no. 04, pp. 225–236, 2021.

[8] A. B. Jaffe, R. G. Newell, and R. N. Stavins, "A tale of two market failures: technology and environmental policy," *Ecological Economics*, vol. 54, no. 2-3, pp. 164–174, 2005.

[9] A. Jordan, R. K. W. Wurzel, and A. R. Zito, "Comparative conclusions - "new" environmental policy instruments: an evolution or a revolution in environmental policy?" *Environmental Politics*, vol. 12, no. 1, pp. 201–224, 2003.

[10] Y. K. Xu, Y. Qi, and P. F. Song, "Environmental punishment corporate performance and emission reduction incentive--empirical evidence from China's industrial listed companies," *Journal of China University of Geosciences*, vol. 20, no. 04, pp. 72–89, 2020.

[11] C. Han, Z. Wang, and L. Tian, "The mechanism of environmental regulation driving emission reduction: pollution treatment behavior and resource reallocation effect," *Journal of China University of Geosciences*, vol. 44, no. 08, pp. 82–105, 2020.

[12] J. Huang, J. Zhao, and J. Cao, "Environmental regulation and corporate R&D investment-evidence from a quasi-natural experiment," *International Review of Economics & Finance*, vol. 72, pp. 154–174, 2021.

[13] U. Farooq, J. Ahmed, M. I. Tabash, S. Anagreh, and B. H. Subhani, "Nexus between government green environmental concerns and corporate real investment: empirical evidence from selected Asian economies," *Journal of Cleaner Production*, vol. 314, Article ID 128089, 2021.

[14] F. X. Cheng and Y. T. Sun, "An empirical study on the effects of environmental regulation on low-carbon manufacturing practice-A case of cement enterprises," *East China Economic Management*, vol. 32, no. 03, pp. 167–175, 2018.

[15] Q. Zhu and Y. Geng, "Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers," *Journal of Cleaner Production*, vol. 40, pp. 6–12, 2013.

[16] J. Pang and W. D. Li, "On low-carbon preference and consumption function," *China Population,Resources and Environment*, vol. 21, no. 09, pp. 76–80, 2011.

[17] S. Du, L. Hu, and M. Song, "Production optimization considering environmental performance and preference in the cap-and-trade system," *Journal of Cleaner Production*, vol. 112, pp. 1600–1607, 2016.

[18] W. Wen, P. Zhou, and F. Zhang, "Carbon emissions abatement: emissions trading vs consumer awareness," *Energy Economics*, vol. 76, pp. 34–47, 2018.

[19] L. Sun, X. Cao, M. Alharthi, J. Zhang, F. Taghizadeh-Hesary, and M. Mohsin, "Carbon emission transfer strategies in supply chain with lag time of emission reduction technologies and low-carbon preference of consumers," *Journal of Cleaner Production*, vol. 264, Article ID 121664, 2020.

[20] W. Chen and Z.-H. Hu, "Using evolutionary game theory to study governments and manufacturers' behavioral strategies under various carbon taxes and subsidies," *Journal of Cleaner Production*, vol. 201, pp. 123–141, 2018.

[21] R. Zhao, X. Zhou, J. Han, and C. Liu, "For the sustainable performance of the carbon reduction labeling policies under an evolutionary game simulation," *Technological Forecasting and Social Change*, vol. 112, pp. 262–274, 2016.

[22] S. Zhang, C. Wang, and C. Yu, "The evolutionary game analysis and simulation with system dynamics of manufacturer's emissions abatement behavior under cap-and-trade regulation," *Applied Mathematics and Computation*, vol. 355, pp. 343–355, 2019.

[23] I. Macho-Stadler, "Environmental regulation: choice of instruments under imperfect compliance," *Spanish Economic Review*, vol. 10, no. 1, pp. 1–21, 2008.

[24] L. N. Yu, L. Qiu, and J. J. Yu, "Incentives of carbon emission policies for corporate low-carbon technologies R &D," *Journal of Ocean University of China*, vol. 02, pp. 51–55, 2014.

[25] S. A. Wu, "Discussion on reforming and perfecting my country's pollution charge system," *Finance & Trade Economics*, vol. 08, pp. 65–67, 2007.

[26] R. Jones and H. Mendelson, "Information goods vs. industrial goods: cost structure and competition," *Management Science*, vol. 57, no. 1, pp. 164–176, 2011.

[27] Y. Jiang, S. Han, and Y. Zhao, "Differential game analysis of dynamic carbon emission reduction strategy of three-echelon supply chain under low-carbon economy," *Operations Research and Management Science*, vol. 12, no. 9, pp. 89–97, 2020.

[28] D. Friedman, "Evolutionary games in economics," *Econometrica*, vol. 59, no. 3, pp. 637–666, 1991.

[29] M. E. Drumwright, "Socially responsible organizational buying: environmental concern as a noneconomic buying criterion," *Journal of Marketing*, vol. 58, no. 3, pp. 1–19, 1994.

[30] B. A. Lafferty and R. E. Goldsmith, "Corporate credibility's role in consumers' attitudes and purchase intentions when a high versus a low credibility endorser is used in the ad," *Journal of Business Research*, vol. 44, no. 2, pp. 109–116, 1999.

[31] J. B. Hockenstein, R. N. Stavins, and B. W. Whitehead, "Crafting the next generation of market-based environmental tools," *Environment: Science and Policy for Sustainable Development*, vol. 39, no. 4, pp. 12–33, 1997.

[32] M. Sinayi and M. Rasti-Barzoki, "A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention," *Journal of Cleaner Production*, vol. 196, pp. 1443–1458, 2018.

[33] R. Kemp, *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments*, Edawrd Elgar Publishing, Cheltenham, 1997.

[34] Z. Wang, A. E. I. Brownlee, and Q. Wu, "Production and joint emission reduction decisions based on two-way cost-sharing contract under cap-and-trade regulation," *Computers & Industrial Engineering*, vol. 146, Article ID 106549, 2020.

[35] J. Ji, Z. Zhang, and L. Yang, "Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference," *Journal of Cleaner Production*, vol. 141, pp. 852–867, 2017.

[36] J. Li, Y. S. Jiang, J. Wang, and C. Liu, "Research on the impact mechanism of corporate social responsibility on consumer brand evaluation," *Soft Science*, vol. 34, no. 8, pp. 19–24, 2020.

[37] S. Gächter, E Renner, M Sefton, and Sefton, "The long-run benefits of punishment," *Science (New York, N.Y.)*, vol. 322, no. 5907, p. 1510, 2008.

[38] L. Xu, C. Wang, Z. Miao, and J. Chen, "Governmental subsidy policies and supply chain decisions with carbon emission limit and consumer's environmental awareness," *RAIRO - Operations Research*, vol. 53, no. 5, pp. 1675–1689, 2019.

[39] G. Xu and D. Yue, "Pricing decisions in a supply chain consisting of one manufacturer and two retailers under a carbon tax policy," *IEEE Access*, vol. 9, pp. 18935–18947, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7561210, 12 pages
https://doi.org/10.1155/2022/7561210

Research Article

Residents' Budget Preference, Private Willingness to Pay, and Budget Resource Allocation Satisfaction Based on the Analysis of the Survey Data of J City

Tianyu Han,[1] **Guoqin Zhao**,[2] **and Jun Wang**[3]

[1]*School of Finance and Taxation, Central University of Finance and Economics, Beijing 10034, China*
[2]*Research Institute of Finance and Economics, Central University of Finance and Economics, Beijing 102206, China*
[3]*Tianqiao District Bureau of Statistics, Jinan 250000, China*

Correspondence should be addressed to Guoqin Zhao; bnuzgq@126.com

Received 7 May 2022; Revised 28 June 2022; Accepted 8 July 2022; Published 2 August 2022

Academic Editor: Lele Qin

As finance is the foundation and important pillar of the national governance system, the participation of residents in the core budget process is vital. Accurately revealing the resident budget preferences is the logical starting point for residents to participate in the budget. Based on more than 1500 resident surveys in City J, the work used the contingent valuation method to measure resident budget preferences. On this basis, the relationship between population heterogeneity and budget preference was analyzed by seemingly unrelated regressions. It was found that the structure of resident budget preferences is consistent with the structure of public expenditure. Residents believed that among budget categories, the expenditures on education, social security, and employment are the highest, and the expenditures on commercial services and finance are the lowest. Attention should be paid to the voice that may be ignored during the allocation of budget funds through the revelation and aggregation of residents' preferences as the entry point for the aggregation of financial consensus. Besides, the threshold for citizens' budget participation can be reduced by integrating program budget concepts and deepening the fiscal-expenditure classification reform.

1. Introduction

The people-centered approach reflects the nature of China's state system and national governance system. Adhering to the people-centered approach should not only be included in the results of continuously improving people's livelihood and enhancing people's well-being but also in the process of people's continuous participation and integration into national governance. According to the report of the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China, the basic goal of the "full security of the people's equal participation and equal development rights" should be reached by 2035. As finance is the foundation and important pillar of the national governance system, the participation of residents in the process of allocating the core budget resources of public finance is extremely important.

For a long time, Musgray's theory of fiscal function and the theory of political behaviors of public choices have regarded the government as the main body of budget resourcing [1]. They both discuss the desirability of resource allocations on this basis. However, the foreign institutes have gradually focused on residents in recent years, and their logic lies in the huge gap between public expectations and the actual performance of the government as recognized by many scholars, such as Wielch et al. [2] and Royo et al. [3]. This drop weakened residents' trust in the government and caused the so-called "democracy deficits" [4]. Therefore, more studies use different methods to establish a direct measurement of residents' preferences and budget resourcing, for example, the calculation of the WTP of public projects in different categories [4, 5], the cross-border comparison of resident budget preferences using the

Contingent Valuation Method [6], and the investigation of the preference of residents to different public sector resource allocations using the best-worst scaling [7–9]. In practice, institutional innovations represented by participatory budgeting are performed in small scopes, such as allowing local citizens to identify and discuss the priority of specific public expenditure projects [10].

Compared with foreign theories and practices, China has practical explorations, including establishing resident preferences and budget resourcing in Wenling and other places. However, at the theoretical research level, domestic research focuses more on the participation of residents in the budget formulation process, i.e., in the preparation, approval, and supervision of the budget, and it is different from the direct measurement of resident budget preferences in foreign literature. Some references on the direct correlation between resident preferences and budget resourcing allocation either replace direct residents' expressions with proposals of NPC deputies [11] or simply aggregate residents' needs with "responsive spending" [12], lacking in-depth studies on the direct measurement of resident budget preferences. Therefore, the gap between theoretical exploration and practical attempts provides an entry point for the work, and a series of related questions need to be solved urgently, which are as follows: how to directly measure the budget preferences of Chinese residents? Are the current resident budget preferences consistent with the result of the allocation of government budget resourcing? Can the population characteristics of the residents affect the population's budgetary preference, and which factors are greater? What are the implications of these studies for improving budget resourcing?

The work collected the budget preference information on more than 1,500 residents in City J using the contingent valuation method (CVM) to solve the above questions. Residents' private willingness to pay (WTP) was estimated for comparison with actual budgeting. The relationship between population heterogeneity and budget preference was analyzed by seemingly uncorrelated regression (SUR). There are two potential innovation points in the work: compared with many people's concerns about the participation in the budget process, the work, in combination with China's reality, showed a realistic and feasible way to measure the residents budget preferences. The WTP of the residents was estimated through the measurement of the resident budget preferences to provide ideas for the disclosure and aggregation of residents' preferences in the participatory budgeting. Besides, the factors affecting the resident budget preferences were analyzed through their group characteristics, and the related analysis could provide ideas for budget reforms.

2. Literature Review

As early as the last century, a scholar complained about the concern of budget organization and programming processes on the rationality of the budget portfolio. According to his statement, "What is the decision-making basis for assigning x US dollars to A instead of B [13]?" In other words, the "relative value" of public services should be identified more precisely so that all expenditures are worth more than their alternatives [14]. Meanwhile, concerning the impact of early interest groups on budget resource allocation, the researchers of welfare economics have given a new answer to this question, i.e., public decision-making should be developed based on its impact on individual benefits, and individuals are most qualified to decide what this impact is [15]. Moreover, the government's continuous response to residents' preferences is the key feature of democracy [16]. Especially in public expenditures, policymakers tend to provide the high level of the expenditure expected by the public [17].

Therefore, Wildawsky [18] took the lead to optimize the "integration and allocation process of public resources for the budgeting agency." It helps to improve government functions [19]. In practice, the program budget, zero-based budgeting, results-based budgeting, and other tools are proposed to improve the responsiveness to the population in increasing the allocation of budget resources. These tools do expand budget flexibility and provide more responsiveness than incremental budgets. However, from the correlation analysis of the relationship between the budgeting agency and fiscal results, they are more responsive to the median voter than to all residents as a whole.

Although the status of the resident preference in the public budget process is both significant and important, people have different opinions on the form and extent of the integration of resident preferences into the budget. Unlike the participation of residents in other administrative areas, the professionalism of budgeting may be the highest unattainable barrier [20]. Although the starting point for linking residents' preferences and budget resourcing allocation is good, in practice, individuals cannot handle many complex and difficult problems. Berry et al. [21] put forward necessary conditions for the effectiveness of residents' participation after comprising fifteen cities. Comparison focuses on the fields of granting the exclusive right to citizens to realize the control of resource allocation, balancing the relationship between administrative staff and resident associations, and the participation of all citizens in the coverage.

Such a threshold allows researchers to focus on the direct disclosure of resident budget preferences from the embedding process. This process is difficult because of certain reasons. To be specific, from the perspective of the interaction relationship between the government and the residents under the principal-agent framework, the public sector is expected to deliver public goods that meet the residents' preferences at reasonable costs, i.e., resources collected directly or indirectly from the people should be used in the best way to satisfy people's preferences, which requires the government to accurately identify people's preferences. On the other hand, the nonexclusive and noncompetitive characteristics of public goods determine the existence of the "free-riding" problem. Besides, residents who pursue their maximal interests may hide their real preferences for public goods [22].

Another difficulty in revealing the resident budget preferences is that there is a huge difference in the preference of

population groups. Sørensen [23] found that influenced by the generation effect and life cycle course, elderly people tend to increase healthcare and pension expenditure and reduce education expenditure in terms of social welfare expenditure. Bellani and Scervini [24] found that based on the U.S. population data, the heterogeneity of people's preferences tended to reduce physical reallocation, however, income inequality tended to increase in-kind redistribution. Gärtner et al. [25] believed that there was a positive correlation between personal income redistribution preference and risk aversion. That is to say, the uncertainty of income will lead to more redistribution of individuals on public policies.

Finally, in the face of heuristic questions, respondents tend to simplify decision-making rules [26]. For example, in the process of collecting residents' preferences, some respondents tend to anchor specific information to reduce their workload [6]. This move makes the results show greater randomness and further affects the information quality of decision-makers.

Berry et al. [21] listed many methods of revealing residents' preferences to participate in the budget process to solve the above problems and reveal the real resident budget preferences. It included panel discussion or focus group, problem advisory committee, open information discussion, and the contingent valuation method. Among them, the contingent valuation method is the most widely used. However, the contingent valuation method has many shortcomings. Therefore, Freeman et al. [27] and Gärtner et al. [25] provided a theoretical basis for WTP, making up for some of the shortcomings of the contingent valuation method. On this basis, the CVM has been gradually applied to measure the resident budget preferences.

After the basic theory has been completed, the shortcomings of CVM have been gradually improved and many new ways of application have been created. For example, Simonsen [28] emphasized the provision of budget information in the questionnaire. Robbins and Simonsen [29] proposed the adoption of the "dynamic" process, i.e., on one hand, allowing the residents to choose the required public services under the budget constraints, and allowing residents to pay for the required public services on the other. It is similar to the structured value public vote proposed by McDaniels [30]. He allowed residents to select the public services in the order they needed. Koford [5]combined these two methods to assess the WTP of the resident and assess the strength of the resident budget preferences through WTP.

Furthermore, how does residents' budget preferences affect government's fiscal expenditure structure? Researchers focus more on discussing this issue from the perspective of public election and participatory budget. Fox et al. [31] found that the financial structure of big cities played a decisive role in deciding whether the residents moved. People who were dissatisfied with public services were more likely to express their preferences by moving and complaining [32]. Funk and Gathmann [33] showed that voter preference has a great influence on the stability of government expenditure. On the other hand, the government's response to residents' budgetary preferences is constrained. Brueckner [34] found that in a sound democratic system, the basic feature of a government that satisfies residents' preference for public service is the pursuit of maximum social welfare. Shah [35] argues that the response of public spending to local residents' budgetary preferences is subject to the construction of local institutions (such as democracy, transparency, and government capacity).

These studies have provided a good basis for this study, and there are still some deficiencies in the in-depth discussion of this issue in China. Firstly, how to reveal the meaning of the resident budget preference is more obvious than the process of embedding the budget concerning the resident budget preference, which is also a logical starting point for the study of the participation of residents in the budget. However, residents tend to simplify decision-making rules when expressing what they want in the face of inspiring questions. They reduce their workload by anchoring specific information. Therefore, the randomness of the answers should be avoided in the study design to reflect people's real preferences. Secondly, in the discussion of resident budget preferences and public expenditure structure, in addition to the interaction relationship between the two, it should also pay more attention to the important issues under China's national conditions. Under the current China system, are the resident budget preferences consistent with the actual budget preferences? Thirdly, can the population characteristics of the residents affect the resident budget preferences, and which factors have a greater impact?

3. Research and Design

3.1. Research Methods. The contingent valuation method (CVM) is adopted for the purpose hereof. The CVM is originally designed to estimate the environment value [36] and is then widely applied in various fields because of its important role in utility evaluation. It is defined as follows: "CVM determines residents' preferences by asking them how much monetary value they are willing to provide for the benefits provided by the public goods, i.e., their private willingness to pay (WTP) [37]. The method designs a virtual market for public goods in which residents voluntarily pay a price for the public goods. It sidesteps the problem of missing markets for public goods in the real world." The CVM method avoids the problem of the lack of market for public products and provides a virtual market for consumers to purchase such products. Virtual markets can be modeled after private markets or political markets. Because of WTP, the value depends on the contingent virtual market described by the respondent. Hence, the method becomes contingent valuation. However, with the wide application of the method, many problems are emerging, two of which are the most critical: one is to assume the deviation, as the contingent valuation method is based on the virtual market. Hence, the respondents may not take it seriously. The other is the estimation of WTP out of control by the actual budget constraint, i.e., the "unlimited resources" that the residents prefer [28].

For the above questions, two solutions are designed for the questionnaire: firstly, estimate the degree of cognitive effort of interviewees to determine whether they take the

investigation seriously (see 4.1 for details). Secondly, put forward a clear budget constraint line in the questionnaire design, i.e., the total amount of all budget funds must be 100.

3.2. Model Design. This work draws on the budget allocation model established by Blomquist et al. [38] to establish links between the willingness to pay (WTP) and the budget allocation.

Firstly, we assume that each family allocates different categories of public budgets to maximize the effect. It is assumed that the family utility function is as follows:

$$u = u(m, n), \tag{1}$$

where m is the vector of services provided by the government, and n is a vector representing all other goods and services. A family maximizes its utility by choosing b, and the process depends on the budget line.

$$i = p'n, \tag{2}$$

where i is equal to the income, and p is the vector of the market price. Replacing the solution of utility maximization with a utility function produces an indirect utility function.

$$v\,n\,v(p, n, i)\mathrm{n}u(x(p, n, i), \mathrm{n}). \tag{3}$$

Government services are produced by the production functions of the government. Hence,

$$n = f\left(a_j, t\right), \tag{4}$$

where a is the vector of government allocations corresponding to each service j. t represents the production technology of the government. Although the budget selection technology does not allow families to select services, it does allow them to choose the allocation. Maximizing household effect on governmental services means that families will allocate budget increments so that the marginal effects of each dollar allocated are equal. Therefore, each family allocates budgets according to its preferences, and families will allocate budget increments as follows:

$$\begin{aligned} \frac{\partial u}{\partial a^j} &= \frac{\partial u}{\partial a^k}\ (j \neq k), \\ a^j &= T, \end{aligned} \tag{5}$$

where T is the total additional funds allocated between the budget categories. Therefore, the marginal willingness of any two budget categories between j and k is weighted as follows:

$MWTTO_{jk} = a_j/a_k$. So far, how to allocate budget increments to maximize utility has been shown. Users may have a clear idea of how a family's WTP is linked to its allocation to public budget increments. Assuming that families have allocated budgets following their preferences, they have the opportunity to express their WTP for the expansion of services of a particular budget category. The expanded WTP can be represented by indirect utility functions.

$$v\left(p, n\left(a_j, t\right), i\right) = v\left(p, n'\left(a_j, t\right), i - WTP\right). \tag{6}$$

The last Eq is used to take the initial utility as the utility associated with the increased services, however, WTP is reduced by the income. Therefore, WTP can be gained with the increased services related to specific budget categories. From the willingness of the individuals to expand the WTP for a particular sector, the willingness to expand the payment for other services can be drawn from the ratio shown in equation (7). That is to say, WTP reflects the service value of a single budget category, while the ratio in the equation shows how the funds should be allocated so that the marginal utility of each dollar is the same among different categories. These ratios are also relative valuations to measure a family's expenses for the service of a particular budget category.

3.3. Questionnaire Design. The question design of the questionnaire has taken the reference of questions in Simonsen to collect the respondents' budget preference information [28]. Questionnaires are designed to present the purpose to respondents and put forward the following questions:

Questionnaires take the budget expenditure category of City J as an example. A hundred represents a million, and it also represents a percentage. If the number is set to 10 or 1000, combined with 18 budget categories, respondents will give up answering questions carefully because the number is too small or too large, thus affecting the accuracy of the data. In addition, this article will add that 100 represents the percentage. If one invests more in a specific area, the project in that area will be expanded. If no funds are allocated to a specific area, the project will remain at the current level. The total number is 100.

Table 1 shows specific conditions. The budget category in Devereux and Weisbrod [32] is designed according to the local specific budgeting table. Therefore, Table 1 is formulated following the budget category in the Report on the Budget Implementation of City J for 2019 and the Draft Budget for 2020, consisting of 18 categories. When the questionnaires are distributed, the investigators put forward two requirements to the respondents: one is to fill out questionnaires according to their own personal or family needs. The other is that the total sum of all budgetary funds must be 100. The survey requires respondents to fill in according to the needs of individuals or families in their daily lives to fully expose their budgetary preferences. The existence of budget constraints means that respondents must measure their preferences for each budget category, rather than deciding casually according to their preferences. Meanwhile, investigators explain that RMB 100 million is an addition. If the fund is allocated to a specific item, the expenditure on this item will expand in the next year. If the allocation to a specific item is zero, it means the expenditure on this item maintains the current level.

After the statistics of resident budget preferences have been completed, they will be converted into a willingness to pay (WTP) by the formula. Based on the MWTTO estimate, WTP needs to be determined for a base budget category. We

Table 1: Questionnaire model.

General public service expenditure: salary expenditure of basic administrative staff, transactional expenditure of each department, maintenance expenditure of each department, etc.
Military expenditure
Public safety expenditure: procuratorate, court, judicial national security, etc.
Education expenditure: general education, vocational education, adult education, special education, etc.
Science and technology expenditure: basic research, application research, high-tech research, popularization of science and technology, etc.
Cultural tourism sports and media expenditure: culture and tourism, cultural relics, radio and television, etc.
Social security and employment expenditure: human resources and social security services, civil administration affairs: pension of administrative institutions, employment subsidies, social welfare, etc.
Health and wellness spending: public hospitals, primary medical and health institutions, public health, family planning services, etc.
Agriculture and forestry utilities: agricultural and rural areas, forestry and grasslands, water conservancy, flood prevention, and poverty alleviation
Transportation expenditure: road haulage, rail-road transport, air transport, high-speed rail, etc.
Expenditure on commercial services: commercial circulation, foreign-related development affairs, etc.
Energy saving and environmental protection expenditures: pollution prevention and control, pollution reduction and emission reduction, conservation of natural resources, etc.
Urban and rural community expenditures: urban and rural community public facilities, urban and rural community environmental sanitation, etc.
Financial expenditure: financial development expenditure, etc.
Natural resources and meteorological expenditure: natural things, ocean affairs, etc.
Disaster prevention and control and emergency management expenditure: earthquakes, fire protection, forest fire prevention, etc.
Housing security expenditure: housing provident fund, public rental housing, indemnificatory housing rent subsidies, etc.
Expenditure of grain & oil reserves

assume that the base WTP is 100 because of the unavailability of data. By calculating the ratio between the base budget category and other budget categories (a_j/a_k), the WTP of each budget category is estimated (see Section 4.5 for details).

Please consider the budget expenditure category of City J. Assuming that an additional RMB 100 million will be added to the existing budget, how much will one invest in each of the following budget expenditures? If one invests more in a specific area, the project in this area will be expanded. If no funds are allocated to a specific area, the project will remain at the current level. The total number is 100.

3.4. Data Sources. The data source of the work was completed by the Statistics Bureau of District T, City J, Shandong Province, China. The 1556 questionnaires were collected from July to August 2020, including 626 paper questionnaires, 91 Word documents, and 839 Tencent questionnaire procedures. Word documents and Tencent questionnaire procedures are online questionnaires, which are a total of 930. It includes 91 Word documents and 839 Tencent questionnaire procedures. After screening, the number of qualified copies was 1,004. Unqualified questionnaires have the following features: firstly, the interviewees did not fill in. Secondly, the interviewees filled in only a single type. Thirdly, the filled questionnaires were average, which could not reflect the preference of the interviewees. Fourth, interviewees tried to find out how to fill in the questionnaire, or the investigators did not effectively correct the invalid filling method.

The questionnaire was also used to collect the group characteristics of the interviewees to further explore the factors that affect budgetary preference. Table 2 shows the demographic characteristics of the valid questionnaire.

4. Results and Discussions

4.1. Degree of Cognitive Effort of Interviewees. Judging the authenticity and effectiveness of the questionnaire data was the basis for the follow-up analysis. Studies revealed that when respondents found that answering a problem was cumbersome and troublesome [39], they might reduce the workload of the task. Taking this survey as an example, the questionnaire covered 18 categories, and the total number was 100. If the interviewees wanted to be "lazy" or did not fill in carefully, the best strategy was to randomly allocate fund 10 for 10 selected categories and 0 for other categories. Otherwise, select a bigger number (60, 80, or 90), while keeping the other 0. Therefore, if the occurrence frequency of 0 or 10 in the frequency distribution was high, it was very likely that the respondents have not seriously filled out the questionnaire.

Table 3 shows specific frequency distribution. The occurrence frequency of "0" is 5.89%. The occurrence frequency of around "10" is 37.55% (33.38 + 4.17). The sum of occurrence frequency of larger numbers (60–90) is no more than 1%. Therefore, it is concluded that the respondents have a high probability of filling out the questionnaire carefully.

4.2. Allocation of Budget Selection. The respondents' budget preference information was analyzed based on real and effective data. In effective questionnaires, 95% of the numbers in the questionnaire were added to 100, while 5% were not. 95.11% (955) of the numbers in the questionnaire were added to 100, while 4.89% were not. We adjusted the

Table 2: Demographic characteristics.

Demographic characteristics	Gender	Frequency
Gender	Male	45.10
	Female	54.90
Ethnicity	Han	96.30
	Hui	2.70
	Mongolia	0.10
	Tujia	0.10
	Olunchun	0.10
	Man	0.50
	Gaoshan	0.10
	Miao	0.10
Age range	Under 18 years old	0.50
	18–25	7.50
	26–30	14.50
	31–40	34.90
	41–50	22.70
	51–60	11.60
	More than 60	8.40
Education background	Uneducated	0.40
	Primary school	2.40
	Junior middle school	9.60
	High school	23.20
	Junior college	37.80
	Undergraduate college	19.40
	Master's degree or above	7.20
Annual household income (nonpersonal)	Less than 36,000	20.20
	36,000–72,000	38.00
	72,000–120,000	23.60
	120,000–200,000	12.80
	200,000–500,000	4.10
	More than 500,000	1.30

Table 3: Distribution characteristics of the frequency.

	Frequency											
	0	(0, 5]	(5, 10]	(10, 15]	(15, 20]	(20, 30]	(30, 40]	(40, 50]	(50, 60]	(60, 70]	(70, 80]	(80, 90]
GPSE	52	516	320	58	24	20	6	4	0	0	0	0
DE	36	317	506	84	30	21	4	2	0	0	0	0
PSE	57	555	355	29	3	1	0	0	0	0	0	0
EE	13	316	512	82	55	19	0	2	0	0	1	0
STE	15	466	410	68	36	3	1	1	0	0	0	0
CSME	61	659	249	20	7	3	1	0	0	0	0	0
SSEE	20	418	455	77	18	10	1	0	1	0	0	0
HE	25	436	449	54	32	4	0	0	0	0	0	0
EAFH	78	630	264	20	6	2	0	0	0	0	0	0
TE	70	660	244	18	4	1	2	0	0	1	0	0
BSE	106	708	173	10	0	2	1	0	0	0	0	0
ESEPE	58	584	324	28	4	1	1	0	0	0	0	0
URCE	50	554	335	48	11	2	0	0	0	0	0	0
FE	122	666	192	17	3	0	0	0	0	0	0	0
ME	100	660	225	10	3	0	2	0	0	0	0	0
EDPEM	71	568	331	27	2	1	0	0	0	0	0	0
HSE	41	512	373	47	18	6	1	1	0	0	0	1
EGOR	85	563	291	54	4	1	2	0	0	0	0	0
Total	1060	9788	6008	751	260	97	22	10	1	1	1	1
% of all allocations	5.89	54.38	33.38	4.17	1.44	0.54	0.12	0.06	0.01	0.01	0.01	0.01

Table 4: Descriptive statistics of overall budget category (unit: RMB 1 million).

Budget category	Average	Standard deviation
Education expenditure	8.09	5.39
Military expenditure	7.10	5.32
Social security and employment expenditure	6.92	4.15
Science and technology expenditure	6.66	3.98
General public service expenditure	6.61	5.92
Health and wellness spending	6.53	3.83
Housing security expenditure	5.99	4.69
Urban and rural community expenditures	5.49	3.32
Public safety expenditure	5.21	3.00
Energy-saving and environmental protection expenditure	5.09	3.01
Expenditure of grain & oil reserves	5.02	3.41
Disaster prevention and control and emergency management expenditure	5.01	2.85
Cultural tourism sports and media expenditure	4.76	3.22
Transportation expenditure	4.68	3.55
Agriculture and forestry utilities	4.66	2.89
Natural resources and meteorological expenditure	4.21	2.86
Financial expenditure	3.99	2.56
Expenditure on commercial services, etc.	3.97	2.82

Note. A significant difference in allocation at a 5% level is separated by a shadow row. The average distribution amount is RMB 5.55 million (100/18).

proportion of 5% questionnaires to make their sum to be 100, thus facilitating unified processing.

Table 4 shows the descriptive statistics of respondents' overall budget category. Education in this form obtains the largest allocation fund of RMB 8.09 million. The education budget category is the most concerned and the most promising category of expenditure. Hence, China's investment in education in recent years is consistent with people's expectations. The military expenditure is followed by RMB 7.1 million. The funds allocated to social security expenditure are similar to those for military expenditure, which is RMB 6.92 million. The difference between the amounts allocated to science and technology, general public services, and health and wellness spending is less than RMB 100,000, which is consistent. The last is financial expenditure and business service expenditure, which is RMB 3.99 and 3.97 million, respectively. The shaded area indicates that the *T*-test is significantly different at a 95% confidence interval. Table 4 shows a significant difference between the budget categories, without average distribution among all items.

4.3. Comparison of Budget Allocations of the Questionnaire and Actual Budget Allocation. We compared the actual budgeting of City J in 2019 with the budget preference information of respondents in the questionnaire to reflect the external effectiveness of questionnaire data. During the survey interview, investigators did not provide respondents with any actual information on the budgeting of City J. Therefore, it was assumed that respondents did not understand the actual budgeting of City J.

Table 5 provides local actual budgeting and questionnaire budget incremental ranking. In addition to the expenditure of several special categories, other sorting is basically the same as that of the actual budgeting of City J. Special categories, such as urban and rural community expenditures (the 1st in real term and 8th in the questionnaire), agriculture and forestry utilities (the 8th in real term and 15th in the questionnaire), natural resources and meteorology (the 10th in real term and 16th in the questionnaire) have been integrated into the daily life of respondents. Hence, the interviewees lack the perception of such expenditure, and the amount of funds provided is less. In particular, there are many projects involving urban and rural community expenditures, and the types are complicated. Most are closely related to the actual lives of residents, such as the renovation of old communities.

It is worth noting that expenditure on grain and oil reserves (the 18th in real term and 11th in the questionnaire) reflects people's concerns and anxiety about future food shortages to a certain extent. According to David Beasley, Executive Director of the World Food Program, a total of 25 countries face severe hunger risks this year, and the world is on the brink of the worst food crisis in at least 50 years.

Military expenditure (the 16th in real term and 2nd in the questionnaire) is the largest change. Although military expenditure is the central expenditure function and the local government expenditure is small, the 2nd place is sufficient to explain the psychological expectations of the interviewees about the possible outbreak of local war in the future.

In Table 5, except for a small number of budget expenditure categories, the respondents' budget preferences information collected by the questionnaire is consistent with the actual budgeting of the government. The fact indicates that the current fiscal expenditure arrangement in China is in line with the residents' budget preferences. Furthermore, the financial arrangement adopted by the NPC (The National People's Congress—the highest organ of power in the Chinese government that has the function of examining and supervising the budget) deputies is consistent with the budgetary preferences directly displayed by residents, which reflects the opinions and suggestions of China's

Table 5: Comparison with local actual budgeting sorting.

Serial number	Local actual budgeting	Budget increment by questionnaire
1	Urban and rural community expenditures	Education expenditure
2	Social security and employment expenditure	Military expenditure
3	Education expenditure	Social security and employment expenditure
4	General public service expenditure	Science and technology expenditure
5	Public safety expenditure	General public service expenditure
6	Health and wellness spending	Health and wellness spending
7	Science and technology expenditure	Housing security expenditure
8	Agriculture and forestry utilities	Urban and rural community expenditures
9	Transportation expenditure	Public safety expenditure
10	Natural resources and meteorological expenditure	Energy-saving and environmental protection expenditure
11	Expenditure on commercial services, etc.	expenditure of grain & oil reserves
12	Cultural tourism sports and media expenditure	Disaster prevention and control and emergency management expenditure
13	Housing security expenditure	Cultural tourism sports and media expenditure
14	Disaster prevention and control and emergency management expenditure	Transportation expenditure
15	Energy-saving and environmental protection expenditure	Agriculture and forestry utilities
16	Military expenditure	Natural resources and meteorological expenditure
17	Financial expenditure	Financial expenditure
18	expenditure of grain & oil reserves	Expenditure on commercial services, etc.

representative democracy model that can represent most residents and effectively "examine the people's feelings and listen to public opinions."

4.4. Budget Category for Determining the Maximized Utility. Budget categories that maximize utility can be found by estimating the WTP. According to the formula MWTTO (a_j/a_k) (see Section 3.2), the preference for the allocation preference of the respondents' budget category is linked to the WTP. Firstly, determine a base budget category, where health and wellness spending is set as initial value 1. It is necessary to connect health and wellness spending with the overall budget category to relate to the overall budget category and WTP. Then, estimate the trade-off ratio between various budgetary expenditures and health-related expenditures. For example, the trade-off ratio of education and health is 1.24 (8.09/6.53), which means that the utility of RMB 1.24 per education expenditure is the same as that of the expenditure of RMB 1 in health. Besides, the value obtained is multiplied with the weighing ratio previously estimated, finally reaching the WTP in the total budget expenditure category (See Table 6 for specific values). The WTP for education is the highest (1338.16) and that for commercial services is the lowest (655.57).

4.5. Incremental Regression of Group Characteristics and Overall Budget Category. Furthermore, we will return the population characteristics to the budget category increment to analyze the influence of the population heterogeneity of the interviewees on the allocation of budgetary funds. For each budget category, the allocated funds are regressed on the demographic information of the respondents. Since the total amount of budgetary allocations is limited by budgetary surpluses (totaling 100), the increase in a type of allocation means that another type of allocation is reduced so that each budget category does not seem to have a relationship. However, there are unpredictable factors that mutually affect people's choices. Therefore, SUR is used to study the relationship between demographic information and budget choices. The specific equation is as follows:

4.6. Incremental Regression of Group Characteristics and Overall Budget Category. Furthermore, we will return the population characteristics to the budget category increment to analyze the influence of the population heterogeneity of the interviewees on the allocation of budgetary funds. For each budget category, the allocated funds are regressed on the demographic information of the respondents. Since the total amount of budgetary allocations is limited by budgetary surpluses (totaling 100), the increase in a type of allocation means that another type of allocation is reduced so that each budget category does not seem to have a relationship. However, there are unpredictable factors that mutually affect people's choices. Therefore, SUR is used to study the relationship between demographic information and budget choices. The specific equation is as follows:

$$A_j = \sum \beta_m B_m + \varepsilon_j, \tag{7}$$

where A_j represents a total of 18 variables from general public service expenditure (GPSE) to grain and oil reservation expenditure (EGOR). On the right of the equal sign, there are six random disturbance items for gender, ethnicity, age, a permanent resident or not, education background, and annual household income. The second line of the table lists 18 budget categories, and the first column shows demographic information. The coefficient indicates the change in the budget allocation when demographic information changes by one unit. The relationship between demographic

Table 6: WTP in total budget expenditure categories.

Total budget category	In health and wellness spending	WTP
Education expenditure	1.24	1,338.16
Military expenditure	1.09	1,174.21
Social security and employment expenditure	1.06	1,143.94
Science and technology expenditure	1.02	1,101.37
General public service expenditure	1.01	1,093.17
Health and wellness spending	1.00	1,080.00
Housing security expenditure	0.92	989.76
Urban and rural community expenditures	0.84	907.39
Public safety expenditure	0.80	861.52
Energy saving and environmental protection expenditure	0.78	841.13
Expenditure of grain & oil reserves	0.77	829.47
Disaster prevention and control and emergency management expenditure	0.77	827.83
Cultural tourism sports and media expenditure	0.73	787.58
Transportation expenditure	0.72	774.16
Agriculture and forestry utilities	0.71	770.27
Natural resources and meteorological expenditure	0.64	695.93
Financial expenditure	0.61	659.46
Expenditure on commercial services, etc.	0.61	655.57

Table 7: Incremental regression of the group characteristics and overall budget category.

	Gender	Ethnicity	Age range	Whether a permanent resident in city J?	Education background	Annual household income	Observations	R-squared
GPSE	−0.3972	2.7105***	0.0278	3.1310***	0.1991	0.1466	1,000	0.552
DE	0.7740**	2.7994***	0.3871***	2.9482***	0.0512	−0.2745*	1,000	0.638
PSE	−0.0619	1.7241***	0.1654**	2.5856***	0.0622	0.1371	1,000	0.740
EE	−0.2654	2.6541***	0.2536**	2.9605***	0.3490**	0.3667**	1,000	0.694
STE	0.4243*	1.4182**	0.3015***	2.1220***	0.5313***	−0.0505	1,000	0.733
CSME	0.0498	0.1331	0.1738**	2.7106***	0.3061***	0.0892	1,000	0.672
SSEE	0.4702*	2.8520***	0.2598***	1.7289***	0.4085***	−0.1568	1,000	0.730
HE	0.5130**	2.4187***	0.3990***	1.6969***	0.3257***	−0.2225**	1,000	0.744
EAFH	0.0419	0.9667**	0.2460***	1.8622***	0.2916***	−0.0909	1,000	0.706
TE	0.4771**	1.2396**	0.0686	1.2390**	0.4634***	0.0131	1,000	0.634
BSE	0.1122	1.3450***	0.1404**	1.1548**	0.2221***	0.0738	1,000	0.650
ESEPE	−0.0037	1.0458**	0.2296***	1.8763***	0.3115***	0.1553*	1,000	0.732
URCE	0.2001	1.1532**	0.4061***	1.9003***	0.1950**	0.1722*	1,000	0.726
FE	0.3935**	0.7651**	0.2204***	1.2316***	0.2336***	0.1205	1,000	0.697
ME	0.0218	1.3116***	0.2654***	1.4560***	0.1154	0.0761	1,000	0.670
EDPEM	−0.1521	1.9455***	0.2207***	1.7229***	0.1909**	−0.0017	1,000	0.748
HSE	0.8912***	1.9253***	0.1094	2.9032***	0.1676	−0.1230	1,000	0.613
EGOR	−0.3219	1.5855***	0.4180***	1.1713**	0.2367**	0.0765	1,000	0.680

t-s, Statistics in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

information and budget allocation also proves that respondents make budget allocations according to their preferences rather than randomness.

In Table 7, the age of respondents is significantly positively correlated with the increment of most budget categories (15 categories). With the growth of age, respondents have more material wealth than in the younger period. According to Maslow's curve of needs, the pursuit of spiritual life focuses on the premise of meeting the needs of material life. On the other hand, the decline in physical function also leads to the requirement for a stable and comfortable environment. The creation of such an environment requires the government's additional investment of resources in various budget categories. According to the data of the seventh census of the Municipal Bureau of Statistics in City J [40], compared with 2010, the proportion of the 60-year-old population increased by 5.83%, and the proportion of the population aged 65 and above rose by 4.76%. Therefore, with the further aggravation of population aging in City J, it can be estimated that the pressure on the budget expenditure of City J will be even greater in the future.

The education background is significantly positively correlated with the increment of most of the budget categories (13 categories). Generally speaking, people with a higher level of education have higher requirements for work, and most of them are engaged in high-tech and well-paid jobs. Most are provided by capital-intensive or technology-intensive enterprises. Such enterprises have high requirements for local infrastructure and require the government to create a good and stable social environment. In addition to

work, people with higher education backgrounds have higher requirements for life quality. A good ecological environment and rich spiritual and cultural life are also essential for people with high education. Therefore, because of the dual demand for work and life, the higher the education background, the higher the degree that the interviewees generally wish to increase the increment of each budget category. According to the data of City J's population census in 2020 [28], compared with 2010, the number of students with junior college and bachelor's degrees in 100,000 people has increased by 7,879, with a decrease of 835 from students who had high school diplomas. Among the resident population, the average years of education of the population aged 15 and above has been increased from 10.10 to 10.97 years. Compared with 2010, the illiterate population decreased by 77,091, and the illiteracy rate dropped by 1.29%. Over the next period, with the improvement of education, the financial burden of the City J will gradually increase.

The above analysis shows that with the larger age group and the higher education background, the residents tend to increase the expenditure of various budget categories in an all-around way. It shows that the people of higher age and higher education are more inclined to increase the size of the budget expenditure. With the intensification of the aging population and the improvement of the level of education of residents, City J's government should not only pay attention to the changes in the expenditure structure but also maintain the growth of expenditure scale, especially the scale of expenditure in the areas of people's livelihood. In the case that the rapid growth of fiscal revenues in a short period is not available, the growth of the scale of expenditure requires "improving quality and increasing efficiency."

Meanwhile, the household annual income only has a significant correlation with military expenditure, education expenditure, health and wellness spending, energy-saving and environmental protection expenditure, and urban and rural community expenditures. Moreover, the correlation with other budget categories is not obvious. From the above regression, the higher the annual income of the family, the lower the demand for various budget expenditures. However, there are significant requirements for healthcare (health and wellness spending), education (education expenditure), housing, and supporting environments (energy saving and environmental protection expenditure and urban and rural community expenditures).

According to the 2020 Residents' Income and Consumption Expenditure [41], the per capita residential consumption expenditure accounted for 24.6% of the total per capita consumption expenditure. The per capita education, culture, and entertainment consumption expenditure accounted for 9.6% of the total per capita consumption expenditure. Per capita healthcare consumption expenditure accounted for 8.7% of the total consumption expenditure, and the total share of three expenditures was 42.9%, which was close to the total expenditure in general. As for the higher income group, according to the 2019 New Middle-Class Family Consumption and Financial Management Report jointly released by Tencent Wealth Management and the twenty-first Century Institute of Economic Research, more than half of the "new middle class" (people with RMB 200,000 and above) have the largest proportion on housing and education expenditure, and they prefer to raise education expenditure and medical expenditure in the future. Therefore, the issues of medical, education, and housing significantly affect low-income groups, the relatively higher income groups, and high-income groups.

5. Discussion

Firstly, resident budget preferences are consistent with the structure of the real government fiscal expenditure, which proves that China's fiscal expenditure is in line with the public opinion. Secondly, the education, social security, and employment budget categories have the highest utility of residents among all categories, while the business service expenditure and financial expenditure categories have the lowest utility for the services provided. Thirdly, there is a significant difference in the budget preferences of different groups. With the aging population and the increased average number of years of education in City J, the pressure on the future financial expenditure will be on a rise.

The work aimed to establish a link between the WTP and public spending in combination with China's actual situation. Meanwhile, the technology had strong practicality and controllable costs. The questionnaire design could be adjusted according to the local actual budget and had better practical operability compared with other preference revealing and incentive methods.

Resident budget preferences reveal that the starting point can promote the use of participatory budgeting in a larger range. Compared to the current participatory budgeting tools (forums and civic teams) in local governments and limited projects, the direct measurement of resident budget preferences helps lay the foundation for higher levels of budget resourcing allocation.

5.1. Policy Implications. The above research has the following policy implications: firstly, attach importance to the process of gathering consensus. The Chinese budget process remains relatively closed, however, it does not lead to a larger bias between government budget arrangements and resident budget preferences, which is inseparable from the process of gathering consensus. In the new century, the Chinese government's expenditure has been gradually shifted to the areas of people's livelihood, constantly improving the level and expenditure efficiency of various people's livelihood expenditures, thus promoting the financial satisfaction of residents. After the 18th National Congress of the Communist Party of China, the government has reduced administrative expenses through a series of measures, such as simplifying administrative procedures, delegating powers to lower levels, and strictly controlling expenditures, which responds to the question of the financial arrangement raised by the residents and public opinion. Meanwhile, the logic of budget resourcing arrangement is the pursuit of optimal efficiency and strengthening the cohesion of the community. The process of gathering consensus is both the process of

increasing the satisfaction of the budget resourcing of residents and the coupling process of resident budget preferences and government public expenditure. Therefore, in practice, we should optimize the process of budget resourcing and pay attention to the feelings of residents. It is very necessary for consensus building.

Secondly, introduce the concept of the program budget. While it is true that the logic of fiscal revenue and expenditure classification can collect residents' opinions on the allocation of budgetary resources. The path to more effectively incorporate residents' preferences is not simply to allocate funds at the scale level but to establish a transmission path from funds to the output of activities and residents' needs. Therefore, the idea of introducing the program budget can be explored to accurately collect and respond to the residents' preferences by planning an effective management system, classification system, and program-budget coordination system. For example, the high preference of residents for education expenditure may be more reflected in the need for high-quality and balanced education development. Following the original structure and project activity arrangement, simply increasing education expenditure may not help improve the responsiveness of fiscal expenditures. In this case, residents' preferences should be integrated into the planning, reflected in activities, and implemented in specific projects to finally realize the closed-loop demand-response in the form of project results.

Finally, efforts to accelerate the reform of fiscal revenues and expenditure classification should be made. The classification of "four budgets" and functional fiscal expenditure has led to the fuzzy use of fiscal expenditures, especially for the residents who have not received any professional training. For example, in the current financial resource configuration, most of the general public budget expenditures are used for recurrent expenditure, and the government fund budget is mostly used for capital expenditures. However, concerning the two key functional expenditure classifications of education and healthcare, the share of governmental funds in these two categories has gradually increased in the process of making up for the shortcomings of urbanization infrastructure. Therefore, the residents' satisfaction evaluation of education and fiscal expenditure does not only come from the general public budget expenditure. Meanwhile, for ordinary residents who do not have a background in finance, some names of financial expenditures may cause ambiguity, e.g., the general public service expenditure. Therefore, making government budget report readable and understandable and reflecting more information through effective fiscal-expenditure classification should be the direction of future reforms and the basic requirement for residents to participate in the budget.

6. Conclusions

There is still a chance to improve in future research. Firstly, matching China's budgeting, the resident's preference for an incremental capital budget should be more detailed. The budget preference of existing, annual capital and flows may conceal the stock problems of past financial expenditures. Then, similar to the previous one, the financial balance may become an important consideration for budgeting because of many factors, such as the complicated global economic and trade environment, COVID-19 epidemic, cultivation cycle mismatch of tax reduction, and tax base. The budget that residents give up voluntarily in the new form may also be the content to be paid attention to. In this case, rational residents will first reduce the minimum plans with minimum marginal gains and ultimately make the marginal gains or losses in each category equal in the context of budget balance. There is no empirical fact for this type of budget reduction program, however, understanding the preference for residents' reduction plans will also be a trend in the future.

The budgeting is dynamic, and the change in the residents' budget preferences is also dynamic. The data obtained from the questionnaire are only the information at a fixed time point in the budget year, such as expenditure information on defense and food reserves, and a more systematic institutional design is required for the integration of resident budget preferences into the budget process. For resident participatory budget, preference revealing is only the first step, and the preference aggregation and the effectiveness of resident participation are also worth exploring.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This study was supported by Youth Project of the National Social Science Fund "Research on Regional Financial Cooperation Framework under the Demand of Beijing-Tianjin-Hebei Collaborative Development and Upgrading" (19CGL048), Beijing Social Science Fund Project "Logic Demand and Path Optimization of Beijing Municipal Government Purchase of Preschool Education Service Reform" (18JDGLB002), and Central University of Finance and Economics Research Innovation Team Support Program (Project Name: "Regional Air Pollution Control and Policy Research").

References

[1] R. G. Holcombe, *Public Finance and Public Choice: Two Contrasting Visions of the State*, Public Choice, 2001.

[2] E. W. Welch, C. C. Hinnant, and M. J. Moon, "Linking citizen satisfaction with e-government and trust in government," *Journal of Public Administration Research and Theory*, vol. 15, no. 3, pp. 371–391, 2004.

[3] S. Royo, A. Yetano, and B. Acerete, ""Citizen participation in German and Spanish local governments: a comparative

study"," *International Journal of Public Administration*, vol. 34, no. 3, pp. 139–150, 2011.

[4] L. C. Walters, J. Aydelotte, and J. Miller, ""Putting more public in policy analysis," *Public Administration Review*, vol. 60, no. 4, pp. 349–359, 2000.

[5] B. C. Koford, "Public Budget Choices and Private Willingness to pay"," *Public Budgeting & Finance*, vol. 30, no. 2, pp. 47–68, 2010.

[6] N. Soguel, E. Caperchione, and S. Cohen, ""Allocating Government Budgets According to Citizen Preferences: A Cross-National Survey"," *Journal Of Public Budgeting Accounting & Financial Management*, vol. 32, 2020.

[7] F. Xie, E. Pullenayegum, K. Gaebel, M. Oppe, and P. F. M. Krabbe, "Eliciting preferences to the EQ-5D-5L health states: discrete choice experiment or multiprofile case of best-worst scaling?" *The European Journal of Health Economics*, vol. 15, no. 3, pp. 281–288, 2014.

[8] T. N. Flynn and T. J. Peters, "Joanna Coast., " Quantifying response shift or adaptation effects in quality of life by Synthesising best-scaling and discrete choice data"," *Journal of choice Modelling*, vol. 6, pp. 34–43, 2013.

[9] A. A. J. Marley and D. Pihlens, "Models of best -- worst choice and ranking among multiattribute options (profiles)," *Journal of Applied Mathematics Mathematical tended*, vol. 6, pp. 34–43, 2013.

[10] T. T. Yemeke, E. E. Kiracho, A. Mutebi et al., "Health versus other sectors: multisectoral resource allocation preferences in Mukono district, Uganda," *PLoS One*, vol. 15, no. 7, Article ID e0235250, 2020.

[11] G. Bao and B. Guan, "Does the collective preference of citizens affect the public expenditure structure of local governments ?-an empirical study based on the theory of public value," *Journal of Northeastern University*, vol. 21, no. 2, pp. 156–164, 2019.

[12] H. Yin and L. Yang, "Response research of local finance to local residents' preference," *Social Sciences in China*, vol. 5, pp. 96–115, 2014.

[13] V. O. Key, ""The lack of a budgetary theory"," *American Political Science Review*, vol. 34, no. 6, pp. 1137–1144, 1940.

[14] V. B. Lewis, "Toward a theory of budgeting"," *Public Administration Review*, vol. 12, no. 1, p. 42, 1952.

[15] E. J. Mishan and E. Quah, *Cost-benefit Analysis"*, Routledge, England, UK, 2020.

[16] R. A. Dahl, *"Polyarchy: Participation and Opposition" Yale*, University Press, Cambridge, England, 2008.

[17] S. N. Soroka and C. Wlezien, *"Degrees of Democracy: Politics, Public Opinion and policy"*, Cambri dge University Press, Cambridge, England, 2010.

[18] A. Wildavsky, *"Political Implications of Budgetary Reform"*, pp. 183–190, 1961.

[19] P. McNutt, *"The Economics of Public choice" Edward*, Elgar Publishing, Massachusetts, 2002.

[20] J. Beckett and C. S. King, "The challenge to improve citizen participation in public budgeting: a discussion," *Journal of Public Budgeting, Accounting and Financial Management*, vol. 14, no. 3, pp. 463–485, 2002.

[21] J. M. Berry, K. E. Portney, and K. Thomson, *"The Rebirth of Urban Democracy" Brookings*, Institution Press, California, 2002.

[22] R. A. Musgrave and T. Alan, *Peacock. Classic Literature in the History of Financial Theory"*, Shanghai University of Finance and Economics Press, Shanghai, China, 2015.

[23] R. J. Sørensen, ""Does aging affect preferences for welfare spending? A study of peoples' spending preferences in 22 countries," *European Journal Of Political Economy*, vol. 29, pp. 259–271, 1985.

[24] L. Bellani and F. Scervini, "Heterogeneous preferences and in-kind redistribution: theory and evidence," *European Economic Review*, vol. 78, pp. 196–219, 2015.

[25] M. Gärtner, J. Mollerstrom, and D. Seim, "Individual risk preferences and the demand for redistribution," *"Individual risk preferences and the demand for redistribution""Journal of Public Economics*, vol. 153, pp. 49–55, 2017.

[26] R. C. Mitchell and R. T. Carson, ""Using Surveys to Value Public Goods: The Contingent Valuation Method"," *Resources For the Future*, 1989.

[27] A. M. Freeman III, J. A. Herriges, and C. L. Kling, *"The Measurement of Environmental and Resource Values: Theory and methods"*, Routledge, England, UK, 2014.

[28] W. Simonsen, *"Citizen Participation in Resource allocation"*, Routledge, England, UK, 2018.

[29] M. D. Robbins and B. Simonsen, "A dynamic method of citizen preference revelation," *Journal of Public Budgeting, Accounting and Financial Management*, vol. 14, no. 3, pp. 445–461, 2002.

[30] T. L. McDaniels, "The structured value referendum: eliciting preferences for environmental policy alternatives," *Journal of Policy Analysis and Management*, vol. 15, no. 2, pp. 227–251, 1996.

[31] W. F. Fox, H. W. Herzog Jr, and A. M. Schlottman, "Metropolitan fiscal structure and migration," *Journal of Regional Science*, vol. 29, no. 4, pp. 523–536, 1989.

[32] P. J. Devereux and B. A. Weisbrod, "Does "satisfaction" with local public services affect complaints (voice) and geographic mobility (exit)?"," *Public Finance Review*, vol. 34, no. 2, pp. 123–147, 2006.

[33] P. Funk and C. Gathmann, "Voter preferences, direct democracy and government spending," *European Journal of Political Economy*, vol. 32, pp. 300–319, 2013.

[34] J. K. Brueckner, "A "test for Allocative Efficiency in the Local Public Sector"," *Journal Of Public Economics*, vol. 19, no. 3, pp. 311–331, 1982.

[35] A. Shah, "Balance "Accountability, and Responsiveness: Lessons about Decentralization"," *the World Bank*, 1999.

[36] R. K. Davis, "Recreation planning as an economic problem," *Natural Resources Journal*, vol. 3, p. 239, 1963.

[37] W. Malcolm and G. Kate, "A review fo community nusrsing in doncaster west PCT," *Unviersity of Sheffield ScHARR Report Series*, vol. 108, no. 3, pp. 47–70, 2002.

[38] G. C. Blomquist, M. A. Newsome, and D. B. Stone, "Public preferences for program tradeoffs: community values for budget priorities," *Public Budgeting & Finance*, vol. 24, no. 1, pp. 50–71, 2004.

[39] T. T. Yemeke, E. E. Kiracho, A. Mutebi et al., "Health versus other sectors: multisectoral resource allocation preferences in Mukono district, Uganda," *PLoS One*, vol. 15, no. 7, Article ID e0235250, 2020.

[40] Y. Wang, *Statistics Bulletin of Jinan Municipal Bureau of Statistics*, http://jntj.jinan.gov.cn/art/2021/6/16/art_18254_4742896.html.

[41] "Income and Consumption Expenditure of Residents in 2020," *2021-08-26*, http://www.stats.gov.cn/tjsj/zxfb/202101/t20210118_1812425.html.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4416617, 15 pages
https://doi.org/10.1155/2022/4416617

Research Article

The Teaching of Sports Physical Education Skills under Exercise Physiology Based on Support Vector Machine

Zhen Jiang

Department of Physical Education, Yancheng Teachers University, Yancheng 224002, Jiangsu, China

Correspondence should be addressed to Zhen Jiang; jiangz@yctu.edu.cn

Received 30 March 2022; Revised 14 June 2022; Accepted 15 June 2022; Published 30 July 2022

Academic Editor: Lele Qin

As the core component of a physical education teacher's professional skills, sports skills are the precondition for physical education teachers to teach and also a key factor for the level of a physical education teacher's professional skills. According to the survey, the current sports skills of graduates majoring in physical education are not satisfactory, and a considerable number of students think that their sports skills are difficult to meet the needs of educational practice. In the era of basic education reform and teacher professional development, we analyze the advantages and make up for the deficiencies in order to improve the effect of physical education professional sports skills training and meet the society's needs for high-skilled sports talents. The experiment randomly selected five physical education students from five schools and five students as the research objects. Based on the support vector machine, the questionnaire survey method, interview method, and statistical method are used to conduct related research and analysis on it. The results show that sports skills are the advanced stage of sports technology development. At present, there are many sports skills that students learn in major colleges and universities, but they really master the sports skills. Motor skills are rare. At present, the future talents of physical education major are mostly "compound" and "specialized" talents, and there are few references to applied talents. The training objectives should be clear, the curriculum should be closely linked to the training objectives, the selection of skills teaching methods by teachers should be adapted to the teaching content, and teachers and students should be actively active among these elements, which are both used and influenced by these elements.

1. Introduction

Pedagogical skills are the basic skills needed to work as a physical education teacher. Graduates of the College of Physical Education are an important driving force for future physical education teachers, but good teaching skills are also required. Teaching skills are therefore essential professional competence for graduates of the College of Physical Education. The main goal of training graduates in physical education is to qualify them as physical education teachers in colleges and universities. Physical education colleges are the cradle of physical education teachers. Improving the teaching level of graduates majoring in physical education in physical education colleges requires the continuation and improvement of the schools themselves. Strengthening the preparation of physical education graduates in pedagogical skills is in line not only with the development needs of students but also with the needs of future jobs and the requirements of physical education reform. Currently, there is a lack of research that focuses on evaluating the teaching skills of graduate teachers with physical education in the classroom. Through his research, the author found that the purpose of classroom teacher skills training for physical education undergraduates is unclear and unfocused, resulting in a lack of understanding of the entire classroom teacher skills training system in the implementation of classroom teacher skills training plans for physical education undergraduates, resulting in unbalanced and incomplete development of students' classroom teaching skills. Moreover, the assessment of students' classroom teaching skills is a one-off assessment after the placement. Due to the relatively unique purpose of assessment, it is not possible to predict and analyze students' ability levels in the classroom and all the functions that assessment should have in due

course. Therefore, the above points provide a sound basis for the development of a system for indexing classroom teacher assessment skills for undergraduate physical education students.

Many national and foreign experts are also studying the maintenance of vector machines and the teaching of sports and physical skills. Escriva-Boulley et al. have used a randomised controlled trial to investigate the impact of a professional development program for teachers based on self-determination theory (TPD) on improving teachers' motivational models to increase students' physical activity during PE lessons [1]. White et al. strongly advocate the removal of rugby from physical education in schools, as rugby is the leading cause of rugby injuries [2]. Bekiari and Pylarinou investigated the relationship between PE teachers' claims and students' perceived social communication styles and students' reasons for learning the subject. The sample included 252 students aged 10–12 years [3]. Bouboulis et al. proposed a new framework of complex support vector regression (SVR) and support vector machines (SVM) for quarterly classification. This method uses the concept of extensive linear estimation to model the relationship between input and output of complex data [4]. Badau's study aimed to assess the level of training related to the application of AE subjects in academic physical education and sports programs [5]. Zhang and Xie's study investigated the application of nontraditional models for modelling travel mode choice, which have traditionally been based on decomposing discrete choice models such as polynomial logit models [6]. However, because the data and methods used in these studies are not appropriate, there are some controversial issues that lead to meaningful results that are not recognized by the general public.

The assessment of physical teaching competence in the classroom is an important symbol of the standardisation and institutionalisation of the management of physical teaching and an important criterion for assessing the impact of the development of teacher education in the classroom. The implementation of teaching level evaluation in physical education classroom is a powerful guarantee for the self-improvement and self-restraint mechanism established in the internal implementation process of physical science education management. The aim of this paper is to guide and evaluate the evaluation of postgraduate education in physical education by creating a system of indicators for assessing physical education competencies and to make a preliminary evaluation of the application of the indicator system in physical education. Since there has been no relevant research on indicators for evaluating physics students' teaching skills in the classroom, an indicator system for evaluating teaching skills in the classroom was investigated for the first time in the study in combination with the actual needs of physics students. It conducted a thorough evaluation of physical education students' classroom teaching and management skills to understand the problems and gaps in the development of classroom teaching skills, analyze the factors that affect them, explore countermeasures, and help students clarify development goals and interventions. It provides an effective reference point for meaningful assessment and monitoring of the development of teaching skills in physical education. It has laid a solid foundation for the sustainable construction and development of physical education. The Physical Education Skills Assessment Framework promotes the comprehensive and timely development of physical education skills. It provides a theoretical framework and concrete measures for testing physical education and is of particular practical importance. Building a system of assessment indicators provides physical education teachers with a framework for developing their classroom teaching skills in the future and is important for improving teachers' basic skills as teachers [7]. The construction of the evaluation index system provides a reference for physical education teachers to cultivate the classroom teaching skills of physical education graduates in the future and has important significance for improving their basic ability to teach as teachers.

2. Methods

Extract the parallelization features and map them into SIMD instructions; this process is called autovectorization and is the main research field of this paper. Automatic vectorization reduces the requirements for programmers, saves a lot of investment in writing repetitive code, and can effectively solve the problem of error-prone manual analysis, thereby shortening the development cycle of the chip and improving the portability of the code.

The DSP vector architecture also has a complete development area, as shown in Figure 1. Development tools include collectors, compilers, and coordinators; repair tools include debuggers and tracers; analysis tools include application development tools and bug diagnostic fixes. All these provide the basic conditions to support the research on this subject. In practical applications, many research institutes and processor manufacturers have identified the differences between traditional vector machines and SIMD command sets, and these differences will affect the results. To increase vectorization, research studies this problem at the hardware and software levels. From the hardware point of view, it learns the characteristics of the multimedia extension instruction set and discovers how to apply SIMD to the hardware level. It looks at the relationship between indexes and data in contrast to traditional analytics. The SIMD vectorized summation method focuses on how to improve the alignment accuracy of command and data alignment methods to improve the performance of SIMD modification [8].

In recent years, LLVM has developed rapidly, and the reason is that it has the following characteristics: reusable, copyright-free, and LLVMIR. In the previous section, reusability makes compiler development easier, and copyright-free makes development less expensive. And LLVMIR plays a key role in the development of LLVM for two reasons: LLVM defines an intermediate description language of its own, which is independent of the front and rear ends so that a large number of optimizations can be carried out here; LLVM first proposed a full-time optimization that attracted wide attention in the industry. Full time is link time, runtime, idle time, compile time, and install time, as shown in Figure 2 [9].

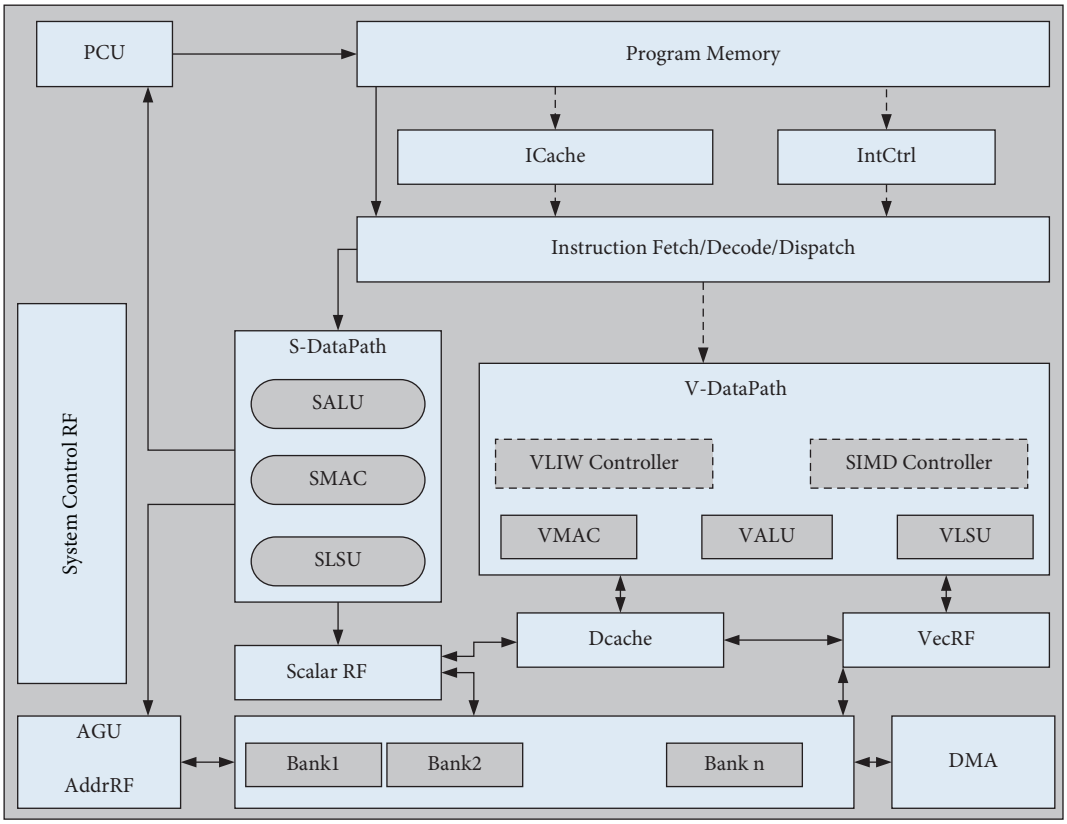


Figure 1: Vector DSP architecture.

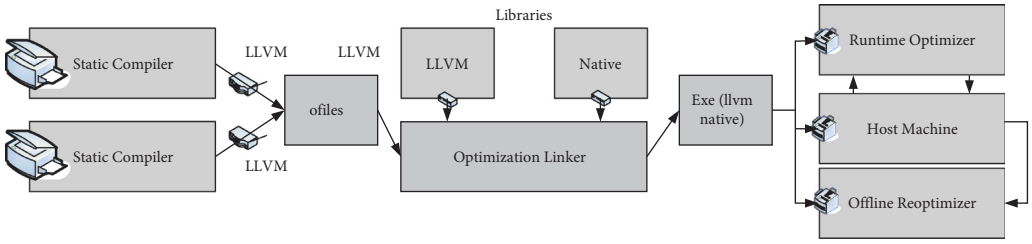


Figure 2: LLVM system architecture.

2.1. Nonsingular Twin Support Vector Machine. However, Table 1 does not allow us to clearly assess the effectiveness of NSTWSVM and TWSVM-b. Table 2 shows the experimental results of NSTWSVM, TBSVM, TWSVM-a, TWSVM-b, and SVM under nonlinear conditions, where these five algorithms all use the RBF kernel function. A comparison shows that the classification accuracy of the nonlinear NSTWSVM is significantly higher than that of TBSVM, TWSVM-a, TWSVM-b, and SVM for most datasets. Moreover, NSTWSVM and TWSVM-b require less computation time than other algorithms. SVM has higher classification accuracy on three of the datasets, but its computational efficiency is significantly lower than that of the other algorithms [10, 11].

In order to demonstrate the ability of NSTWSVM to solve large-scale problems, the NSTWSVM based on SOR technology is tested on the NDC dataset. The scale of the test set is 1000–30000 samples, and each sample includes 10-dimensional features. As can be seen from Figure 3, NSTWSVM has almost the same test time as TWSVM-b and is significantly less than TBSVM. This is consistent with the theoretical analysis; that is, the selection of parameters will affect the calculation speed of TBSVM. Figure 3 shows TWSVM [12] using the QP method on the same dataset. For example, the change of value is realized by 2, 4, 6, and so on each time. Inductive variable optimization is very important in loop optimization, and the way it is chosen can determine the size and performance of the code.

The linker links .obj files together to generate executable files, so the linking process can see the whole program for the first time. The optimization shown in Figure 4 can be performed on the program at this stage. Link-time optimizations at this point manipulate the LLVM bytecode directly and optimize the program with advanced information encoded into it. For example, the link-time optimization APA algorithm directly uses the type information

Table 1: Test rates for linear NSTWSVM.

Dataset	NSTWSVM accuracy Time (s)	TBSVM accuracy Time (s)	TWSVM-a accuracy Time (s)	TWSVM-b accuracy Time (s)	SNM accuracy Time (s)
Australian (690 × 14)	89.47 0.185	88.42 0.919	87.56 2.192	86.52 0.176	87.62 8.36
German (1000 × 24)	75.62 0.156	76.2 1.623	474.5 4.852	71.52 71.32	72.65 15.6
Sonar (208 × 60)	77.21 0.158	73.8 0.158	76.6 0.526	0.123 73.25	79.23 1.25
Bupa (345 × 6)	79.56 0.065	78.64 0.235	76.25 0.606	0.036 78.65	73.75 3.25
WDBC (569 × 31)	97.63 0.025	96.63 0.428	96.56 1.635	0.015 96.54	72.35 4.574
Breast cancer (699 × 11)	87.65 0.125 3.526	87.23 0.159 1.152	85.62 2.035 2.34	0.344 83.65 0.158	84.25 7.654 84.62
Heart (270 × 13)	87.65 0.035	87.652 0.125	83.15 1.65	86.65 0.065	5.35 78.32
Diabetes (768 × 8)	78.65 0.152	76.51 0.845	75.65 9.6	77.62 0.175	78.52 29.36
Ionosphere (351 × 34)	91.62 0.051	92 0.255	88.65 1.651	89.65 0.035	87.65 5.962

Table 2: Test rates for nonlinear NSTWSVM.

Dataset	NSTWSVM accuracy Time (s)	TBSVM accuracy Time (s)	TWSVM-a accuracy Time (s)	TWSVM-b accuracy Time (s)	SNM accuracy Time (s)
Australian (690 × 14)	86.52 0.266	86.06 1.265	85.62 7.6	85.62 0.3512	86.75 18.65
German (1000 × 24)	78.26 0.015	77.6 0.15	77.52 1.652	78.35 0.016	80.64 4.158
Sonar (208 × 60)	65.35 0.026	64.2 0.226	64.62 2.512	63.54 0.035	65.56 6.54
Bupa (345 × 6)	86.54 0.041	85.6 0.185	85.61 2.654	63.52 0.345	83.6 7.523
WDBC (569 × 31)	66.21 0.2568	67.69 1.452	64.65 8.625	92.8 0.064	64.65 29.654
Breast cancer (699 × 11)	94.5 0.051	93.58 1.723	92.35 3.256	71.6 0.045	90.6 11.542
Heart (270 × 13)	73.5 0.13	73.6 2.35	72 13.547	71.5 0.212	70.5 38.651
Diabetes (768 × 8)	77.652 0.265	76.65 1.132	75.68 2.154	76.54 0.251	74.68 7.954

provided by LLVM and allocates the linked structure allocated on the heap in a continuous memory pool to optimize the program. The compile-time and link-time optimizers use a number of techniques to speed up interprocedural analysis. For example, the summary information of each function is summarized and attached to LLVMIR at compile time, and then the function summary information is used directly to complete the analysis of the program during linking without reobtaining the information from the source code, which can reduce compilation time without unduly affecting accuracy [13].

The goal of LLVM design is to develop a new runtime optimization strategy, which collects the running information of the program at runtime and uses it to guide subsequent code generation and optimization. Idle-time optimizations often work in conjunction with runtime optimizations. Idle optimization reads the running information obtained at runtime to guide the code generator to generate more efficient code. Traditional runtime optimization methods have two shortcomings: the information obtained at runtime comes from developers rather than users, but developers actually rarely use the information to guide feedback. Therefore, in practice, the speedup obtained with runtime optimizations is not very noticeable. The reason why LLVM's runtime optimization is different from traditional methods is that the information it uses to guide

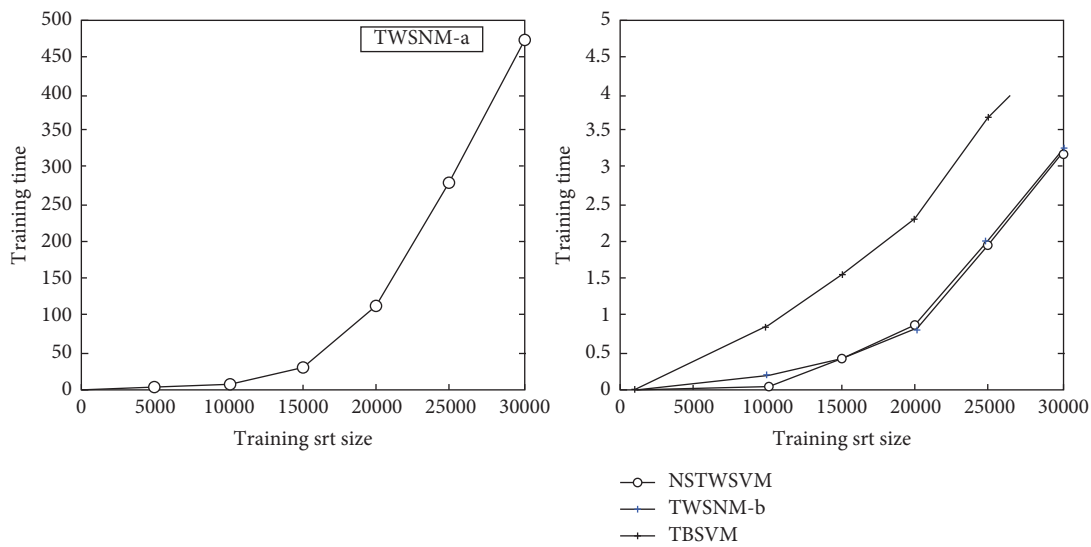


Figure 3: Training time of the model in the linear case.

code generation is the user's runtime information rather than the developer's test information [14].

2.2. LLVM Virtual Instruction Set. LLVMIR is the core of LLVM architecture and the basis of analysis and optimization, and it is a low-level language with high-level type information. It can not only save high-level type information but also is low-level to language-independent, so it can complete a lot of analysis and optimization, which is the biggest difference between LLVM and other systems. The LLVM virtual instruction set is similar to the three-address format RSIC, which is register-dependent and avoids specific machine constraints such as the number of physical registers and pipelining. At the same time, to facilitate program optimization, LLVMIR provides a set of infinite virtual registers in the form of SSA. In addition, it is a strongly typed language, using an explicit exception control flow mechanism to limit specific instructions to operate memory. If you operate on virtual registers and memory, you must use load, store, and alloca instructions. Figure 5 is an abstract summary of the LLVM virtual instruction set, in which the syntax and semantics are described in more detail in the LLVM reference manual [15].

Usually, whether a loop invariant is controlled by a conditional expression can be verified by using the method of determining whether the expression is a must-pass node in the loop. Figure 6 shows the control flow diagram of the program optimized using LoopRotate. Then, in order to judge whether the invariant will be executed in the loop, it is necessary to find the basic block BB3 where the invariant expression $2/(m-n)$ is located. Then, it is found that, in the process from BB2 to BB4, there is not only BB3, a basic block connected to BB2 and BB4, but also an edge that leads directly from BB2 to BB4. So BB3 is not a mandatory node in the loop, so it is controlled by the conditional expression. It is not necessarily executed in the loop, so the invariant cannot be mentioned. And the basic block where the 7th line instruction $a = a + n * n$ is located is the necessary node in the loop, so this statement can be mentioned. It reduces the program runtime by reducing the number of times. Redundancy is having more than one repeated computation on a certain path in the flow graph. Therefore, if expressions are redundant at program points, they can be deleted while maintaining program correctness. The subexpression $x * y$ in $d = x * y$ is assigned in all paths to BB4 (BB2 and BB3), so it can be redundantly optimized. The optimized method is to reassign the expression in BB3 and BB2 and store the value of the expression in the temporary variable t to replace all the use of $(x * y)$ [16].

In addition to redundant removal, there are also partial redundant removal (PRE) methods, which combine methods such as partially redundant expression recognition and insertion of additional computations along different program paths. First, make the expression fully redundant, and then delete the redundant expression. There are several optimization methods for partial redundancy removal, the most common of which is to use lazy code movement, and it is partially redundant in BB3. The reason why it is partially redundant is that it is only assigned in BB1 and not in BB2 in order to make the statement fully redundant. Using the method of inserting this statement in BB2, the expression becomes completely redundant, and then the program is optimized by deleting the completely redundant expression. Among the optimization methods introduced above, both LICM and redundant expression removal optimization are related to redundant computation, and both require implicit or explicit analysis of data flow. In addition to the two methods described above, redundant computing also includes optimization methods such as common subexpression deletion and code promotion.

2.3. Twin Support Vector Machines. In general, compared to SVMs, TWSVMs are usually used to solve large binary classification problems. Standard TWSVM models are faster than SVMs in terms of learning speed since they can be reduced to solve a few small convex quadratic programming problems. Due to its high work efficiency, TWSVM is more suitable for solving large classification problems. However, in the process of solving quadratic programming problems using TWSVM, there is a

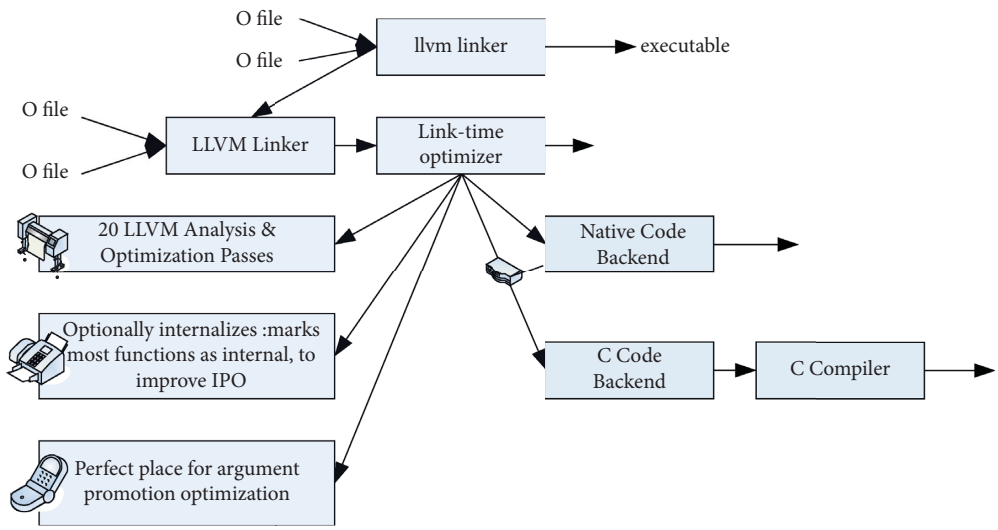


Figure 4: LLVM link-time optimization.

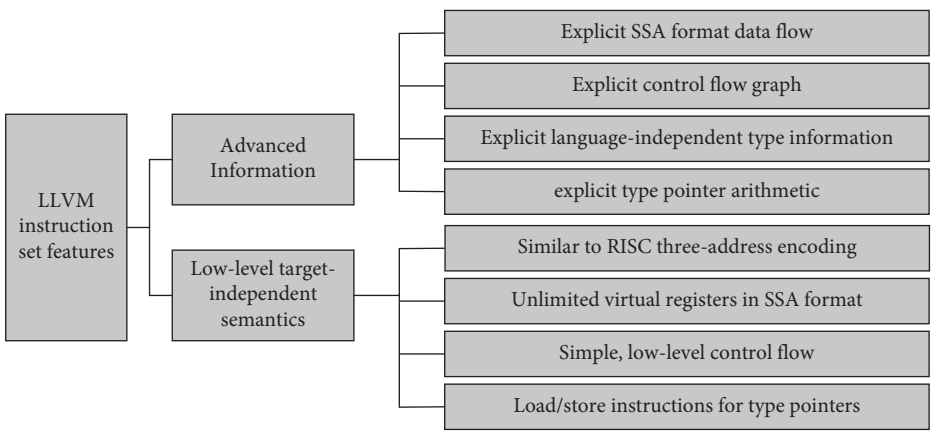


Figure 5: LLVM instruction set features.

"singularity" problem; that is, the matrix of the dual problem of the original TWSVM model is positive (semipositive) definite.

$$\begin{aligned}
&\min_{w1,b1,\xi,\xi*} \frac{1}{2}c3\left(\|w_1\|^2 + b_1^2\right) + \frac{1}{2}\xi^{*T}\xi^* + c_1 e_2^T \xi,\\
&s.t. Aw_1 + e_1 b_1 = \xi,\\
&-\left(BW_1 + e_2 b_1\right) + \xi \geq e_2, \xi \geq 0,\\
&\min_{w1,b1,\eta,\eta*} \frac{1}{2}c4\left(\|w_2\|^2 + b_2^2\right) + \frac{1}{2}\eta^{*T}\eta^* + c_1 e_2^T \eta,\\
&s.t. Bw_1 + e_1 b_1 = \eta^*,\\
&-\left(AW_2 + e_1 b_2\right) + \eta \geq e_1, \eta \geq 0.
\end{aligned} \tag{1}$$

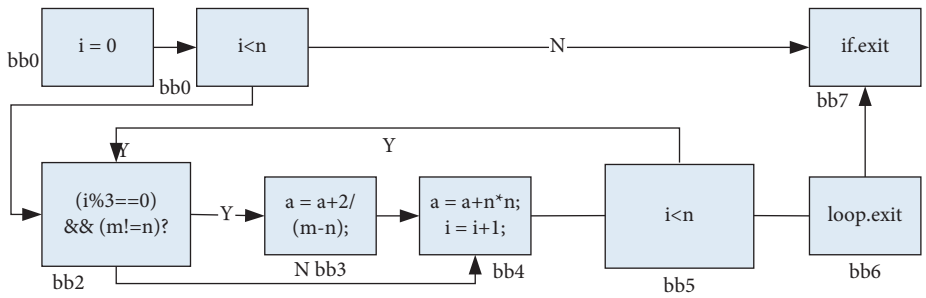


Figure 6: Use case diagram for senior managers.

Now, we can reasonably describe the distance with

$$1\sqrt{\|W_1\|^2 + B_1^2},$$

$$L(w_1, b_1, \alpha, \beta) = \frac{1}{2}c_3\left(\|w_1\|^2 + b_1^2\right) + \frac{1}{2}\|Aw_1 + e_1 b_1\|^2 + c_1 e_2^T \xi, \quad \alpha^T(Bw_1 + e_2 b_1 - \xi + e_2) - \beta^T \xi. \tag{2}$$

According to the above method, the following dual problems can be obtained:

$$\begin{aligned} c_3 w_1 + A^T(Aw_1 + e_1 b_1) + B^T\alpha &= 0, \\ c_3 b_1 + e_1^T(Aw_1 + e_1 b_1) + e_2^T\alpha &= 0, \\ c1e_2^T - \beta^T - \alpha^T &= 0 \\ -(Bw_1 + e_2 b_1) + \xi e_2, \xi &\geq 0 \\ \alpha^T(Bw_1 + e_2 b_1 - \xi + e_2) &= 0, \\ \beta^T \xi &= 0. \end{aligned} \tag{3}$$

The quadratic programming problem is as follows:

$$\begin{aligned} 0 \leq \alpha \leq c1, \\ \left(\left[A^T, E_1^T\right][A, e_1] + c_3 I\right)[w_1, b_1]^T + \left[B^T, e_2^T\right]\alpha = 0, \\ \left(H^T H + c_3 I\right)V_1 + G^T\alpha = 0, \\ v_1 = -\left(H^T H + c_3 I\right)^{-1} G^T \alpha. \end{aligned} \tag{4}$$

By weighted average, the overrelaxed iterative formula for solving the system of equations is obtained:

$$\begin{aligned} a_{ii}x_i^{(k+1)} &= (1-w)a_{ii}a_{ii}x_i^{(k)} \\ &\quad + w\left(b_i - \sum_{j=1}^{i-1} a_{ij}x_j^{(k+1)} - \sum_{j=i+1}^{n} a_{ij}x_j^{(k)}\right), \\ Dx^{(k+1)} &= (1-w)Dx^{(k)} + w\left(b + Lx^{(k+1)} + U_x^{(k)}\right), \\ (D - wL)x^{(k+1)} &= ((1-w)D + wUx)x^{(k)} + wb \\ x^{(k+1)} &= (D - wL)^{-1}((1-w)D + wU)x^{(k)} \\ &\quad + w(D - wL)^{-1}b. \end{aligned} \tag{5}$$

3. Experimental Analysis and Results

The paper selects 400 students from 5 colleges and 25 physical education teachers in physical education colleges as research objects. It retrieves relevant Chinese and foreign literature, such as "Curriculum and Teaching Theory," "Physical Education Teaching Skills," "Physical Education Teaching Theory," reading, thinking, and summarizing skills, and physical theory. And in accordance with the established requirements, these materials are studied and analyzed in detail to provide a specific theoretical basis for the subsequent discussion, analysis, and solution of current problems.

Question design: in order to ensure the accuracy and validity of the content layout, the research questionnaire was designed on the basis of reviewing the literature and listening to the opinions of tutors and experts. After the approval, a formal questionnaire is formed, and the validity of the questionnaire is tested: according to the content of the questionnaire, four evaluation levels of "very reasonable, reasonable, general, and unreasonable" are designed, and an expert evaluation test is carried out. The basic situation is shown in Table 3.

As can be seen from Table 3, the number of experts evaluated at each level is 12, of which "very reasonable" and "reasonable" account for 92% of the total, and the result

Table 3: Statistics on the validity evaluation results of the questionnaire for 12 experts.

Index	Very reasonable	Reasonable	Generally	Unreasonable
Frequency	3	8	1	0
Percentage (%)	25	67	8	0
P value	0.026	0.063	0.041	0.052

Table 4: Students questionnaire statistics of the questionnaire distribution and recovery of 30% again.

School name	Questionnaires issued	Number of returned questionnaires	Number of valid questionnaires	Effective recovery rate (%)
A	24	24	24	100
B	24	24	22	91.7
C	24	24	19	79.2
D	24	24	20	83.3
E	24	24	23	95.5

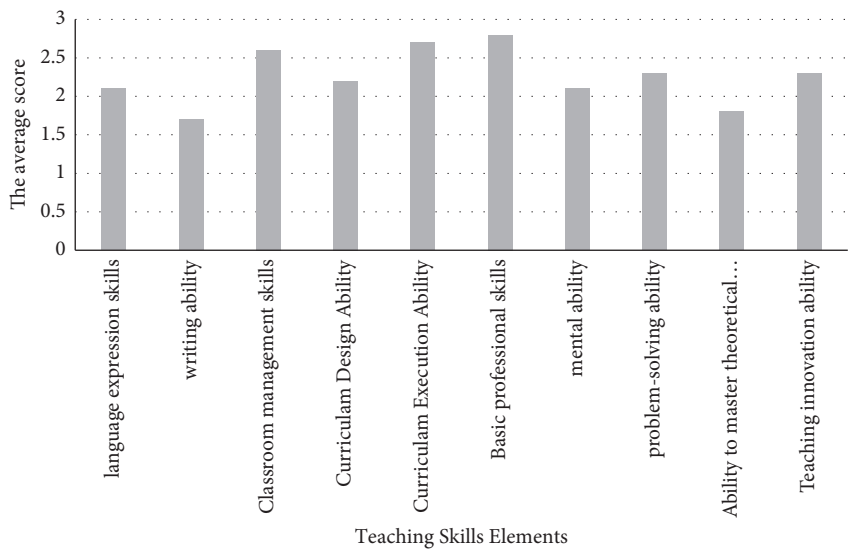


Figure 7: 25 teachers and 376 students' cognitive evaluation results of the components of teaching skills.

shows that the content of the question is valid. Question reliability test: select 30% for retest. At the same time, in order to ensure the reliability and validity of the question, the researchers conducted a survey. It requires the question to be distributed in person, with the necessary explanation for the purpose, as shown in Table 4.

Figure 7 shows the evaluation results for 25 teachers and 376 students. Teachers and students' evaluation of the importance of each teaching skill element is weighted according to the "3-point system"; that is, 3 points are the most important. The average score is obtained by dividing the number of people who evaluated the importance of each teaching skill element in the questionnaire survey by their respective total number, and the importance of the teaching skill element is weighed according to the average score. It can be seen from the table that the overall cognitive situation of teachers and students is consistent. They believe that classroom management ability, curriculum execution ability, and basic professional skills ability are the most important. According to the research results in Figure 7, random interviews were conducted between students and teachers, and it was found that the reason why their cognitive situation was consistent was that students were influenced by teachers' teaching concepts, methods, and training content to a large extent. What teachers think is important will often teach students more information about this aspect in the classroom, and over time, students will form the same views as teachers. In the current teaching state, students' teaching skills and abilities are dominated by physical education. A questionnaire survey was conducted on 25 teachers and 376 students in these five schools. Through the statistics of the questionnaire survey results, the self-evaluation of each school's students' current situation of teaching skills and ability, the overall situation of each school, and the teachers' evaluation of the current situation of their students' teaching skills and ability are obtained. For details, see Tables 5 and 6.

Table 5: The self-evaluation results of 376 physical education students on each teaching skill ability.

Elements of teaching skills and their evaluation levels		The name of the school and students' self-evaluation of their own teaching skills. The number of people in the class and the overall situation				
		A University	B University	C University	D University	E University
Language expression skills	Good (3 points)	11	6	7	16	9
	General (2 points)	47	34	31	42	33
	Bad (1 point)	21	35	32	14	38
Writing ability	Good (3 points)	22	17	15	24	18
	General (2 points)	43	34	31	39	32
	Bad (1 point)	14	24	24	9	30
Classroom management skills	Good (3 points)	17	7	8	15	10
	General (2 points)	35	31	29	34	32
	Bad (1 point)	27	37	33	23	38
Curriculum design ability	Good (3 points)	19	10	12	22	114
	General (2 points)	38	31	27	37	31
	Bad (1 point)	22	34	31	13	35
Curriculum execution ability	Good (3 points)	18	11	10	20	13
	General (2 points)	35	33	29	35	32
	Bad (1 point)	26	33	31	17	35
Basic professional skills	Good (3 points)	26	31	16	28	21
	General (2 points)	38	18	26	34	27
	Bad (1 point)	15	29	28	10	32
Mental ability	Good (3 points)	29	28	23	24	26
	General (2 points)	35	27	31	34	36
	Bad (1 point)	15	33	16	14	18
Problem-solving ability	Good (3 points)	17	15	14	21	16
	General (2 points)	36	12	27	35	30
	Bad (1 point)	26	31	29	16	31
Ability to master theoretical knowledge	Good (3 points)	15	32	9	16	11
	General (2 points) 28	36	7	26	33	30
	Bad (1 point)	30	42	35	23	37
Teaching innovation ability	Good (3 points)	11	6	6	15	9
	General (2 points)	32	26	26	29	27
	Bad (1 point)	36	45	38	28	44
The overall comprehensive evaluation of students' teaching skills and abilities in each school	Good					
	General	√			√	
	Bad		√	√		√

The table shows that the overall situation in the five schools is very bad, except for schools A and D, which are at an average level. This phenomenon has been considered separately by the author, and the main reasons are as follows. From the students' point of view, these two schools belong to private universities. The overall quality standards of the students are slightly higher than those of the other schools. Given the management and confidence of the students, it is not surprising that they are better than some of the other schools. In terms of teachers' education of pupils' educational skills: different schools have different teachers' pedagogical skills and hardware conditions, and teachers' level of education is also an important factor influencing the education of pupils' educational skills. Teacher training methods and teaching concepts in the two schools have been somewhat updated based on the traditional teaching method. The emphasis is on students learning independently and shifting the teacher's role to that of students as primary learners. The excellent hardware environment provides students with more opportunities to acquire teaching skills. In terms of school management, the school management systems and policies have a big impact on the development of students' teaching skills. In comparison, these two schools have a more rigorous management system than the other three schools, and the implementation of formulated pedagogical measures is higher than that in the other schools. Table 6 shows the statistics of the overall assessment of the current situation of the five PE teachers in each school regarding the development of pedagogical skills and abilities of the student athletes in each school. The table shows that all

Table 6: The overall evaluation results of 25 physical education teachers on students' teaching skills and abilities in each school.

Teaching skills elements	Evaluation level	The name of each school and the number of teachers who evaluated the overall situation of their students' teaching skills and abilities				
		A University	B University	C University	D University	E University
Language and writing skills	Good (3 points)	2	0	0	2	0
	General (2 points)	2	2	2	3	4
	Bad (1 point)	1	3	3	0	1
Classroom management skills	Good (3 points)	0	0	0	1	0
	General (2 points)	4	2	3	4	2
	Bad (1 point)	1	3	2	0	3
Curriculum design and execution ability	Good (3 points)	2	0	0	3	0
	General (2 points)	3	2	2	2	3
	Bad (1 point)	0	3	3	0	2
Basic professional skills	Good (3 points)	2	0	0	2	0
	General (2 points)	2	3	3	3	2
	Bad (1 point)	1	2	2	0	3
Psychological quality and problem-solving ability	Good (3 points)	1	1	1	2	1
	General (2 points)	3	2	3	2	3
	Bad (1 point)	1	2	1	1	1
Theoretical knowledge mastery and teaching innovation ability	Good (3 points)	1	0	0	1	0
	General (2 points)	3	1	2	3	2
	Bad (1 point)	2	4	3	1	3

schools have PE teachers who assess the pedagogical skills and abilities of pupils for each of the elements of pedagogical skills. The percentage of each element can be used to assess the overall level of students in a given school. Intuitively, the table shows that the schools with slightly better overall ratings are University A and University D.

Teaching skills are an essential characteristic of all teachers, and the quality of teaching skills is directly related to the employability of PE students. Many students think that it is enough to know at least a little about all aspects of the profession. They do not know that teaching skills cover many aspects, and they do not know how important teaching skills are for themselves. A questionnaire survey was conducted to find out to what extent the students themselves are aware of the importance of cultivating the elements of teaching skills. The concrete results are presented in Figure 8.

Figure 9 is a statistical table of questionnaires on the cognition of physical education students in five universities (i.e., 79 students from A University, 75 students from B University, 70 students from C University, 72 students from D University, and 80 students from E University) about their own teaching skills training. It can be seen that the students majoring in physical education in each school have cognition on the cultivation of various teaching skill elements. Judging from the proportion of the number of people shown, the proportion of people who think "important" is the largest, followed by "general," again "very important," and finally "unimportant." In this way, most students have a clear understanding of their own teaching skills training, but some students have not paid attention to it. The level of students' teaching skills will directly affect their employment, so teachers should strengthen the training and training of students' teaching skills in all aspects in the usual teaching process so as to arouse their awareness and attention to the training of teaching skills.

As shown in Figure 10, it can be seen that the proportion of students in each school is very dissatisfied with the curriculum. Academic courses include big and small ball, martial arts, aerobics, gymnastics, and track and field; theoretical courses include school sports, sports psychology, sports training, introduction to sports, sports human body and anatomy, sports statistics, and sports measurement and evaluation. Students study a lot of courses every day. Some courses are not interesting to students but they are offered more, but there are very few class hours that are really ranked in professional courses. The professional courses arranged by the five schools are basically two classes per week. Due to the limited space and equipment in the schools, students usually do not learn anything at all after a class and cannot meet the needs of students. Therefore, in the implementation of the curriculum, schools should follow the actual situation of the school, try to meet the needs of students, reasonably arrange the structure of class hours, and improve the teaching system. The evaluation grading standard is based on the responses to the student questionnaires surveyed by each school. A total of 80 questionnaires were distributed to students in each school. The questionnaire responses were more than 40 points as good, 30–40 points as average, and less than 30 points as poor. Through the statistics of the questionnaire and the author's field investigation, the results of the table are in line with reality. The quality of the school's hardware facilities is also an important factor affecting the formation of students' teaching skills. Due to the lack of venue equipment, students may not be able to take classes normally, reduce their enthusiasm and attitude in class, and make students tired of taking certain classes. Students' learning attitude plays a direct role in the formation of their teaching skills. D University is a national "211" and "985" key university, A University is a national first-class key university, and the

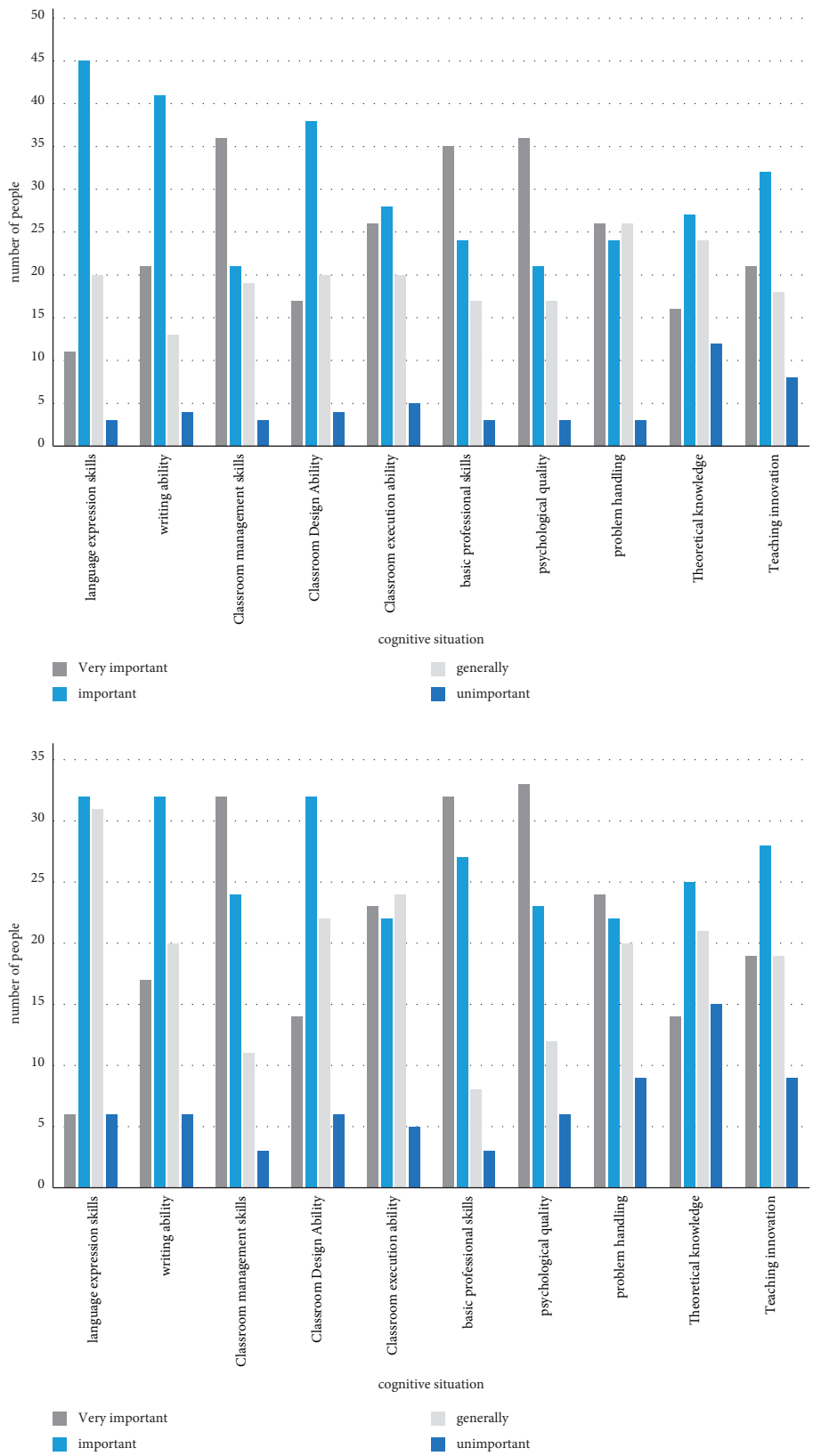


Figure 8: 376 students' perceptions of the importance of the cultivation of various teaching skill elements. The results of the questionnaire A and B University survey.

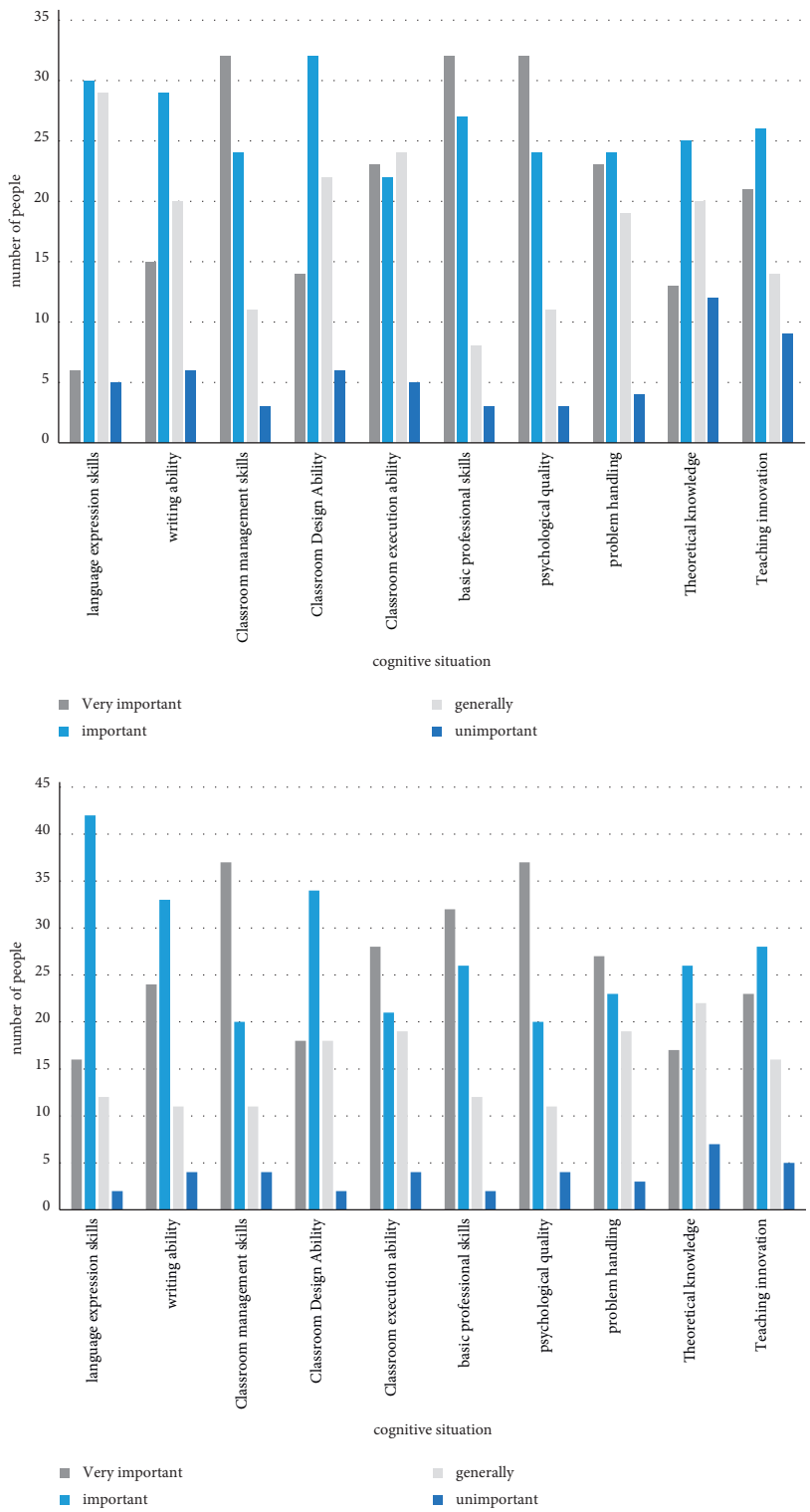
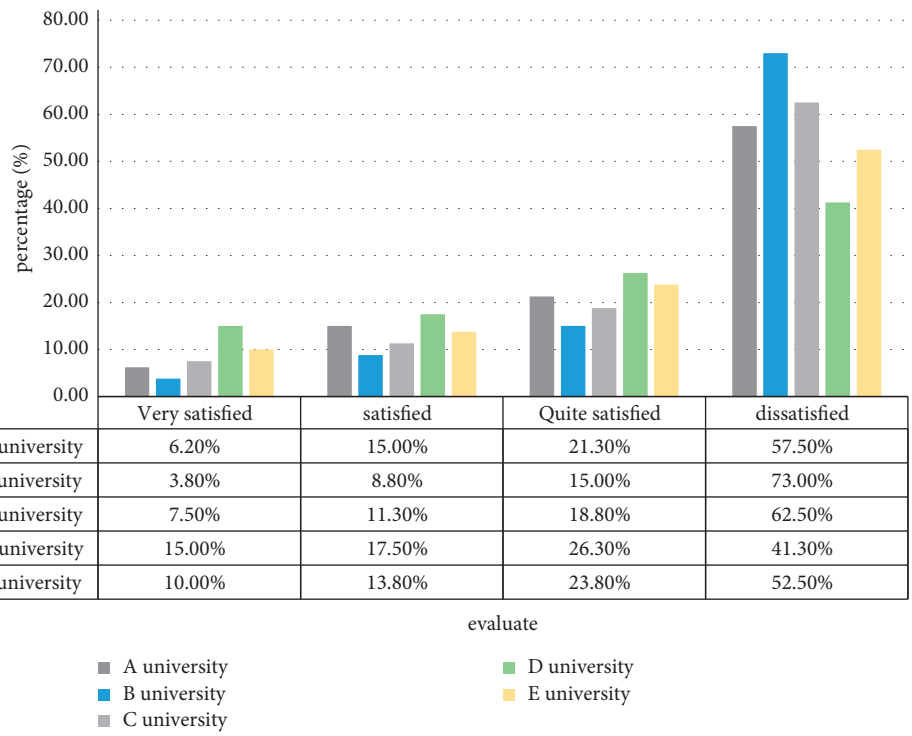


Figure 9: 376 students' perceptions of the importance of the cultivation of various teaching skill elements. The results of the questionnaire C and D University survey.

other three institutions are second-level institutions. Due to the geographical location of each school and the degree of economic development in the region, as well as the country's emphasis on it, the hardware facilities of each school are also quite different.

4. Discussion

From the factors affecting the formation of students' teaching skills, in response to the question of whether the relevant departments of each school attach importance to it,



	Very satisfied	satisfied	Quite satisfied	dissatisfied
A university	6.20%	15.00%	21.30%	57.50%
B university	3.80%	8.80%	15.00%	73.00%
C university	7.50%	11.30%	18.80%	62.50%
D university	15.00%	17.50%	26.30%	41.30%
E university	10.00%	13.80%	23.80%	52.50%

Figure 10: Satisfaction survey results of 376 students with course implementation.

although the school has adopted certain management systems and measures, few can really improve the level of students' teaching skills. Many management systems and measures are not in line with the actual situation of the school, which leads to the failure to meet the needs of students, weakens their enthusiasm for learning, and makes their attitudes become passive and neglectful. Teachers' teaching skill level, students' own learning attitude, and cognitive situation are also one of the important influencing factors. We can see the overall cognition of 376 students and 25 teachers on each teaching skill element, and their cognition will affect their poor attitude towards teaching skill learning and unclear goals. In the research, we can see the ways that students acquire teaching skills, and most of the ways they acquire teaching skills are obtained through educational practice. After investigation and interviews with experts, teachers, and students, it is found that each school arranges the students' educational practice time for a short time, which also restricts the formation of their teaching skills to a certain extent. From the statistics, we can know the curriculum settings of each school and the teaching methods, means, and content of teachers to cultivate students' teaching skills. In terms of teaching content, teachers of various majors rarely cultivate students' teaching skills. Most of the teachers teach with specialized technology as the main content, and only a small number of teachers can give consideration to all three of specialized technology, specialized theory, and classroom teaching skills, which will cause students to fail to recognize the importance of teaching skills and fail to draw attention to them. During the experiment, it can be seen that teachers' teaching methods and means are relatively simple, and such teaching methods will make students feel tired of learning.

There are too many curriculum settings and unreasonable structures in the curriculum setting, which shows that the school's teaching system is not perfect. The school's hardware and software facilities will restrict the practice and exercise of students' teaching skills. These are all important factors that affect the formation of teaching skills for students majoring in physical education. Judging from the school's assessment and evaluation, each school has not yet formed a relatively complete assessment and evaluation system, and there is no authoritative evaluation system. The specific assessment method is mainly the assessment of the special skills of the students majoring in physical education by professional teachers, and most teachers conduct a summative assessment. The second is diagnostic evaluation, the third is formative evaluation, and the frequency of evaluation is not high. Such evaluation methods make many students realize and fail to understand the importance of teaching skills training to themselves. At the same time, it is not conducive to improving the quality of the teaching process and systematically improving the relevant comprehensive skills, which also shows that each school does not pay much attention to the training of students' teaching skills.

The focus of foreign research on the cultivation of teaching skills for students majoring in physical education is to evaluate the physical education process, results, and benefits. They emphasized that the professional theoretical knowledge should be closely combined with the cultivation of practical teaching ability so as to achieve the coordinated

development of theory and technology and achieve a win-win goal. They pay attention to the education mode that combines the students' off-campus and on-campus practice, the teaching skills training method is novel, and the effect is remarkable. They mainly use multimedia teaching methods such as video, slide, and projection to strengthen the training of students' teaching skills. In addition, extracurricular training and competition are also important means of their training. Compared with foreign teaching skills training models, these phenomena and problems found in this investigation on the current situation of physical education students' teaching skills training are worthy of our pondering. These schools are relatively representative sports colleges, and their overall situation can represent the current status of the teaching skills training of students majoring in physical education. The quality of teaching skills of students majoring in physical education in colleges and universities is directly related to the future development of the physical education industry. Through this small-scale practice test, it is further confirmed that the evaluation index system of classroom teaching skills for physical education graduates designed in this paper has certain rationality and practicability, but whether it has more extensive rationality, scientificity, and practicability and whether the evaluation index system can fully realize the regulation function of the physical education graduates in the classroom teaching practice training, we still need to further test and improve through long-term practice.

5. Conclusion

This paper starts from the perspective of sports skills training in colleges and universities, and on the basis of investigation and research on the training objectives, curriculum settings, sports skills teaching methods, comprehensive quality of teachers and students, training effects, and training environment for college physical education professionals, it is necessary to study sports skills. Education majors should think rationally about the training of sports skills. The results show that, in the process of training sports skills of physical education majors, the training goal is the basis, the curriculum setting is the foundation, the teaching staff is the guarantee, the quality of the students is the key, and the hardware facilities are the premise, which are both independent and interrelated. At present, the future talents of physical education majors in major colleges and universities are mostly "compound" and "specialized" talents, and there are few references to "applied" talents. Teachers' selection of sports skills teaching methods is mostly concentrated on traditional teaching methods, and the selection of new teaching methods is less. The training goal of physical education major should be oriented to applied talents, embody the people-oriented educational concept, highlight the differences in levels and regions, and strengthen the guidance of sports skills. In view of the current phenomenon of a large number of people and few venues in some schools, schools can use WeChat and other public platforms to update the availability of venues in a timely manner, improve the utilization rate of venues, and ensure the smooth development of teaching. In this paper, only a small-scale trial is carried out for the determined index system. Due to time constraints, the evaluation system cannot be repeatedly evaluated in the process, and there may be some limitations. In order to obtain a more complete index system, it is suggested that, in future research, a larger-scale empirical study can be conducted to obtain more extensive opinions and to modify and improve the evaluation index system.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] G. Escriva-Boulley, D. Tessier, N. Ntoumanis, and P. Sarrazin, "Need-supportive professional development in elementary school physical education: effects of a cluster-randomized control trial on teachers' motivating style and student physical activity," *Sport, Exercise, and Performance Psychology*, vol. 7, no. 2, pp. 218–234, 2018.

[2] A. J. White, J. Batten, and S. Robinson, "Tackling in physical education rugby: an unnecessary risk?" *Injury Prevention Journal of the International Society for Child & Adolescent Injury Prevention*, vol. 24, no. 2, Article ID 042672, 2018.

[3] A. Bekiari and M. Pylarinou, "Instructor argumentativeness and socio-communicative style and student discipline: using physical education students' class as an illustration," *Open Journal of Social Sciences*, vol. 05, no. 03, pp. 122–136, 2017.

[4] P. Bouboulis, S. Theodoridis, C. Mavroforakis, and L. Evaggelatou-Dalla, "Complex support vector machines for regression and quaternary classification," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 26, no. 6, pp. 1260–1274, 2015.

[5] D. Badau, "The educational impact of implementation the education through adventure discipline in physical education and sports academic curriculum," *Physical Education of Students*, vol. 21, no. 3, p. 108, 2017.

[6] Y. Zhang and Y. Xie, "Travel mode choice modeling with support vector machines," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2076, no. 1, pp. 141–150, 2008.

[7] C. Kyrkou, C. S. Bouganis, T. Theocharides, and M. M. Polycarpou, "Embedded hardware-efficient real-time classification with cascade support vector machines," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 27, no. 1, pp. 99–112, 2016.

[8] H. Yu, L. Gao, W. Liao, B. Zhang, A. Pizurica, and W. Philips, "Multiscale superpixel-level subspace-based support vector machines for hyperspectral image classification," *IEEE Geoscience and Remote Sensing Letters*, vol. 14, no. 11, pp. 2142–2146, 2017.

[9] W. Hu, W. Zhang, and Y. Min, "Real-time emergency control decision in power system based on support vector machines," *Proceedings of the Csee*, vol. 37, no. 16, pp. 4567–4576, 2017.

[10] K. Tatsumi, R. Kawachi, M. Akao, T. Kawachi, and T. Tanino, "Performance evaluation of multiobjective multiclass support vector machines maximizing geometric margins," *Numerical*

Algebra, Control and Optimization, vol. 1, no. 1, pp. 151–169, 2011.

[11] A. Burinskiene, "Pharma supply chain: efficiency modelling approach," *Journal of System and Management Sciences*, vol. 8, no. 2, pp. 65–73, 2018.

[12] S. Nakamura, M. Kakuta, and K. Shimizu, "1P-013 Development of protein local structure prediction method based on combination of multiple support vector machines(Protein: Structure, the 47th Annual Meeting of the Biophysical Society of Japan)," *Seibutsu Butsuri*, vol. 49, no. supplement, p. S65, 2009.

[13] N. Gordini and V. Veglio, "Customers churn prediction and marketing retention strategies. An application of support vector machines based on the AUC parameter-selection technique in B2B e-commerce industry," *Industrial Marketing Management*, vol. 62, no. APR, pp. 100–107, 2017.

[14] S. Maldonado, J. Pérez, and C. Bravo, "Cost-based feature selection for Support Vector Machines: an application in credit scoring," *European Journal of Operational Research*, vol. 261, no. 2, pp. 656–665, 2017.

[15] F. Deng, S. Guo, R. Zhou, and J. Chen, "Sensor multifault diagnosis with improved support vector machines," *IEEE Transactions on Automation Science and Engineering*, vol. 14, no. 2, pp. 1053–1063, 2017.

[16] S. Maldonado and J. López, "Synchronized feature selection for Support Vector Machines with twin hyperplanes," *Knowledge-Based Systems*, vol. 132, no. sep.15, pp. 119–128, 2017.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1368067, 15 pages
https://doi.org/10.1155/2022/1368067

Research Article

Dynamic Mechanisms of the Environmental Effects of FDI: An Empirical Test Based on the PVAR Model

Jiameng Yuan,[1] **Huimin Cui**,[2] **Hongguang Wang**,[1] **and Weiguo Sun**[1]

[1]*School of Civil Engineering, Northeast Forestry University, Harbin 150040, China*
[2]*School of Business, Shandong University, Weihai 264209, China*

Correspondence should be addressed to Weiguo Sun; davisun7811@163.com

Received 14 April 2022; Revised 20 June 2022; Accepted 22 June 2022; Published 20 July 2022

Academic Editor: Lele Qin

This study selected relevant data of China from 2006 to 2019 and adopted a panel vector autoregression (PVAR) model to conduct an empirical analysis on the dynamic mechanism of a series of problems including "FDI (foreign direct investment), economic scale, and environmental pollution," "FDI, industrial structure, and environmental pollution," and "FDI, production technology, and environmental pollution." Our research results showed that there are differences in the optimal lag order under different conditions, such as under the action mechanism of economic scale and industrial structure, and the optimal lag order was 1, while under the action mechanism of production technology, its value was 2. FDI had a long-term effect on the environment; under the dual-action mechanism of economic scale and industrial structure, the environmental effect of FDI reached the maximum within 2 periods, the effect lasted a relatively long time, and the response of environmental pollution to the technological level reached the maximum between the fourth period and the sixth period. In terms of the overall situation in China, the FDI did not produce an obvious effect on environmental pollution; on the contrary, it exhibited a trend of environmental improvement, which varied with the action mechanism and the region; and also, the improvement of technological level can also significantly improve the quality of environment.

1. Introduction

In the past decades, as the flow speed of international capital was accelerating and the global environmental problem was becoming increasingly serious, the relationship between foreign direct investment (FDI) and environmental pollution has attracted the eyes of field scholars around the world. Now the global economic situation is very complicated; there are more uncertainties during economic development; in this context, China has proposed to promote the high-quality development of economy; and such "high quality" covers multiple aspects including technological innovation, industrial structure upgrade, product added value increase, and the status improvement of value chain. During the high-quality development process, we will have to face the challenges of replacing old growth drivers with new ones and solving contradictions between environmental protection and economic development, and between fairness and efficiency. In these contradictory relationships, how does FDI affect the economic scale, industrial structure, and technological level? What is the dynamic mechanism by which FDI affects the ecological environment in these three aspects?

This study took China as the research object and empirically studied the environmental effects of FDI in the country. At first, this study reviewed relevant literature and analyzed the change trends and features of FDI and environmental pollution in China since 2006. In the benchmark analysis, this study built three models for "FDI, economic scale, and environmental pollution," "FDI, industrial structure, and environmental pollution," and "FDI, production technology, and environmental pollution," and employed the PVAR model to study the three dynamic mechanisms between FDI and environment, including the appearance time, turning point, and time lag of the scale effect, technological effect, and structural effect; also, the regional differences of the environmental effects of FDI had been analyzed. This study extended the research on the

environmental effects of FDI on the host country and upgraded the static analysis of total effect to the dynamic analysis of time points, thereby deepening and enriching our understanding of the environmental effects of FDI and its action mechanisms. In the end of the text, this study proposed a few suggestions for the policy-making of the government based on the research conclusions obtained from the case study of China.

2. Literature Review

2.1. Two Hypotheses about FDI's Environmental Effects on Host Country. There are many studies on FDI's environmental effects; according to the research conclusions, they can be divided into two types: the pollution haven hypothesis and the pollution halo hypothesis.

The pollution haven hypothesis holds that developed countries generally have stricter environmental control standards and higher pollution control costs; in contrast, the requirements of developing countries for environmental protection standards are lower; and as a result, accompanied by foreign investments, the high-polluting industries of developed countries will gradually relocate to developing countries, leading to a decline in the environmental quality of the host country [1, 2]. Since the pollution haven hypothesis had been proposed, field scholars took ASEAN (Association of Southeast Asian Nations), Latin America, and other regions in the world as research objects to study global countries with high-, middle-, and low-income levels; they adopted research methods such as PMG-based dynamic panel model, fixed-effect panel model, and random-effect panel model to prove the pollution halo effect [3–5]; and from a few perspectives of pollution control costs, environmental control standards, and capital accumulation, they demonstrated the viewpoint that FDI can aggravate the environmental pollution of the host country.

The pollution halo hypothesis holds that MNEs (multinational enterprises) generally have complete pollution control technologies and environmental management standards, and introducing foreign investors is helpful for the host country to promote more advanced pollution control technologies and environmental management systems to domestic firms, who can then apply more green production technologies and optimize their environmental management measures. Through the spillover effect on technology and management brought about by MNEs, the host country can upgrade the environmental protection level of the country. Some scholars also argued that foreign investment has a demonstrative effect on domestic firms of the host country, and FDI can promote the advancement of the pollution control technologies of the host country and improve its environmental quality to varying degrees [6–8].

In terms of research method selection, most existing studies chose the autoregressive distributed lag (ADL) model in researching the assumption of the environmental Kuznets curve (EKC), and the results proved that this assumption is true for some regions [9, 10]. Some scholars chose to use the spatial lag model (SLM) and spatial error model (SEM) in their studies and found that there is a significant spatial autocorrelation between FDI and environmental pollution level, both of which showed an obvious path-dependent feature, which had confirmed the pollution haven hypothesis [11].

In terms of the problem of whether FDI has an impact on the host country's environment, existing studies constructed measurement models and adopted significance test to study the problem, but they can only answer it with "yes" or "no," and for more questions like this, is the impact of FDI on the host country's environment fast or slow? Strong or weak? Long or short? They have no answer yet.

2.2. The Action Mechanisms of FDI on Environment. Some scholars believe that the impact of FDI on the host country's environment is complex and multidimensional, and the environmental effects obtained under different conditions are different as well. Through research, they discovered that the environmental effects of FDI on the environment vary with the host country's economic level, industrial structure, and environmental policies [12–14].

According to the analysis framework of Grossman and Krueger [15], the environmental effects of foreign investment on the host country can be decomposed into three categories: first, the scale effect, which means that the inflow of FDI will trigger the host country to expand its production scale, thereby increasing pollution emissions; second, the structural effect, which means that, as foreign investment enters the host country, the industrial structure will shift from the primary industry-oriented structure to the secondary industry-oriented structure, and this process will increase pollution emissions; later, as the industrial structure continues to shift to low-polluting industries: the service industry and the knowledge-intensive industry, the emissions for per unit output will decrease accordingly; third, the technological effect, which means that the technology spillover effect brought by foreign investment will make the production technologies of the host country to transform to greener and cleaner technologies, thereby reducing the pollutant emissions. The action mechanisms of FDI's environmental effects on the host country are shown in Figure 1.

Field scholars have attained fruitful research results on the scale effect, and some scholars studied the causal relationship between FDI, economic growth, and environmental conditions. For example, Hammami [16] adopted the VAR panel data model to study the data of 17 Middle East and North African countries from 1990 to 2012 and found that there is a one-way causal relationship between FDI stocks and CO_2 emissions to economic growth. Moreover, with the help of a dynamic simultaneous equation model and GMM, Hammami [17] drew the conclusions that there are two-way causal relationships between economic growth and FDI inflow, between economic growth and CO_2 emissions, and between FDI inflow and CO_2 emissions. Based on the data of Vietnam, Phuong and Tuyen [18] analyzed the data of 4-order lagging, and their research results showed that there are causal relationships among CO_2 emissions, FDI, and economic growth. The relationships among economic

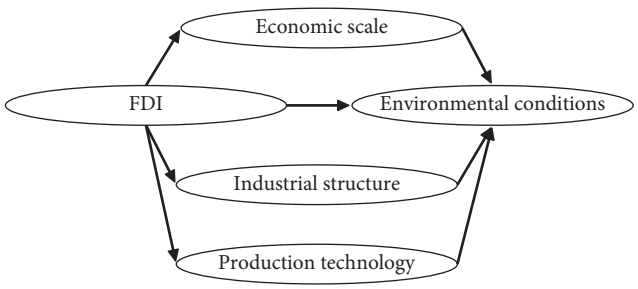


Figure 1: The action mechanisms of FDI's environmental effects on the host country.

growth, FDI, and CO_2 emissions are nonlinear. In most cases, they conform to the EKC hypothesis. FDI can increase CO_2 emissions via the scale effect and the structural effect.

However, few studies have talked about the structural effect or the technological effect, and those concerned about the three action mechanisms are even fewer.

3. Trends and Features of China's FDI and Environmental Pollution

In 2004, the amount of FDI that had been actually used in China was 60.63 billion US dollars, of which the amount used by foreign-invested enterprises accounted for the highest proportion of 66.34%; followed by the amount used by joint-stock ventures, accounting for 27.03%; and the proportions of FDI used by cooperative ventures, foreign-invested joint-stock enterprises, and cooperative development were relatively low. By 2020, the amount of FDI actually used in China was 144.37 billion US dollars, the proportion of FDI used by foreign-invested enterprises increased by 3.37%, and the proportion used by foreign-invested joint-stock enterprises increased by 3.66%, while the proportion used by joint-stock ventures decreased. From the perspective of the industries that the FDI had flowed into, in 2004, nearly three-quarters of FDI entered the manufacturing industry, and the direction was quite concentrated; while in 2020, the flow directions of FDI became more scattered, wherein the manufacturing industry accounted for 21%; the proportion of information transmission, computer service, and software industries increased by 14.45%; and the proportion of leasing and business service, scientific research, and technical service industries and the proportion of geological exploration, real estate, and transportation industries both increased as well. Between 2004 and 2020, the FDI introduced into China increased fast, and the FDI was mainly used by foreign-invested enterprises and joint-stock ventures; while in recent years, the proportion of FDI used by foreign-invested joint-stock enterprises increased to some extent. In addition, during the development process of this decade, the FDI introduced into China was distributed in more industries, and the proportion of the manufacturing industry decreased fast. Figure 2 shows the specific data, which are quoted from the China Statistical Yearbook. Since the China Statistical Yearbook has only been updated to 2020, the detailed data in Figure 3 are only updated to 2019. Now the quarterly data of basic

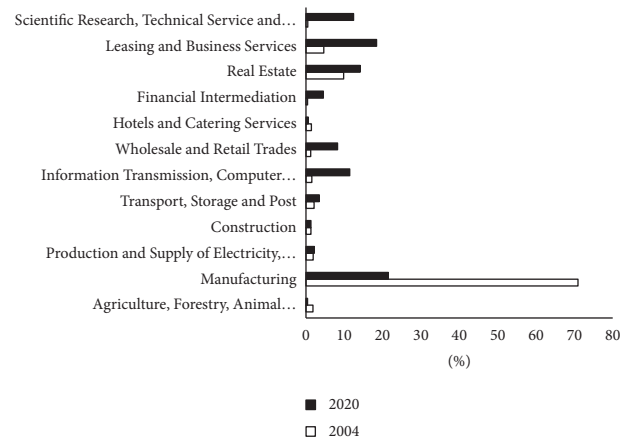


Figure 2: Distribution of China's FDI in different industries.

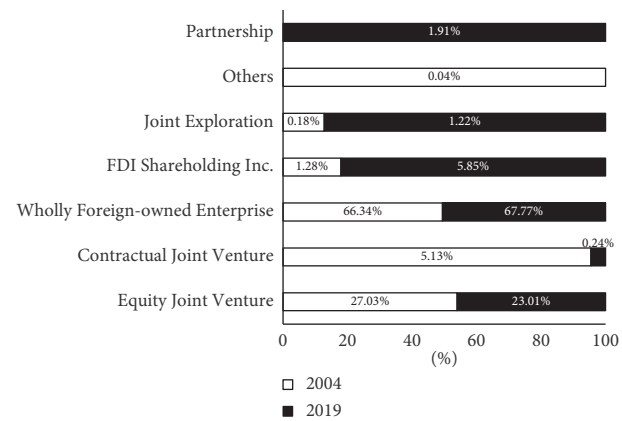


Figure 3: Proportions of FDI used by enterprises of different ownership types in China.

national economy statistics released by the Chinese government only involve agriculture, industry, and construction industries, so we could not get the latest quarterly data of FDI, and the data of the year 2021 will be released in early 2023.

Since the reform and opening-up policy had been implemented in China in 1978, the Chinese government has attached great importance to economic construction, and the GDP growth rate had remained above 8.00% for quite a long time. However, what comes together with the fast economic growth is the environmental pollution, which gets worse over time these years. In 2004, the Chinese government determined to take ecological and cultural construction as a strategic task and building a moderately prosperous society in an all-round way as a new objective. Since then, the environmental protection system, institutions, and measures have been developed and improved continuously in China; the enforcement of the environmental protection law has been strengthened; and the degree of environmental pollution has abated to some extent. The SO_2 emissions decreased from 22.55 million tons in 2004 to 8.75 million tons in 2020, with a drop of more than 157.71%; fume emissions also dropped from 10.95 million tons in 2004 to 7.96 million

tons in 2020. Figure 4 shows the change trajectories of SO_2 emissions and FDI in China from 2004 to 2020. During these 16 years, the degree of environmental pollution had decreased, while FDI had constantly increased, but whether there is a correlation between the two is still pending for subsequent research and analysis. Meanwhile, besides FDI, other social and economic factors might affect the environmental pollution status as well; in view of this, they will be discussed further in the fifth chapter of this study.

4. Empirical Analysis

4.1. Data Source and Sample Selection. The relevant data used in this research were quoted from the *China Statistical Yearbook*. The independent variable pollutant emissions include a few aspects such as air pollution, water pollution, waste pollution, sound pollution, and eco-environment damage. For the problem of how to use a single indicator to well describe the overall damage level of the environment and resources in a country or in a region, existing studies have not given a satisfactory answer yet. Therefore, existing studies mostly used multiple specific pollution indicators. Although China has been constantly adjusting and optimizing its energy structure in recent years and the coal consumption speed has slowed down obviously, still coal accounts for more than 50.00% of China's primary energy consumption, and the burning of the sulfur-containing fuels (mainly the coal) is a major source of pollutant SO_2. Although CO_2 can aggravate the greenhouse effect, causing temperature rise, sea level rise, and other phenomena, CO_2 is not an air pollutant and the damage caused by it to the environment is not regarded as pollution. This study also chose SO_2 as the indicator to describe the environmental pollution level in the estimation of the basic model; moreover, in this study, the total investment of foreign-invested enterprises was used to represent the amount of FDI invested by country i to China within time period t; its unit was one billion dollars; and GDP was used to represent the economic scale. In addition, the number of patent applications refers to the quantity of patent applications received by patent institutions applying for the grant of patents of technical inventions; it is the sum of invention patent applications, utility model patent applications, and design patent applications; and this indicator can reflect the activity degree of technological development and the initiative level of inventors to apply for patent protection. The more the number of patent applications, the higher the innovation capability of a society, and the more dynamic the society is; in this study, the number of patent applications is used to describe the regional technological level based on two considerations: first, the number of patent applications can reflect the competitiveness and innovativeness of a region and whether technological development activities are active or not, and the more the number of patent applications, the strong the innovation ability of the region; second, the number of patent applications can also reflect the technology update status of a region, the changes in the number of patent applications can indicate the technology update cycle, and the greater the increment of the number of patent applications, the faster the technology innovation in the region, the faster the technology update, and the more obvious the technological advancement in the region. Thus, this study chose to use this indicator to represent the technological level of the regions.

In addition, this study also quoted data from the Statistical Yearbooks of provinces, municipalities, and autonomous regions of China. In a country, when the focus of its economic development or industrial structure has gradually shifted from the primary industry to the secondary and tertiary industry, it can be considered that the country's industrial structure is being optimized, so this study chose to use the total output of the tertiary industry to represent the industrial structure of the region (Table 1).

In specific analysis, considering the stability of the variables, this study performed logarithmic difference processing on the abovementioned variables, and all variables mentioned in the following texts are variables after being subjected to logarithmic difference processing. Subsequently, the indicator data were sorted and the panel data of 31 Chinese provinces, municipalities, and autonomous regions (this study had only analyzed the mainland areas of China) from 2006 to 2019 were listed in the samples. All data were from the China Statistical Yearbook and the Statistical Yearbooks of 31 provinces, municipalities, and autonomous regions of China; and the selected variables, which involved nominal value data had all been converted into US dollars (in 2006 constant price).

Note that indicator SO_2 refers to the SO_2 emissions of each province, municipality, and autonomous region, units in 10,000 tons. Indicator gdp refers to the gross domestic product of each province, municipality, and autonomous region, units in billions of dollars. Indicator thi refers to the gross domestic product of the tertiary industry of each province, municipality, and autonomous region, units in billions of dollars. Indicator teca refers to the number of patent applications of each province, municipality, and autonomous region. Indicator fdi refers to the total investment of foreign-invested enterprises of each province, municipality, and autonomous region, units in billions of dollars. All nominal values were converted into US dollars (in 2006 constant price).

4.2. Benchmark Analysis. To a certain extent, the increase in FDI has a direct impact on pollutant emissions, and at the same time, it also has an indirect impact on it through the mechanisms of scale effect, structural effect, and technological effect. So in this study, the three variables of scale, structure, and technology had been included in the analysis. Based on the Copeland-Taylor model [2], this study introduced the technological factor and constructed an environmental pollution model containing multiple influencing factors.

The PVAR (panel vector autoregression) model proposed by Holtz-Eakin et al. can analyze the interaction between endogenous variables of panel data, and it regards all variables as endogenous variables to analyze each variable and its relationship with the lag term. Compared with the

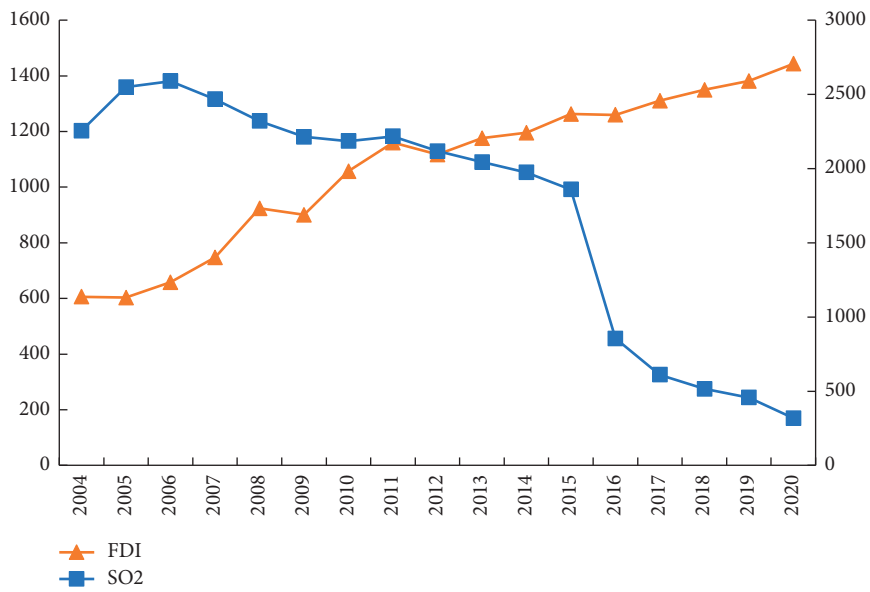


Figure 4: Changes in SO_2 emissions and FDI in China (2004–2020). Note: the axis on the left is the total SO_2 emissions of 31 provincial administrative regions in mainland China from 2004 to 2020, and the unit is 10,000 tons; the axis on the right is the total amount of FDI of the 31 provincial administrative regions in mainland China from 2004 to 2020, and the unit is 1 billion US dollars. The FDI values here are the total investment data of foreign-invested enterprises, and all data were quoted from the China Statistical Yearbook.

Table 1: Descriptive statistics of main variables.

Variable	Obs	Mean	Std. dev.	Min	Max
dlnso2	403	−0.0693	0.1857	−1.0838	0.4790
dlngdp	403	0.0909	0.0450	−0.2643	0.2118
dlnthi	403	0.1076	0.0384	−1.4889	0.2972
dlnteca	403	0.2215	0.1568	−0.3461	0.9888
dlnfdi	403	0.0795	0.1952	−1.2804	1.8773

long time-series requirements of the conventional VAR models, the PVAR model has the features of large cross section and shorter time series, and it can use panel data to effectively solve the problem of individual heterogeneity, and fully consider the individual effect and time effect. Therefore, in this research on FDI and environmental pollution, this model had been taken as the basis, and other important influencing factors of environmental pollution such as economic scale, industrial structure, and technical factors were introduced to fully consider the differences in the effect under different action mechanisms. In the empirical analysis, the PVAR model treated all variables as endogenous variables. Combining with the commonly used PVAR models and the research objectives of this study, the proposed model was set as follows:

$$\begin{aligned} Z_{i,t} &= \alpha_0 + \alpha_1 \sum_{j=1}^{k} \rho_j Z_{i,t-j} + \mu_i + \gamma_t + \varepsilon 1_{i,t}, \\ Y_{i,t} &= \beta_0 + \beta_1 \sum_{m=1}^{p} \beta_m Y_{i,t-m} + \varphi_i + \omega_t + \varepsilon 2_{i,t}, \\ Q_{i,t} &= \varphi_0 + \varphi_1 \sum_{n=1}^{u} \tau_n Q_{i,t-n} + \sigma_i + \theta_t + \varepsilon 3_{i,t}, \end{aligned} \tag{1}$$

where $Z_{i,t}$, $Y_{i,t}$, and $Q_{i,t}$ are column vectors containing 3 endogenous variables; i and t represent the country and the year; α_0, β_0, and φ_0 are intercept term vectors; ρ_j, β_m, and τ_n represent regression coefficient matrixes, wherein j, m, and n represent the lag orders of each variable; μ_i, φ_i, and, σ_i represent individual effects; γ_t, ω_t, and θ_t represent time effects; and $0\varepsilon 1_{i,t}$, $\varepsilon 2_{i,t}$, and $\varepsilon 3_{i,t}$ are random disturbance terms. Model (1) represents the dynamic relationship among FDI, economic scale, and environmental pollution. Model (2) represents the dynamic relationship among FDI, industrial structure, and environmental pollution. Model (3) represents the dynamic relationship among FDI, production technology, and environmental pollution.

The PVAR model proposed in this study gave estimations by referring to the methods of Love and Zicchino [19] and Abrigo and Love [20]. In order to avoid the problem of spurious regression, this study applied the LLC and IPS criteria to test the stability of each variable. The test results are shown in Table 2. Both LLC and IPS tests rejected the original hypothesis that there are unit roots at the 1% significant level, so the variables were all stable sequences.

In the optimal lag-order test of the model, the optimal lag sequence of the model was determined according to three information criteria of MBIC, MAIC, and MQIC, as shown in Table 3, and the results showed that the lag-order values of Model (1) and Model (2) should be 1, that is, the optimal lag order of the two models should be 1, and the optimal lag order of Model (3) should be 2. Therefore, when estimating Model (1) and Model (2), this study chose 1 as the lag order; and when estimating Model (3), this study chose 2 as the lag order. With the help of software Stata 15, the estimation results of the PVAR model were attained, details as shown in Table 4.

Table 2: Variable stability tests.

Variable	LLC statistic	IPS statistic	Test results
dlnso2	−14.1708***	−8.4215***	Stable
dlngdp	−8.1533***	−3.0101***	Stable
dlnthi	−11.8877***	−4.9922***	Stable
dlnteca	−11.1723***	−6.2058***	Stable
dlnfdi	−12.2733***	−6.3312***	Stable

Note. The LLC statistic column is the statistics of bias compensation t_δ, * (adjusted t^*), and the IPS statistic column is the statistics of $w_{\bar{t}}$. ***, **, and *, respectively, represent the significance levels of 1%, 5%, and 10%.

Table 3: PVAR lag-order test results.

		PVAR (1)	PVAR (2)	PVAR (3)	PVAR (4)
Model (1)	MBIC	−142.3318*	−107.0167	−67.5340	−33.3060
	MAIC	−20.6555*	−15.7595	−6.6959	−2.8870
	MQIC	−69.8076*	−52.6236	−31.2720	−15.1750
Model (2)	MBIC	−147.9034*	−120.8728	−73.2340	−34.5923
	MAIC	−26.2271	−29.6156*	−12.3959	−4.1733
	MQIC	−75.3793*	−66.4797	−36.9720	−16.4613
Model (3)	MBIC	−121.1774*	−111.2331	−72.9278	−40.4811
	MAIC	−6.1366	−19.9759*	−12.0897	−10.0620
	MQIC	−55.2888	−56.8401*	−36.6658	−22.3501

The symbols ***, **, and *, respectively, represent the significance levels of 1%, 5%, and 10%.

According to the results of Model (1) and the equation of environmental pollution, we can know that the estimation coefficient of economic scale of the period one-phase behind (the period that has lagged behind the current period for one phase) was significantly positive at the 1% significance level, and the value 2.68 was relatively large, indicating that the expansion of economic scale had a significant promotive effect on the deterioration of environmental pollution; when the economic scale increased by 1.00%, the environmental pollution level would increase by 2.68%; the estimation coefficient of FDI of the period one-phase behind was negative, but not significant, indicating that the adverse impact of DFI on the environment was decreasing, but its inhibitory effect on environmental pollution had not shown yet, and there is only a certain tendency of environmental improvement. In terms of the equation of economic scale, the environmental pollution variable of the period one-phase behind had a significant positive impact on the economic scale of the current period, indicating that, on the whole, the economy of China mainland areas was developing at the cost of environmental pollution; the economic scale of the period one-phase behind had a significant positive impact on the economic scale of the current period. The lag term of FDI was not significant, which indicated that FDI did not necessarily promote the expansion of economic scale. According to the regression results of the equation of FDI, the economic scale variable of the period one-phase behind had a significant negative impact on the FDI of the current period, that is, when the economy has developed to a certain level, the growth rate of FDI invested by foreign-invested enterprises into a region would slow down, while regions with less-developed economic level would attract more foreign capitals, and the growth of investment would be faster.

According to the results of Model (2) and the equation of environmental pollution, the estimation coefficient of the lag term of the industrial structure was significantly positive at the 1% significance level, so the higher the total output of the tertiary industry, the faster the growth rate, and the higher damage level of the environment. The mechanism behind it was that, although the damage brought by the tertiary industry to the environment was weaker compared with that brought by industrial pollution, still the development of tertiary industries such as commerce, catering, and entertainment had brought a great amount of "white pollution," and the burning of nondegradable plastics had produced harmful gases and polluted the atmosphere. In addition, the rapid development of the transportation industry has also put pressure on the improvement of environmental conditions. In terms of the equation of industrial structure, the estimation coefficient of the industrial structure variable of the period one-phase behind was significantly positive, indicating that the upgrading of the industrial structure is an ever-growing process; for regions with better industrial structure, their tertiary industry grew faster; while for those with worse industrial structure, their tertiary industry faced more difficulties during industrial structure optimization and upgrading. In terms of the equation of FDI, the estimation coefficient of the lag term of the industrial structure was significantly negative at the 1% significance level, indicating that for regions with more advanced tertiary industry and better industrial structure, their FDI grew slower, and the possible reason was that the FDI had mainly gone to the secondary industry.

According to the results of Model (3), in terms of the equation of environmental pollution, both the first-order lag term and the second-order lag term of the technological level were significantly positive, and the coefficient values are relatively small, indicating that the improvement of production technology had exerted a negative impact on the environment, which might be because that the improvement of production technology was mainly concentrated in the industrial production field, which took production scale expansion and production efficiency improvement as targets, not concentrated in the high-tech industries. In terms of the equation of technological level, both the first-order lag term and the second-order lag term of the technological level were significantly positive, indicating that the improvement of the technological level is also a continuously growing process. For regions with stronger innovation capability and more active R&D activities, their technological level grew faster; while for regions with weaker innovation capability, their technological level grew slower. Similarly, according to the equation of FDI, the estimation coefficient of the environmental pollution variable of the period one-phase behind was significantly negative.

4.3. Impulse Response. In this study, Monte Carlo simulations were repeated for 500 times to get a graph of the impulse response function of the period ten-phase behind and generate a 95% confidence interval at the same time.

By analyzing the impulse response as shown in Figure 5, we can see that (1) if the economic scale is impacted by an

Table 4: PVAR estimation results.

Model (1)	*dlnso2*		*dlngdp*		*dlnfdi*	
	b_GMM	*t_GMM*	*b_GMM*	*t_GMM*	*b_GMM*	*t_GMM*
L.dlnso2	0.0258	0.5039	0.0344***	4.7770	0.0815	1.0985
L.dlngdp	2.6820***	7.9849	0.6945***	14.8260	−1.9432***	−5.0698
L.dlnfdi	−0.0255	−0.5424	0.0110	1.3418	0.0375	04352
Model (2)	*dlnso2*		*dlnthi*		*dlnfdi*	
	b_GMM	*t_GMM*	*b_GMM*	*t_GMM*	*b_GMM*	*t_GMM*
L.dlnso2	0.2007***	4.7795	0.0298***	3.9626	−0.0687	−1.1355
L.dlnthi	2.9442***	5.7806	0.4136***	5.1031	−2.3588***	−5.0431
L.dlnfdi	−0.0768	−1.4239	−0.0015	−0.1565	0.0881	1.1943
Model (3)	*dlnso2*		*dlnteca*		*dlnfdi*	
	b_GMM	*t_GMM*	*b_GMM*	*t_GMM*	*b_GMM*	*t_GMM*
L.dlnso2	0.2229***	2.9520	0.0217	0.2899	−0.2707***	−3.4658
L.dlnteca	0.5627**	2.3120	0.7574***	3.6170	−0.0898	−0.4078
L.dlnfdi	−0.0610	−0.8188	0.1233	1.4634	0.1448	1.4671
L2.dlnso2	0.0629	0.5735	−0.2045**	−2.3196	−0.1658	−1.5512
L2.dlnteca	0.7623***	4.0316	0.4195***	2.7675	−0.0640	−0.3194
L2.dlnfdi	−0.0296	−0.6545	0.0294	0.4383	−0.0175	−0.3895

Note. L. represents lagging for one phase; b_GMM represents the estimation coefficient; and t_GMM represents the *t*-value. ***, **, and *, respectively, represent the significance levels of 1%, 5%, and 10%.

impulse with the size of a standard deviation, the environmental pollution would give a strong positive response. In the figure, such response reached the maximum at the end of the first period and then gradually decreased, but this impact existed for a long time and remained at the 0.01 level until the end of the seventh period. This means that the expansion of the economic scale had a long-term promotive impact on environmental degradation, as shown in Figure 5; if the economic scale is impacted by a standard deviation, there will be a significant positive response in environmental pollution; and this impact will last for a long time. Moreover, Figure 5 also reflects that FDI will give a negative response under the impact of economic scale. The expansion of the economic scale will lead to a decrease in the growth rate of FDI, thereby weakening the positive impact of FDI on the economic scale; then, the growth rate of FDI will decline; and the environmental condition will be improved accordingly. FDI showed a negative response, which reached -0.06 at the end of the first period and then gradually declined, indicating that the expansion of the economic scale had a negative impact on the growth rate of FDI. (2) If the environmental pollution variable is impacted by an impulse with the size of a standard deviation, the economic scale would give a positive response. In the figure, this response reached the maximum at the end of the first period and then gradually decreased, which was mainly because that regions that are at the initial and middle stage of industrialization would tend to sacrifice their environment to promote economic development; FDI fluctuated a bit within a short time; it responded negatively at first and positively later; and then, it responded negatively and approached 0 continuously, indicating that the response of FDI to changes in environmental pollution was not stable, and it might be influenced by regional development conditions or other economic factors. (3) If FDI is impacted by an impulse with the size of a standard deviation, the environmental pollution variable would give a negative response within a short time; then, the response became positive and gradually approached 0; this shows that FDI had a short-term inhibitory effect on environmental pollution; but in the long run, such effect did not last for a long time; since the zero line remained within the confidence interval all this time, so the economic scale did not have a significant response, there is only a small response in the first period; then, the response gradually decreased and started to approach 0, which was because although FDI had directly expanded the domestic investment scale and promoted economic development via using capital to drive GDP growth, but the economic scale effect of FDI was affected by various factors such as industrial structure, population size, production technology, and sectoral and regional differences, so it is necessary for each region to formulate reasonable plans for FDI and maximize its outcomes.

By analyzing the impulse response shown in Figure 6, we can see that (1) if the industrial structure is impacted by an impulse with the size of a standard deviation, the environmental pollution would give a positive response. In the figure, such response reached the maximum at the end of the first period and then gradually decreased, but its value remained at the 0.01 level by the end of the seventh period, indicating that the growth of the total output of the tertiary industry in each region might be driven by the development of high-polluting industries such as transportation and catering, while the low-polluting high-tech industries and modern service industries such as financial sector, commercial services, and cultural industry only took a small proportion; FDI exhibited a long-term and lasting negative response, which means that for regions with the faster growth rate of tertiary industry and better industrial structure, their FDI grew slower. (2) If the environmental pollution is impacted by an impulse with the size of a standard deviation, the industrial structure would give a positive response, so it can be seen that the environmental pollution can trigger a positive change in the industrial

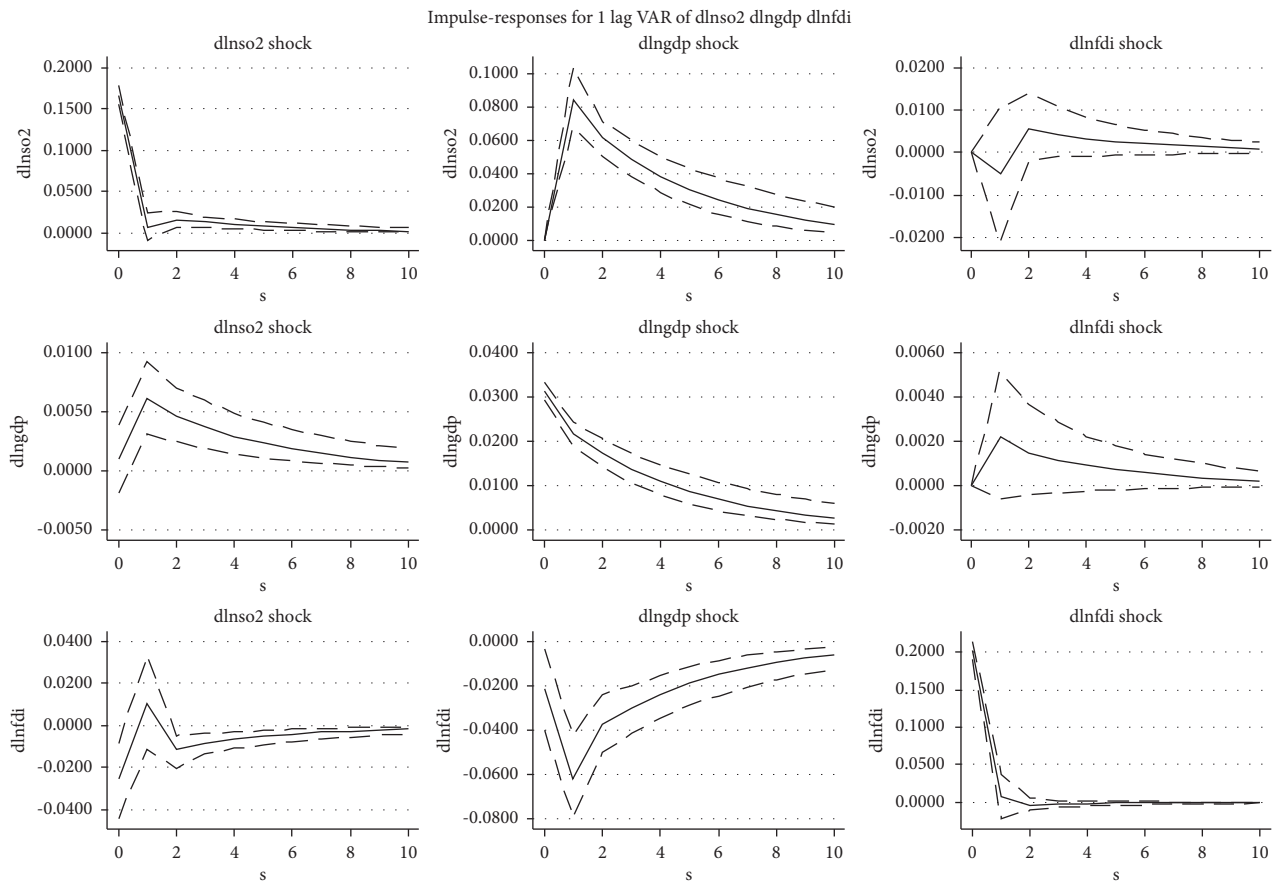


Figure 5: Impulse response of Model (1).

structure within a short time, but in the long run, such impact would approach 0; when the impact came, FDI showed a negative response, that is, when the environmental conditions in a region deteriorate, the country from which the FDI flowed out would tend to reduce its investment in a short time. (3) If the FDI is impacted by an impulse with the size of a standard deviation, environmental pollution and industrial structure would give a negative response, which means that the increase in FDI was not conducive to the optimization of industrial structure, but it had promoted the improvement of environmental conditions to a certain extent.

By analyzing the impulse response shown in Figure 7, we can see that (1) for the impact on the technological level, the environmental pollution gave a positive response. Since the improvement of production technology was mainly concentrated in the industrial production field, which took production scale expansion and production efficiency improvement as targets, it further aggravated the environmental pollution. For any technology, it would require a transition period from the invention stage to the application in the actual production field, so the response of environmental pollution to the technological level reached the maximum between the fourth and the sixth periods; FDI exhibited a negative response; and similarly, its response value reached the maximum between the fourth and the sixth periods. China's labor costs are relatively low, so the local governments had formulated a series of preferential policies to attract foreign capitals. Since foreign capitals generally aim to reduce production costs, they tend to go to less-developed regions with low technological level and labor costs; while in regions with a higher technological level, the growth rate of foreign investment was lower and even became negative. (2) For the impact on environmental pollution, both the technological level variable and the FDI variable showed an alternating positive and negative response. (3) As for the impact on FDI, the environmental pollution variable gave a positive response, whose value reached the maximum in the sixth period; since the zero line was within the confidence interval all the time, the production technology did not give a significant response, and the change in this response value was relatively gentle and continued. On the whole, for most regions in China, FDI mostly has gone to labor-intensive processing and trade industries with a low technological level. In terms of the structure of the introduced technology, the introduced technologies are mostly primary-level technologies, and the foreign investment only had a limited promotive effect on the technological level.

4.4. Variance Decomposition. The variance decomposition can clearly reflect the degree to which each variable explains itself in each period. The results of the variance decomposition are listed in Tables 5-7.

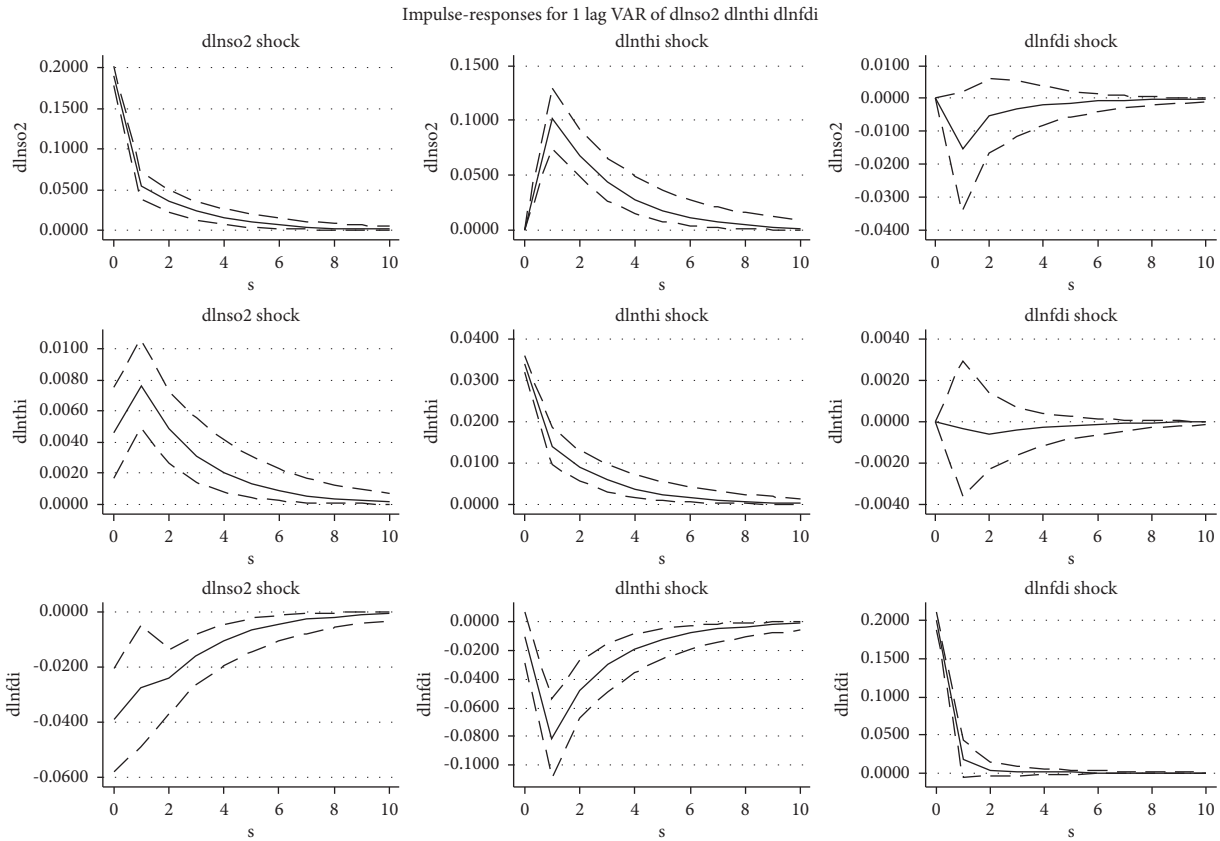


Figure 6: Impulse response of Model (2).

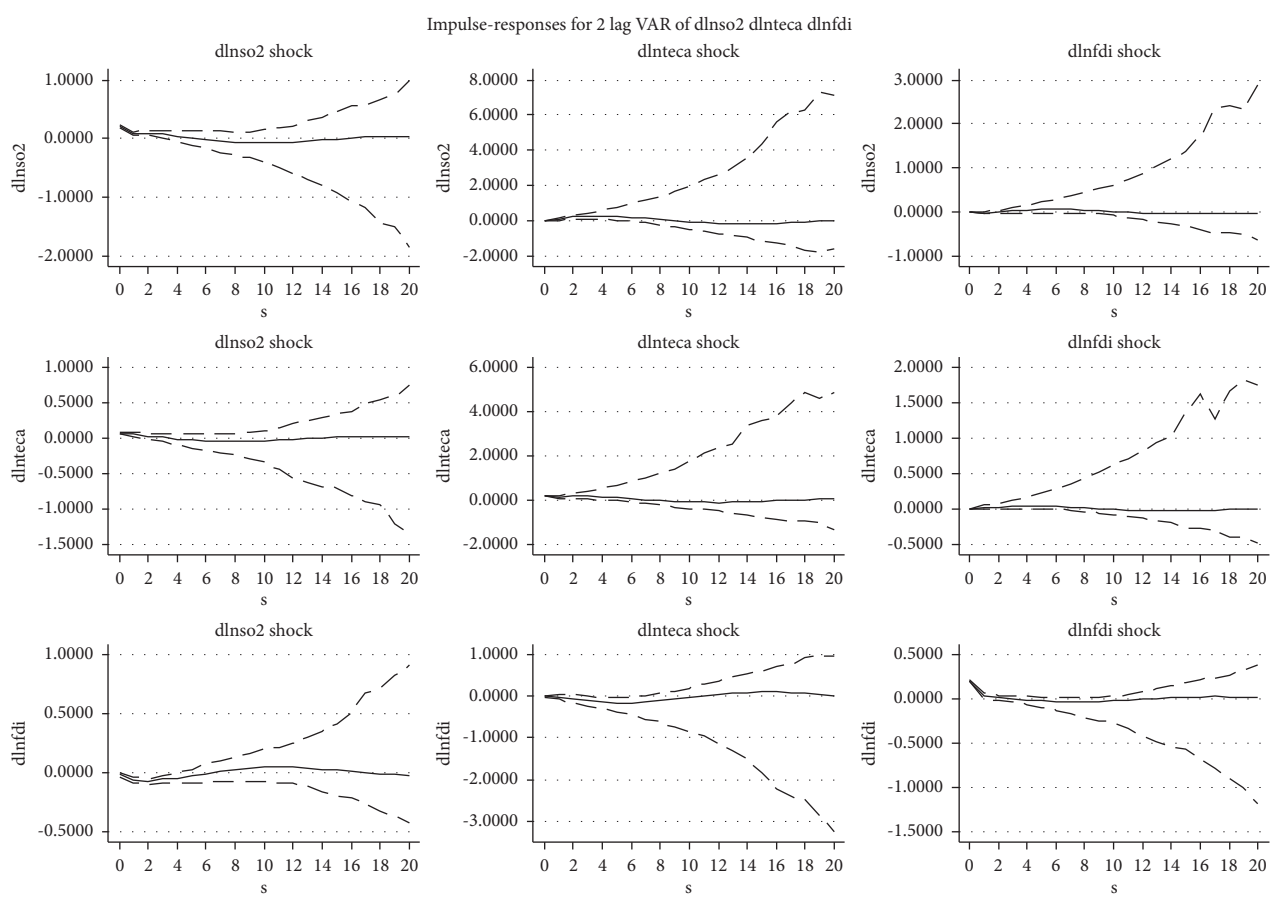


Figure 7: Impulse response of Model (3).

According to the variance contribution rate shown in Table 5, besides the influence of each variable on itself, the economic scale had a strong ability in explaining environmental pollution, and the variance contribution rate tended to be stable around the fifth period and finally stabilized at about 37.53%. Correspondingly, environmental pollution also had a good ability in explaining the fluctuations in the economic scale, and the variance contribution rate reached 3.87% in the fifth period and still showed a gradual upward trend. This indicates that, for the current development status of China, there is a long-lasting correlation between economic growth and environmental deterioration. FDI only had a weak ability in explaining the fluctuations in environmental pollution, and the values of the variance contribution rate between the third and fifth periods were kept under 0.20%. Same as the previous analysis results, the impact of FDI on the environment was not obvious. The ability of FDI in explaining the economic scale remained below 0.40% for a long time, indicating that the various regions in China had not made good use of the foreign capital properly, and the effect of FDI in promoting economic growth had not been fully exerted.

According to the variance contribution rate shown in Table 6, besides the influence of each variable on itself, the variance contribution rate of industrial structure to environmental pollution fluctuations showed an upward trend; its explanation ability was relatively good; and the value reached 30.46% in the tenth period. The variance contribution rate of environmental pollution to the fluctuations of industrial structure also remained at a level of 7.36%, indicating that the transportation and the catering industries occupied a large proportion in the output of the tertiary industry in China; their impact on environmental deterioration was obvious, and such impact would last for a long time. Likewise, FDI had a weak ability in explaining the environmental pollution variable, and the variance contribution rate of the industrial structure variable to FDI gradually increased, reaching 19.41% in the tenth period. There is a strong correlation between the growth rate of FDI of a region and its industrial structure.

According to the variance contribution rate shown in Table 7, besides the influence of each variable on itself, the variance contribution rate of the environmental pollution variable to the technological level had gradually decreased, but it showed an upward trend after the fifth period. The variance contribution rate of technological level to environmental pollutant fluctuations gradually increased, reaching 9.34% in the tenth period. The improvement of the technological level was mainly concentrated in the field of industrial production, so it is closely related to the fluctuations of environmental pollution. On the other hand, the variance contribution rate of technology level to FDI rapidly increased after the third period, reaching 38.99% in the fifth period, and then reaching 66.03% in the tenth period, indicating that the technological level only had a small impact on the introduction of foreign capital within a short time, but in the long run, the technological level had a very strong ability in explaining the scale and growth rate of foreign investment.

Table 5: The PVAR variance decomposition results of Model (1).

	s	dlnso2	dlngdp	dlnfdi
dlnso2	1	1.00000	0.00000	0.00000
	3	0.71710	0.28141	0.00149
	5	0.65422	0.34379	0.00199
	10	0.62244	0.37532	0.00224
dlngdp	1	0.00107	0.99893	0.00000
	3	0.03347	0.96266	0.00386
	5	0.03866	0.95707	0.00427
	10	0.04104	0.95449	0.00446
dlnfdi	1	0.01503	0.01080	0.97417
	3	0.01819	0.11956	0.86225
	5	0.01979	0.14540	0.83482
	10	0.02067	0.15993	0.81939

Table 6: The PVAR variance decomposition results of Model (2).

	s	dlnso2	dlnthi	dlnfdi
dlnso2	1	1.00000	0.00000	0.00000
	3	0.72659	0.26863	0.00478
	5	0.69651	0.29875	0.00473
	10	0.69073	0.30455	0.00472
dlnthi	1	0.01789	0.98211	0.00000
	3	0.06633	0.93337	0.0003
	5	0.07219	0.92736	0.00044
	10	0.07335	0.92618	0.00047
dlnfdi	1	0.03672	0.00266	0.96062
	3	0.05480	0.17190	0.77329
	5	0.05981	0.19080	0.74981
	10	0.06081	0.19406	0.74513

Table 7: The PVAR variance decomposition results of Model (3).

	s	dlnso2	dlnteca	dlnfdi
dlnso2	1	1.00000	0.00000	0.00000
	3	0.48857	0.51011	0.00132
	5	0.24917	0.73684	0.01399
	10	0.17006	0.78892	0.04101
dlnteca	1	0.13778	0.86222	0.00000
	3	0.09486	0.88921	0.01593
	5	0.06194	0.90732	0.03074
	10	0.09342	0.86268	0.04389
dlnfdi	1	0.00932	0.00021	0.99047
	3	0.19367	0.05311	0.75322
	5	0.17213	0.38982	0.43805
	10	0.09728	0.66030	0.24242

4.5. Analysis of Regional Heterogeneity. The Seventh Five-Year Plan formulated by the Chinese government in 1986 divided the mainland areas of China into three major regions: the eastern region, the central region, and the western region. In 1997, Chongqing was established as a municipality and included in the western region. Then, in 2000, the policies and measures concerning large-scale development of the western region granted the Inner Mongolia Autonomous Region and the Guangxi Zhuang Autonomous Region with the same preferential policies. After these adjustments, now the western region includes 12 provincial-

level administrative regions; the central region includes 8 provincial-level administrative regions; and the eastern region includes 11 provincial-level administrative regions. Regarding economic development level, the eastern region's economy is the most developed, its industrial structure is better, and the basic facilities are relatively complete; the central region develops fast in recent years, but the overall development degree is lower than that of the eastern region; the western region enjoys more policy support, but compared with the eastern region and the central region, its economic development level is lower. Since the three mechanism variables of eastern, central, and western regions had all shown obvious features of step development, the regional division can fully reflect whether the differences in the size of mechanism variables have different impacts on the three action paths.

This study conducted an empirical analysis on the dynamic impact of FDI, environmental pollution, and three action mechanisms on each region. The stability test was performed first; then, according to the results of the optimal lag order obtained by the PVAR model, first-order lag had been selected for the three regions under the three action mechanisms (Table 8).

According to the estimation results of Model (1), no matter for the eastern region, central region, or the western region, the GDP of first-order lag had a significant positive promotive effect on the environmental pollution variable. The environmental pollution effect of the economic scale of the eastern region was the strongest, followed by the central region, and the western region was the weakest. For the three regions, all coefficients of the impact of first-order lag GDP were all negative; but in terms of the absolute values of the coefficients, the impact of the eastern region's economic scale on FDI was greater than that of the central region; and the impact of the central region's economic scale on FDI was greater than that of the western region. Just the same as the conclusion obtained from the previous analysis, when the economy has developed to a certain scale, the growth rate of foreign capitals attracted by a region would decrease. Although for the eastern and central regions, the effect of the environmental pollution variable of first-order lag on GDP was positive, it was not significant, and the coefficient was small, indicating that as the economic development of eastern and central regions was transforming and upgrading, the contribution of high-polluting industries to economic development decreased, while for the western region, the expansion of its economic scale was still at the expense of environmental pollution.

According to the estimation results of Model (2), in terms of the coefficient of the impact of industrial structure variable of first-order lag on environmental pollution, the coefficients of all three regions were positive, but the coefficients of the eastern region and the central region were higher, and the coefficient of the western region was lower. China's high-tech industries are mainly distributed in the eastern region, namely, the developed coastal areas of three major economic circles: the Pearl River Delta, the Yangtze River Delta, and the Beijing-Tianjin-Hebei Bohai economic circle. However, the high-tech industries in China are still at the initial stage of development, and manufacturing industries such as electronic and communication equipment manufacturing, electronic machinery and equipment manufacturing, and transportation equipment manufacturing are still taking up the most important position in the industrial layout. As the upgrading of industrial structure in the eastern region is accelerating, the central and western regions have undertaken the industries that are transferred out from the eastern region. In the central region, the infrastructure is relatively complete; the labor resource is sufficient; and it has some advantages in taking in the transferred industries. However, in the western region, the dominant industries of some provinces are generally the tourism industry and the agriculture and animal husbandry industries with local features; in addition, in recent years, these provinces have initiated the project of marginal farmland afforestation and strengthened eco-environment protection and construction; and the environmental pollution effect of the industrial development of the western region is relatively weak. In terms of the coefficient of the impact of FDI of first-order lag on industrial structure, the FDI of the eastern and western regions had not shown a significant promotive effect on the development of the tertiary industry; while for the central region, although the impact of FDI on its industrial structure was not significant, it had shown a negative trend. The coefficients of the impact of industrial structure variable of first-order lag of the three regions were all negative, and there is a common phenomenon in the various regions of China, that is, FDI tends to flow into regions with less-developed tertiary industry and slower growth rate, indicating that the FDI entering China generally pays more attention to the labor force or other cost advantages, since the purpose of foreign investment is to reduce production costs, so it will prefer regions with less-optimized industrial structure.

According to the estimation results of Model (3), in terms of the coefficient of the impact of the technological-level variable of first-order lag on environmental pollution, the coefficients of the three regions were all significantly positive, wherein the coefficient of the central region was the largest, indicating that compared with eastern and western regions, the improvement of the technological level of the central region was mainly in the industrial production field; therefore, the pressure on the environment was higher. The FDI of first-order lag of the eastern region had a significant positive impact on the environmental pollution variable, and this is also in line with previous analysis. A considerable part of the FDI flowing into the eastern region had promoted the development of the low-polluting tertiary industry, exerting an effect of environmental improvement. The coefficients of the impact of the technological-level variable of one-order lag were all significantly negative, indicating that the foreign investment attracted by regions with a high technological level was less. At present, the FDI attracted to China is mainly low-end production, and the investment in technology R&D cooperation is few.

Table 8: The PVAR estimation results of each region.

	Eastern region			Central region			Western region		
Model (1)	*dlnso2*	*dlngdp*	*dlnfdi*	*dlnso2*	*dlngdp*	*dlnfdi*	*dlnso2*	*dlngdp*	*dlnfdi*
L.dlnso2	−0.5930	−0.0003	0.4491**	0.0432	0.0160	0.2894*	0.1707***	0.0571***	−0.0587
L.dlngdp	5.6114***	0.6780***	−3.2730***	3.1288***	0.7975***	−3.2410***	1.7628***	0.7498***	−1.6985**
L.dlnfdi	0.0181	0.0073	0.1048	0.0201	0.0302	−0.3343	−0.0340	0.0134	−0.0005
Model (2)	*dlnso2*	*dlnthi*	*dlnfdi*	*dlnso2*	*dlnthi*	*dlnfdi*	*dlnso2*	*dlnthi*	*dlnfdi*
L.dlnso2	−0.0133	0.0347**	0.0908	0.3900***	0.0183*	−0.1264	0.2022***	0.0274*	−0.1178
L.dlnthi	4.6449***	0.3833**	−2.8989***	3.1628**	0.0955	−3.5888***	1.9660***	0.5624***	−2.1643***
L.dlnfdi	−0.0652	0.0029	0.1585	−0.1878	−0.0212	−0.0693	−0.0351	0.0089	0.0340
Model (3)	*dlnso2*	*dlnteca*	*dlnfdi*	*dlnso2*	*dlnteca*	*dlnfdi*	*dlnso2*	*dlnteca*	*dlnfdi*
L.dlnso2	0.2372***	0.1389**	−0.0548	0.2598***	0.0578	0.0127	0.0574	−0.1638	0.0415
L.dlnteca	0.5916***	0.3234***	−0.3606***	0.8488**	0.5204***	−0.9794***	0.5637**	0.3455	−0.6218*
L.dlnfdi	−0.0771	0.0511	0.1639	0.0403	0.0941	−0.3228	0.0866	0.1267	−0.0997

The symbols ***, **, and *, respectively, represent the significance levels of 1%, 5%, and 10%.

Table 9: Estimation results of the robustness test.

	(1)			(2)		
Model (1)	*dlnso2*	*dlngdp*	*dlnfdi*	*dlnso2*	*dlngdp*	*dlnfdi*
L.dlnso2	0.0300	0.0338***	0.0785	0.7114	0.0386***	0.0551
L.dlngdp	2.6562***	0.7081***	−1.9639***	2.6483***	0.7083***	−2.0305***
L.dlnfdi	−0.0267	0.0124	0.0342	−0.0758	0.0196	−0.0077
Model (2)	*dlnso2*	*dlnthi*	*dlnfdi*	*dlnso2*	*dlnthi*	*dlnfdi*
L.dlnso2	0.1996***	0.0290***	−0.0731	0.2499***	0.0343***	−0.1086**
L.dlnthi	2.9918***	0.4086***	−2.4818***	2.6961***	0.3955***	−2.2372***
L.dlnfdi	−0.0711	−0.0009	0.0807	−0.1833**	−0.0054	0.1048
Model (3)	*dlnso2*	*dlnteca*	*dlnfdi*	*dlnso2*	*dlnteca*	*dlnfdi*
L.dlnso2	0.2446***	0.0249	−0.2695***	0.2427***	0.0507	−0.2655***
L.dlnteca	0.5498**	0.7548***	−0.1110	0.5059	0.9040***	−0.0557
L.dlnfdi	−0.0733	0.1192	0.1395	−0.0818	0.2711	0.1682
L2.dlnso2	−0.0395***	−0.2043**	−0.1638	−0.0460	−0.2105*	−0.1687*
L2.dlnteca	0.7563	0.4152***	−0.0751	0.7292***	0.5061**	−0.0350
L2.dlnfdi	−0.0369	0.0271	0.0167	−0.0201	0.1250	0.0332

The symbols ***, **, and *, respectively, represent the significance levels of 1%, 5%, and 10%.

4.6. Robustness Test. In the comparison of the average values of FDI and SO_2 emissions of each provincial administrative region during 2007 and 2020, it is found that Jiangsu province has the largest amount of FDI introduction, and Shandong province has the largest amount of SO_2 emissions. Therefore, the maximum value is removed for analysis to explore whether the above analysis results effectively exclude outliers. Beijing is the capital city of China. In recent years, the government of Beijing has constantly promoted industrial upgrading and structural adjustment in the city and removed its noncapital functions through the means of removing, transferring, and upgrading. According to the catalogue of prohibitions and restrictions on new industries, Beijing has shut down all high-polluting, high energy consumption, and high water consumption enterprises. Labor-intensive and resource-dependent traditional manufacturing enterprises that do not conform to the strategic positioning of Beijing as the capital city have been relocated. Manufacturing links with less advantage in high-end industries have been adjusted. In 2013, the average annual concentration of SO_2 in Beijing was 27 $\mu g/m^3$, which continuously decreased ever since and became single digits after 2017; in 2021, the concentration further decreased until an extremely low level of 3 $\mu g/m^3$, and compared with 2013, the SO_2 concentration had decreased by 88.7%. Therefore, according to the actual data, Beijing's environmental pollution is not an extreme case in the whole country, so we had only excluded the extreme data. Column (1) of Table 9 is the estimated result after removing two individuals from Jiangsu and Shandong provinces. In order to better exclude the interference of outliers on the results, we abbreviated the continuous variables at the 1% level in column (2). The results had all passed the stability test, and the values of the optimal lag order of the PVAR model were still 1-order, 1-order, and 2-order. Judging from the estimation results of the robustness test, after abnormal values had been excluded, the size and action direction (positive or negative) of the estimation coefficients were not significantly different from those of the benchmark regression.

To better explain the mutual impact of the economic scale, industrial structure, technological level, and environmental pollution, this study performed correlation analysis on the above variables, and the results are shown in Table 10. As can be seen from the table, there is a significant correlation between industrial structure and technological level, and economic scale is also significantly correlated with

Table 10: Correlation analysis of each variable.

	dlnso2	dlnfdi	dlngdp	dlnteca	dlnthi
dlnso2	1.0000				
dlnfdi	−0.1619 (0.0011)	1.0000			
dlngdp	0.3525 (0.0000)	−0.1714 (0.0005)	1.0000		
dlnteca	0.0430 (0.3898)	−0.0140 (0.7799)	0.1688 (0.0007)	1.0000	
dlnthi	0.1701 (0.0006)	−0.0731 (0.1430)	0.5401 (0.0000)	0.1438 (0.0038)	1.0000

Note. Data in the table are correlation coefficients, and the data in the brackets are p values.

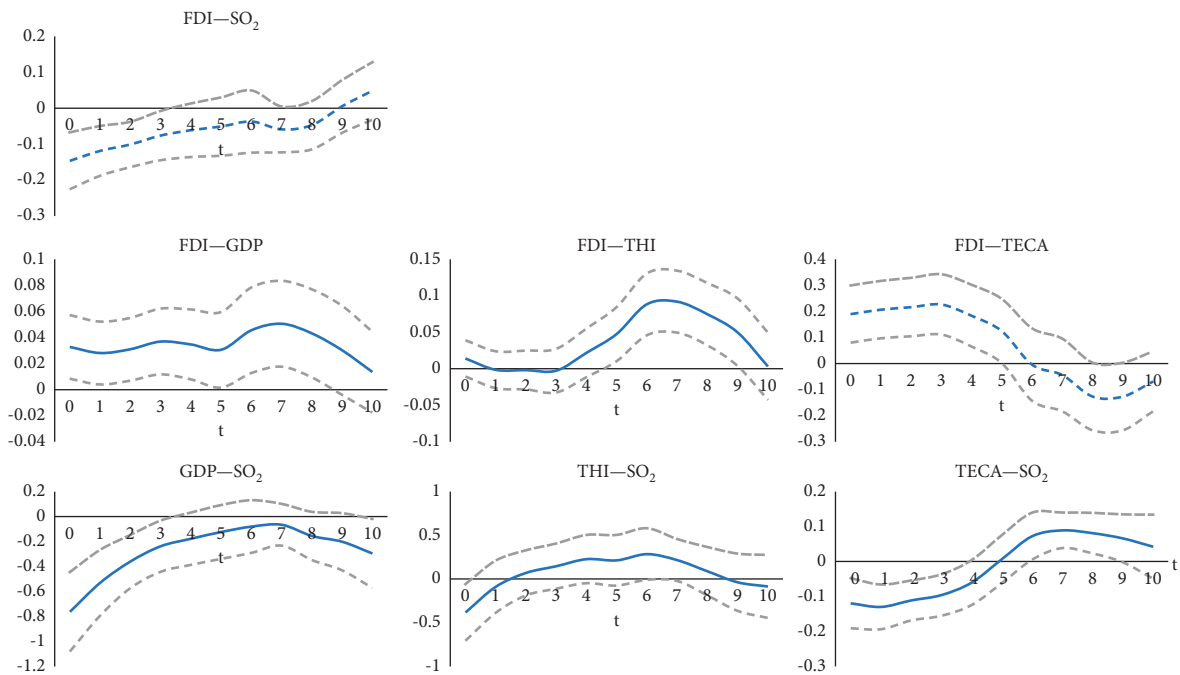


Figure 8: Change trend graph of influence effect among variables. Note: the ordinate is the influence coefficient. The blue solid line is the change trend of the influence effect, and the gray dotted line is the confidence interval. We performed pairwise OLS regression on the variables. The control variables include a series of control variables including the unemployment rate of each province, total capital formation, consumption expenditure, the proportion of students in colleges and universities per 100,000 population, and the area of urban garden green space. It is also derived from the China Statistical Yearbook and controls for time fixed effects and regional fixed effects.

industrial structure and technological level. The horizontal comparison of the impact of the three factors on environmental pollution is given in Figure 8. The economic scale has a negative impact on environmental pollution, and such impact reaches the maximum in the current period; the impact of industrial structure on environmental pollution changes from negative to positive, and the positive impact lasts longer; the technological level has a negative impact on environmental pollution within a short term, but then it turns to positive.

5. Conclusions

Through this research, we have drawn an enlightenment as follows: to correctly answer the question of "whether FDI can cause environmental pollution to the host country," it is necessary to determine the lag period of FDI at first; otherwise, there will be a systematic bias in the research conclusion if the lag period has been arbitrarily determined as 1 phase without analysis just as many other literature had performed. Second, the "fast or slow" impact of FDI on the host country's environment is another question that needs to be analyzed, and it is also a question involving whether the formulation of foreign investment policies, industrial policies, and environmental protection policies is timely and appropriate. Based on the PVAR model, this study explored the interaction of variables in the three models of "FDI, economic scale, and environmental pollution," "FDI, industrial structure, and environmental pollution," and "FDI, production technology, and environmental pollution," and the research results provided a piece of useful evidence for research on the environmental effects of DFI in China. The main conclusions obtained in this study are as follows:

(1) When studying the environmental effects of FDI, the choice of the optimal lag order is different under different action mechanisms. In this study, the optimal lag order for analyzing the dynamic impact

among FDI, economic scale, and environmental pollution was 1; the optimal lag order for analyzing the dynamic impact among FDI, industrial structure, and environmental pollution was 1; and the optimal lag order for analyzing the dynamic impact among FDI, technological level, and environmental pollution was 2.

(2) The expansion of economic scale and the development of tertiary industries such as commerce, catering, entertainment, and transportation will aggravate environmental pollution, but the improvement of technological level can significantly improve environmental quality. The expansion of the economic scale, the optimization of industrial structure, and the improvement of technological level are all processes of continuous development. A region with a better industrial structure will face a faster trend of high-quality development; when the economic scale has developed to a certain level, and the industrial structure has been optimized, then the growth rate of FDI attracted by this region will slow down, while the growth rate of FDI attracted by less-developed regions will be faster.

(3) In the two models of "FDI, economic scale, and environmental pollution" and "FDI, industrial structure, and environmental pollution," the impact lasted longer. Although the response reached the maximum within 2 periods and then gradually decreased, it existed all the time during the 10 periods; the response of environmental pollution to the technological level reached the maximum value between the fourth and the sixth periods, which has corresponded to the real situation that for any technology, it would require a transition period from the invention stage to the application in the actual production field.

(4) The environmental pollution effects of economic scale and industrial structure of the eastern region of China were the strongest, followed by the central region, and the western region came the last. Although FDI had shown an insignificant environmental damage effect under the action mechanism of economic scale, under the action mechanisms of industrial structure and technological level, the FDI of the eastern region showed an insignificant environmental improvement effect. The quality of FDI introduced into the eastern region was relatively high, and a considerable part had entered the tertiary industry, while the FDI of the central region had not exhibited a significant promotive effect on the development of the tertiary industry. In the central and western regions, the promotive effect of FDI on the technological level was mainly concentrated in the field of industrial production, so the pressure on the environment was higher; while in the eastern region, the FDI showed an environmental improvement effect.

Overall, FDI showed an environmental improvement effect in China, but it varied in terms of action mechanism and region. Under the action mechanism of the economic scale, FDI tended to damage the environment, and this effect was the strongest in the central region; under the action mechanism of industrial structure, FDI tended to improve the environment in the eastern and central regions of China, while the situation was the opposite for the western region; and under the action mechanism of technological level, FDI only showed a tendency of environmental improvement in the eastern region. All regions should attach importance to researching greener technologies, developing cleaner energies, and actively promoting the development of high-tech industries. Since the action between FDI and environmental pollution can last for a long time, it is necessary to view the impact of FDI on the environment in different periods from the perspective of long-term development. Moreover, until now China has not yet received the economic benefits that the FDI should have. In fact, FDI should be regarded as a carrier for introducing advanced technologies and management experiences; efforts should be made to actively introduce FDI with intensive capitals and technologies, and use the market mechanism to guide FDI and give full play to the resource allocation function of the market; in the future, we should have the right understandings of the environmental effects of FDI and give proper guidance to it, such as instructing its flow direction to low-polluting industries such as leasing service, information technology, new energy technology, and new material technology.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the innovation training project of the Northeast Forestry University.

References

[1] R. Gour-Tanguay, J. M. Johnson, and R. Gour-Tanguay, "Environmental policies in developing countries," *Verfassung in Recht und Übersee*, vol. 14, no. 1, p. 95, 1981.

[2] B. R. Taylor and M. S. Taylor, "North-South trade and the environment," *Quarterly Journal of Economics*, vol. 109, no. 3, pp. 755–787, 1994.

[3] J. Baek, "A new look at the FDI-income-energy-environment nexus: dynamic panel data analysis of ASEAN," *Energy Policy*, vol. 91, pp. 22–27, 2016.

[4] P. Bastola and U. Bastola, "Foreign direct investment, income, and environmental pollution in developing countries: panel data analysis of Latin America," *Energy Economics*, vol. 64, pp. 206–212, 2017.

[5] M. Shahbaz, S. Nasreen, F. Abbas, and O. Anis, "Does foreign direct investment impede environmental quality in high-,

middle-, and low-income countries?" *Energy Economics*, vol. 51, pp. 275–287, 2015.

[6] F. Kodama and F. Kodama, "Reconciling the conflict between the `pollution-haven' hypothesis and an emerging trajectory of international technology transfer," *Research Policy*, vol. 29, no. 1, pp. 59–79, 2000.

[7] S. Poelhekke and F. van der Ploeg, "Green havens and pollution havens," *The World Economy*, vol. 38, no. 7, pp. 1159–1178, 2015.

[8] Y. Liu, Y. Hao, and Y. Gao, "The environmental consequences of domestic and foreign investment: evidence from China," *Energy Policy*, vol. 108, pp. 271–280, 2017.

[9] F. Seker, H. M. Ertugrul, and M. Cetin, "The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 347–356, 2015.

[10] U. Al-Mulali, S. A. Solarin, and I. Ozturk, "Investigating the presence of the environmental kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach," *Natural Hazards*, vol. 80, no. 3, pp. 1729–1747, 2016.

[11] Q. Liu, S. Wang, W. Zhang, D. Zhan, and J. Li, "Does foreign direct investment affect environmental pollution in China's cities? A spatial econometric perspective," *Science of the Total Environment*, vol. 613-614, pp. 521–529, 2018.

[12] J. He, "Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO2) in Chinese provinces," *Ecological Economics*, vol. 60, no. 1, pp. 228–245, 2006.

[13] C. G. Lee, "Foreign direct investment, pollution and economic growth: evidence from Malaysia," *Applied Economics*, vol. 41, no. 13, pp. 1709–1716, 2009.

[14] N. Adilov, "The lesser of two evils: an empirical investigation of foreign direct investment-pollution tradeoff," *Applied Economics*, vol. 44, no. 20, pp. 2597–2606, 2012.

[15] G. M. Grossman and A. B. Krueger, "Environmental Impacts of a north American Free Trade Agreement," *NEER Working Paper*, p. 3914, 1991.

[16] S. Hammami, "Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries," *International Business Review*, vol. 26, no. 2, pp. 264–278, 2017.

[17] S. Hammami, "The dynamic links between environmental quality, foreign direct investment, and economic growth in the middle eastern and North African countries (MENA Region)," *Journal of the Knowledge Economy*, vol. 9, no. 3, pp. 833–853, 2018.

[18] N. D. Phuong and L. T. M. Tuyen, "The relationship between foreign direct investment, economic growth and environmental pollution in Vietnam: an autoregressive distributed lags approach," *International Journal of Energy Economics and Policy*, vol. 8, no. 5, pp. 138–145, 2018.

[19] L. Love and L. Zicchino, "Financial development and dynamic investment behavior: evidence from panel VAR," *The Quarterly Review of Economics and Finance*, vol. 46, no. 2, pp. 190–210, 2006.

[20] M. R. M. Abrigo and I. Love, "Estimation of panel vector autoregression in Stata," *STATA Journal: Promoting communications on statistics and Stata*, vol. 16, no. 3, pp. 778–804, 2016.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1115967, 10 pages
https://doi.org/10.1155/2022/1115967

Research Article

Visual Aggregation of Spatial Recognition Scientific Computations in the Financial Service Sector Based on the Random Forest Graph Model

Xiaowei Zheng[1,2] and Yaliu Yang[1]

[1]*Business School, Suzhou University, Suzhou 234000, China*
[2]*Department of International Trade, Dong-A University, Busan, Republic of Korea*

Correspondence should be addressed to Yaliu Yang; yangyaliu@ahszu.edu.cn

Received 14 March 2022; Revised 27 May 2022; Accepted 28 May 2022; Published 19 July 2022

Academic Editor: Lele Qin

In view of the current problems in the visual aggregation of the financial service industry, the random forest graph model is applied to the spatial recognition of the financial service industry's scientific calculation visual aggregation in this paper. Based on the detailed analysis of the characteristics of the financial service industry in the past, combined with the characteristics of finance, this method is used to construct a random forest graph model, which mainly optimizes parameters from different aspects such as model structure, data characteristics, and dynamic changes of the model to obtain optimal parameter values of the random forest graph model. Finally, through the analysis of the experimental results, it can be seen that, according to the spatial state of the financial service industry, the method proposed in this paper can be used for visual aggregation analysis. This method can effectively improve the timeliness of the scientific calculation of spatial recognition in the financial service industry.

1. Introduction

As the level of Internet technology continues to improve, various financial service industries based on the Internet have begun to emerge. Domestic scholars have focused on the scientific computation of spatial recognition and its recognition since it is one of the popular visual aggregation types in the financial service sector [1–3]. However, it is highly tricky to acquire details from raw data of the financial service sector for scientific computation of spatial recognition as financial contents are not clearly defined and signal of the financial service sector is based on a time-sequencing method. The random forest graph model can be used according to its concealment. So far, the features of the financial service sector obtained are not accurate due to the relatively simple classification methods.

The financial service sector has gradually become a brand new engine and driving force for the economic growth and development of various countries. In the face of the complicated and grim economic situation in the world, the global economies have accelerated the development of a new generation of information and communication technologies and sped up the transformation and upgrading of the traditional industries in the direction towards more convenient financial services based on the network and intelligent technologies so as to seize the high ground in the development of financial services and gain a head start in the economic growth and competition across the globe. China is vigorously developing the financial service sector, facilitating the integration of the financial service sector with the real economy, accelerating the continuous transformation of old and new growth drivers, and promoting changes in quality, efficiency, and power for economic growth, thereby creating new drive for the modernization and high-quality growth of the economy [4, 5]. As a more advanced and sustainable economic form, the financial service sector is a vial driving force to promote industrial restructuring and achieve sustainable and high-quality growth of the economy. With the

features of game-changing technology innovation, network based platform, and high penetration, it can stimulate the emergence of new industries and promote the transformation and upgrading of the traditional ones through the industrialization of the financial service sector, thereby further driving the optimization and upgrading of the industrial structure. Among them, the industrialization of the financial service sector represented by the Internet of Things (IoT), e-commerce, artificial intelligence (AI), 5G commercialization, and so on has provided new services, new models, and new business modes for the economic growth [6, 7]. The Internet, IoV, big data, AI, and other emerging technologies are actively promoting the upgrading of the traditional industries to improve their production efficiency. The comprehensive index system for the growth in the financial service sector is established and the intermediary effect model. The impact mechanism and threshold of financial service sector on regional total production are analyzed based on the panel threshold model, which has provided theoretical support and empirical basis for implementing the industrial structure transformation and driving the high-quality economic growth [8–10].

In this paper, the spatial recognition scientific computation in the financial service sector is performed based on the random forest graph model. This method can be applied to the spatial recognition scientific computations of financial service sector as current prior knowledge of the financial service sector according to the spatial features of the financial service sector. The financial features in the financial service sector are extracted by information gain. It uses the random forest graph model to constrain the spatial weight, merges financial content information, integrates the spaces with high similarity, and constructs the spatial recognition scientific computations model in the financial service sector. The proposed system of random forest spectral model can enhance the effectiveness and efficiency of parallelization substantially.

2. Methods and Models

The visual aggregation effect in the development of the financial service sector is analyzed in conjunction with the random forest mapping model. The nonlinear time series set is taken as the spatial recognition parameter for the scientific computing of the financial service sector to establish a high-dimensional space with the distribution of spatially identified visual aggregation parameters in the scientific computing of the financial service sector, as described in the following:

$$x_n = x\left(t_0 + n\Delta t\right) = h\left[z\left(t_0 + n\Delta t\right)\right] + \omega_n. \tag{1}$$

In the above equation: h (.) stands for the multivariate value function of the financial services development analysis; ω_n is the function to measure the assessment error. In the high-dimensional feature distribution space, the feature training subset S_i $(i = 1, 2, \ldots, L)$ to analyze and assess the growth can be obtained through the solution vector by analyzing and assessing the full visualization effect of growth aggregation in the financial service sector, and the following conditions are met.

(1) $\Sigma = \mathrm{diag}(\delta_1, \delta_2, \ldots, \delta_r), \delta_i = \sqrt{\lambda_i}, \forall i \neq j.$

(2) $oobF_1(k).$

It is assumed that $X = \{x_1, x_2, \ldots, x_n\}$ is a spatial recognition scientific computation for the visual aggregation of statistical information in the financial service sector, which complies with the decomposition condition $x_k = \{x_{k1}, x_{k2}, \ldots, x_{kp}\}, x_{kj} = [a_{kj}, b_{kj}],\ 1 \leq k \leq n, 1 \leq j \leq p$ for initial value feature, where $U = \{u_{ik}\},\ (i = 1, 2, \ldots, c; k = 1, 2, \ldots, n)$. With regard to the multivariate group, the development class analysis of the financial service sector assesses the sequence $x(n)$ for statistical feature distribution. In the scientific computation for the visual aggregation of the spatial recognition in the financial service sector, the data flow is established according to statistical measure in the previous section:

$$\begin{gathered} c_{1x} = E\{x(n)\} = 0, c_{2x} = E\{x(n)x(n+\tau)\} = r(\tau), \\ \psi_x(\omega) = \ln \psi_x(\omega) = -\frac{1}{2}\omega^2\sigma^2. \end{gathered} \tag{2}$$

It is assumed that the data on the visual aggregation effect for the growth of the financial services is u_{ik}. According to the predicted visual aggregation effect in the growth of financial service sector, the initial feature value is fixed to obtain the estimated probabilistic density generalized function as follows:

$$u_c(t) = Kx_c(t), \tag{3}$$

$\begin{cases} \sum_{i=1}^{c} u_{ik} = 1, & \forall k \\ 0 \leq u_{ik} \leq 1, & \forall k, i \end{cases}$ is continuous model function, and $k \geq 1$ after $k-1$ iterations; gray order sequence of the spatial recognition in the financial service sector for scientific computation of visual aggregation meets $N\ (k) < \mathrm{L}$. The output index for the full visualized aggregation effect is obtained based on random forest mapping model in the analysis and evaluation of the growth of the financial service sector [11, 12], which is taken as the value of K neighboring samples of the information flow in the distributed big data:

$$P_{1J} = \sum_{d_i \in KNN} \mathrm{Sim}(x, d_i) y\left(d_i, C_j\right). \tag{4}$$

The feature value of the main component is established through big data analysis to assess the full visualized aggregation effect in the growth of the financial service sector, and the similarity in the resource distribution of the financial service sector development is resolved by the ambiguous dense joint filling method, as described in the following:

$$\mathrm{Sim}_1\left(d_i, d_{1j}\right) = \frac{\sum_{k=1}^{M} W_{ik} \times W_{1jk}}{\sqrt{\sum_{k=1}^{M} W_{ik}^2} \cdot \sqrt{\sum_{k=1}^{M} W_{1jk}^2}}. \tag{5}$$

In the above equation: g_i stands for the a priori distribution feature vector of the spatial recognition science of

financial service sector to calculate visual aggregation; and $g_i = (g_{i1}, g_{i2}, \ldots, g_{ip}), g_{ij} - [\alpha_{ij}, \beta_{ij}], 1 \le i \le c, 1 \le j \le p$ stands for the vector of K-mean clustering center in layer 1 of big data.

The integration of the full visualized aggregation effect assessment in the growth of the financial service sector is implemented in combination with the fusion method for the linear correlation features [13], and the output fusion equation for the resource information in the growth of the financial service sector is described as follows:

$$P(w|x) = \frac{P(x|w)}{P(x)}. \tag{6}$$

It is assumed that the quantitative recursive feature is $\lambda_k^m = (\lambda_{k1}^m, \lambda_{k2}^m, \ldots, \lambda_{kp}^m)$; the feature of probability density in resource distribution of full visualized aggregation effect is $W = \sum_{i=1}^{c} \sum_{i=1}^{n} (u_{ik})^2 \Phi(x_k, g_i) = \sum_{i=1}^{c} \sum_{i=1}^{n} (u_{ik})^2 \sum_{j=1}^{p} [\lambda_k^m (a_{kj} + b_{kj}/2 - \alpha_{kj} + \beta_{kj}/2)^2]$. Thus, X (i) stream of big data in the scientific computing visualized aggregation for the spatial recognition of the financial service sector includes p (i) submatrices $\begin{cases} \lambda_{ij}^m \ge 0 \\ \prod_{j=1}^{p} \lambda_{ij}^m = 1 \end{cases}$ with the size of $\alpha_{ij} = \sum_{i=1}^{n} (u_{ik})^2 a_{kj} / \sum_{i=1}^{n} (u_{ik})^2$, $\beta_{ij} = \sum_{i=1}^{n} (u_{ik})^2 b_{kj} / \sum_{i=1}^{n} (u_{ik})^2$. Index parameters are clustered and integrated to develop a resource distribution plan for the full visualized aggregation effect. In this way, the optimization of the spatial recognition for the scientific computing visualized aggregation of the financial service sector can be implemented.

In general, firms are aggregated in a vertical chain of industrial connections. The manufacturing sector links upstream to downstream firms, which are in cooperative/competitive relationships. It is assumed that the X set of n samples has been processed by SDA.

$$X = \{x_1, x_2, \ldots, x_n\}. \tag{7}$$

With p as the index, fuzzy clustering is conducted by category:

$$\begin{aligned} x_k &= \{x_{k1}, x_{k2}, \ldots, x_{kp}\}, \\ x_{kj} &= [a_{kj}, b_{kj}], \quad 1 \le k \le n, 1 \le j \le p. \end{aligned} \tag{8}$$

U is the relative membership of model matrix:

$$U = \{u_{ik}\}, \quad (i = 1, 2, \ldots, c; k = 1, 2, \ldots, n), \tag{9}$$

u_{ik} is the membership of sample k in the i category, which complies with

$$\left\{ \sum_{i=1}^{c} u_{ik} = 1, \forall k 0 \le u_{ik} \le 1, \forall k, i, \right. \tag{10}$$

g_i indicates the cluster center in category i:

$$g_i = (g_{i1}, g_{i2}, \ldots, g_{ip}), g_{ij} - [\alpha_{ij}, \beta_{ij}], 1 \le i \le c, 1 \le j \le p. \tag{11}$$

Adaptive parameter λ is introduced to obtain cluster weight:

$$\lambda_k^m = (\lambda_{k1}^m, \lambda_{k2}^m, \ldots, \lambda_{kp}^m). \tag{12}$$

Comprehensive weight is expressed as

$$\begin{aligned} W &= \sum_{i=1}^{c} \sum_{i=1}^{n} (u_{ik})^2 \Phi(x_k, g_i), \\ &= \sum_{i=1}^{c} \sum_{i=1}^{n} (u_{ik})^2 \sum_{j=1}^{p} \left[\lambda_k^m \left(\frac{a_{kj} + b_{kj}}{2} - \frac{\alpha_{kj} + \beta_{kj}}{2} \right)^2 \right], \end{aligned} \tag{13}$$

where it satisfies

$$\begin{cases} \lambda_{ij}^m \ge 0, \\ \prod_{j=1}^{p} \lambda_{ij}^m = 1. \end{cases} \tag{14}$$

Using the Lagrangian method to derive the aggregation function is as follows:

$$\begin{aligned} \alpha_{ij} &= \frac{\sum_{i=1}^{n} (u_{ik})^2 a_{kj}}{\sum_{i=1}^{n} (u_{ik})^2}, \beta_{ij} = \frac{\sum_{i=1}^{n} (u_{ik})^2 b_{kj}}{\sum_{i=1}^{n} (u_{ik})^2}, \\ \lambda_{ij}^m &= \frac{\prod_{h=1}^{p} \left[\sum_{k=1} (u_{ik})^2 (((a_{kh} + b_{kh})/2) - ((\alpha_{ih} + \beta_{ih})/2))^2 \right]^{1/p}}{\sum_{k=1} (u_{ik})^2 (a_{kj} + b_{kj}/2 - \alpha_{ij} + \beta_{ij}/2)^2}, \\ u_{ik} &= \left[\sum_{h=1}^{c} \frac{\sum_{j=1}^{p} \left[\lambda_{ij}^m (((a_{kh} + b_{kh})/2) - ((\alpha_{ih} + \beta_{ih})/2))^2 \right]}{\sum_{j=1}^{p} \left[\lambda_{hj}^m (a_{kh} + b_{kh}/2 + \alpha_{ih} + \beta_{ih}/2)^2 \right]} \right]. \end{aligned} \tag{15}$$

In general, the concentration of firms is subject to natural resources, geographical environment, process technologies, etc. The cooperation of various firms in production and operation is mainly reflected by preliminary integration. Geographical location of firms is integrated through competitive/cooperative relationship. Internal resources of firms are integrated based on the matching degree of the cluster, which has minimized trade costs and maximized profits.

The random forest spectrum model can construct the model in the time series with the highest serialized feature for extensive application during scientific computation of spatial recognition in the financial service sector [14, 15]. In the model, N states are $S = \{S_1, S_2, \ldots, S_n\}$, and the state at t time t is q_t. It is assumed that $A = \{a_{ij}\}$ is established matrix of transition between states; then

$$\alpha_{ij}(k) = P[q_{t+1} = S_j | q_t = S_i], \quad 1 \le i, j \le N. \tag{16}$$

Any state in some RFAMs can be converted to other states in one transition, while other RFAMs allow transitions between specific states only; i.e., $a_{ij} > 0$ for some i and j.

Unlike that in the random forest graph chain, external values can only be observed for each state in the RFAM. The observation vector obtained is discretely or continuously related to the system state.

However, the probability distribution of vectors observed in j state under continuous observation is

$$b_j(v_t) = P\left[v_t | q_t = S_j\right], \quad 1 \le j \le N. \tag{17}$$

The probability distribution is generally used as mixed Gaussian distribution:

$$b_j(v_t) = \sum_{m=1}^{M} \omega_{j,m} N\left(o_t, \mu_{j,m}, \Sigma_{j,m}\right), \tag{18}$$

where M is the distribution count of mixture Gaussian, ω_m is positive mixture weight, and $N(o_t, \mu_{j,m}, \Sigma_j, m)$ is n-dimensional Gaussian distribution.

$$\pi_i = P\left[q_1 = S_i\right], \quad 1 \le i \le N. \tag{19}$$

Thus, RFAM is divided into three groups $\lambda = (A, B, \pi)$. Thus, the sequence observed based on the model is $O = o_1 o_2 \cdots o_T$, where o_t is the vector observed at t time, and T is the total length observed.

The time complexity and space complexity in the spatial recognition scientific computation of the financial service sector are subject to the impact of the dimension of feature vector in the financial service sector. The dimensionality reduction in the financial service sector is processed by extracting model space to make the assessment based on the model more accurate. The mean volume of data in the model is calculated based on information gain algorithm:

$$G(w) = -\sum_{k=1}^{N} P\left(c^k\right) \log_2 P\left(c^k\right) + p(\overline{w}) \sum_{k=1}^{N} p\left(c^k | \overline{w}\right) \log_2 p\left(c^k | \overline{w}\right), \tag{20}$$

where $\overline{w}$ is the complementary set of w; $\overline{w}$ is the space count; T is the mean number of words in the financial service sector in the training set. In the preprocessing stage, word2 vec used in the preprocessed financial service sector is taken as a vector, and the word count is recorded in combination with highly similar word vectors. In the selection of space, the meaning of spatial aggregation vector is taken into account in this paper.

The financial service sector automatically consists of several columns of vocabulary. In the specific financial service sector, various vocabulary will automatically be different. Hence, the establishment of the random forest spectrum model is based on the space itself and the space frequency, but in the space extraction process, the meaning information is merged into the space. The random forest spectrum model is established based on the category space set with the word vector as the hidden state and the corresponding word count as the state sequence observed.

For the constructed random forest graph model the state transition period is a process of space traversal. The spatial output sequence is defined by k, which is the spatial sum in line with similarity threshold. Based on the model, the intermediate state (s_i) is obtained, and the distribution observed in c^k class is

$$v_{c_k}^i\left(w_{c_i}\right) = p\left\{k | s_i = w_{c_i}\right\}. \tag{21}$$

Taking full account of the constraints on the distribution of $b_{c_k}^i$ and spatial frequencies, a greater spatial distance during processing indicates smaller aggregate in different financial service industries.

$$b_{c_k}^i\left(w_{c_i}\right) = IFIDF(i) = \frac{D_c k(i) + 1}{\sum_c k D_c k(i) + |C|} \times \frac{N_c k(i) + 1}{\sum_c k N_c k(i) + |C|}, \tag{22}$$

where $D_c^k(i)$ is business item in the financial service sector (w_{c_i}) of c_k; $N_c^k(i)$ is the occurrences of w_{c_i} in c_k class. Thus, a regularizing effect can be observed in the occurrences of the same class.

The matrix of state transition in state 1 is converted to state 2 until the end position as the random forest graph model (c_k) is classified in the category of financial service sector [16, 17], with A_c^k state transition matrix:

$$a_{ij} = \begin{cases} 1, & j = i + 1, \\ 0, & j \ne i + 1. \end{cases} \tag{23}$$

The probability $\pi = \{1, 0, \ldots\}$ in s_0 initial state is defined, with the random forest graph model in c_k category:

$$\lambda_k = \left\{\Pi, A_{c^k}, B_{c^k}\right\}. \tag{24}$$

With regard to the case where the classification is not precise in the evaluation and computation of the scientific computation visualized aggregation for the spatial recognition in the traditional financial service sector, the random forest mapping model is used in this paper for the evaluation and computation of the spatial recognition scientific computation visualized aggregation in the financial service sector. The performance of the established data model is evaluated by quantitative recursive method to obtain its control features and classify the index parameters for visualized aggregation of spatial recognition in the scientific computation of the financial service sector.

Through the use of this computation method, the assessment of scientific computation visualized aggregation for the spatial recognition of the financial service sector can be carried out effectively. Due to the high capacity in comprehensive analysis of data, it can make the evaluation of full visualized aggregation much more accurate and improve the efficiency of resource utilization in the financial service sector.

A visual aggregation method for the spatial recognition of the financial service sector based on the random forest mapping model is put forward. The random forest mapping model is used to analyze the information related to the assessment of the scientific computational visualized aggregation for the spatial recognition in the financial service sector. Through the experiment, it is verified that the information combination analysis capacity of the proposed method is high, which can greatly increase the evaluation accuracy for the aggregation effect of full visualization and application efficiency of resources to boost the development in the financial service sector by evaluating the visualized aggregation effect in the scientific computation of spatial recognition.

The random forest mapping model was used to analyze the information related to the assessment of spatially identified scientific computational visualized aggregation in the financial service sector.

The experiments verify that scientific computational visualized aggregation of financial service sector spatially identified can be evaluated by the computation method, with a high comprehensive information analysis capacity, substantially increased evaluation accuracy of full visualized aggregation effect, and efficient utilization of financial service sector development resources.

RFM parameters should be initialized before computation based on Baum-Welch algorithm. The results obtained based on aggregation algorithm for scientific computation visualization with initial parameters are highly correlated. Whether the transition matrix or iterative operation is 0 is determined by initializing the transformation matrix, and observation sequence is defined as $O = o_1 o_2 \cdots o_T$:

$$P(O|\lambda_k) \geq P(O|\lambda), \tag{25}$$

$P(O|\lambda)$ is calculated based on forward-backward algorithm. Probability $\alpha_t(i)$ is defined using RFAM parameter λ and state i:

$$\alpha_t(i) = P(o_1 o_2 \cdots o_T, q_t = i|\lambda). \tag{26}$$

Namely, $\alpha_t(i)$ is the probability of sequence $(o_1 o_2 \cdots o_t)$ under parameter A in o_t state at t time.

Based on forward algorithm, $P(O|\lambda)$ can be calculated as follows:

(1) Initialization

$$\alpha_1(j) = {}_j b_j(o_1), \quad 1 \leq j \leq N. \tag{27}$$

(2) Recursion

$$\alpha_t(i) = b_i(o_t)\left[\sum_{j=1}^{N} \alpha_{t-1}(j)\alpha_{ji}\right], \quad 1 \leq t \leq T, 1 \leq i \leq N. \tag{28}$$

(3) Termination

$$P(O|\lambda) = \sum_{j=1}^{N} \alpha T(j), \tag{29}$$

$\beta_t(i)$ and $\xi_t(i, j)$ are defined as

$$\begin{aligned} \beta_t(i) &= P(o_{t+1} o_{t+2} \cdots o_T, |q_t = i, \lambda), \\ \xi t(i, j) &= P(qt = 1, qt + 1 = j|O, \lambda), \end{aligned} \tag{30}$$

$\xi_t(i, j)$ can be expressed by forward-backward computation method:

$$\begin{aligned} \xi t(i, j) &= \frac{P(q_t = i, q_{t+1} = j|O, \lambda)}{P(O|\lambda)} \\ &= \frac{\alpha_t(i)\alpha_{ij} b_j(o_t + 1)\beta_{t+1}(j)}{P(O|\lambda)} \\ &= \frac{\alpha_t(i)\alpha_{ij} b_j(o_{t+1})\beta_{t+1}(j)}{\sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_t(i)\alpha_{ij} b_j(o_{t+1})\beta_{t+1}(j)}, \end{aligned} \tag{31}$$

where the system is in the m component of i state at t time; the probability $\gamma_t(i, m)$ is

$$\gamma_t(i, m) = \left[\frac{\alpha_t(i)\beta_t(i)}{\sum_{i=1}^{N} \alpha_t(i)\beta_t(i)}\right]\left[\frac{\mu_{j,m} N(o_t, \mu_{j,m}, \sum j, m)}{\sum_{m=1}^{M} \omega_{j,m} N(o_t, \mu_{j,m}, \sum j, m)}\right]. \tag{32}$$

Various types of RFAM are first trained by using the labeled training set. Let the scientific computation for spatial recognition be $k = \{1, 2, \ldots, K\}$ and the parameter of each type corresponding to the model be λ_k. Given Bayes formula, the posterior probability is maximized based on maximum likelihood criteria

$$\overline{k} = \arg\max_{1 \leq k \leq K} P(O|\lambda_k) = \arg\max_{1 \leq k \leq K} \frac{P(O|\lambda_k)P(\lambda_k)}{P(O)}. \tag{33}$$

Provided that each type has the same prior probability $P(\lambda_k)$, since P(O) is independent of k, the determination can be ignored.

$$\overline{k} = \arg\max_{1 \leq k \leq K} P(O|\lambda_k). \tag{34}$$

Due to the maximum value $P(O|\lambda_k)$ and the occurrence of underflow at float point during computation, logarithmic values are taken in general. Each equation is weighted if there are several sequences observed.

The random forest graph model cited in this article uses small samples for multiple sampling. Through the random forest graph model, a scientific and reasonable visual aggregation center can be obtained, so as to reduce the unreasonable phenomenon of scientific computing and visual aggregation in the initialization stage and effectively improve the random forest. Performance and accuracy of graph models: The model is based on the MapReduce model for random forest graph model analysis. The operational framework of the random forest graph model is shown in Figure 1.

In the current space identification sector of the financial service sector, the requirements of individual firms should be timely responded to satisfy their different demands. The financial service sector includes two main subsectors: development and design. In the emerging financial service sector, customized services are offered to firms during development and design cycles after comprehensive analysis of market demand variation, along with individualized design based on the actual demand of firms. Though their objectives differ from the primary missions, they are inherently connected. Modularization and standardization are designed in the process of spatial recognition of the financial service sector as the basis of the process of spatial recognition of the financial service sector. The nonsegmented pieces attached to the process of spatial recognition of the financial service sector is converted to a virtual reality (VR) model, which should also has the supporting information on the growth of the emerging sector and firm design based on their needs. The VR-based random forest graph model is established, where virtual objects, scenes, or systems generated by

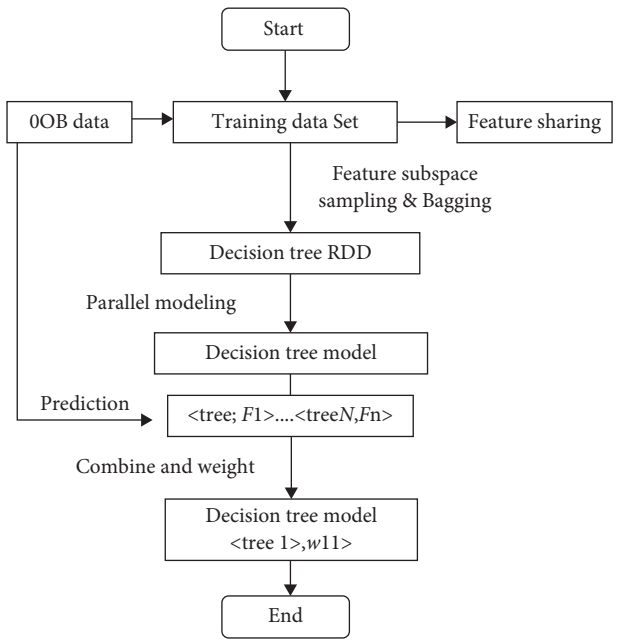


Figure 1: Computing framework of the random forest graph.

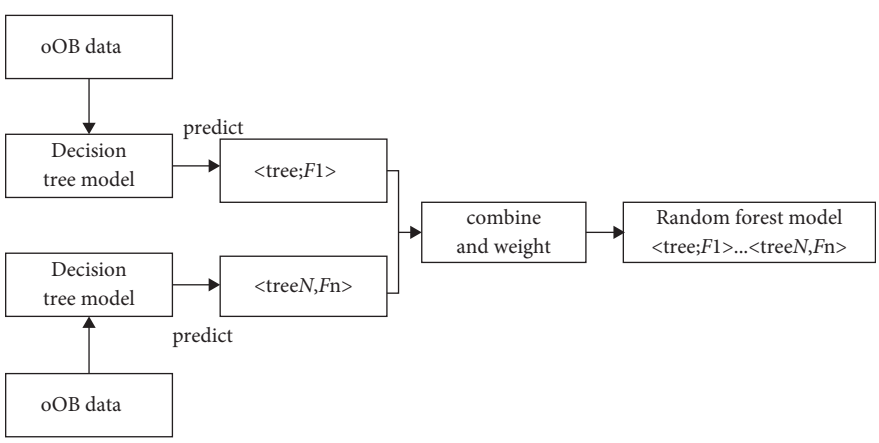


Figure 2: Weighting process.

computer are superimposed to "enhance" the prompt on real-world scenes.

Based on the random forest graph model, virtual objects are introduced to real-world context, and their position and posture consistent with real-world scenes are displayed dynamically. In this way, environment roaming can be observed based on random forest graph model so as to ensure more natural interactions. Additionally, the output is more realistic based on random forest graph model.

Based on the random forest graph model, the actual situation can be photographed with a camera. Each frame in the video is processed by tracking to calculate the coordinates and states of virtual objects corresponding to those in the real world based on geometric computation and construct a virtual scene on this basis. The virtual scenes are combined with real-world streams, and the merged results are timely transmitted and displayed. Computation is performed based on the weight corresponding to each tree according to formula, and the weighted random forest corresponding to these decision trees is combined. Figure 2 is a flowchart of weighting processing.

In the case of the random forest graph model system, the real-time addition of virtual objects to real-world scenes and correct alignment with real-world objects is crucial. Every tree in a random forest requires voting and statistics. In this case, when the number of decision trees is large, the voting process of the entire random forest model is parallelized. Figure 3 is a flowchart of parallelized voting by weighted random forest.

Refer to the design drawings of the financial service sector to zoom in and out of the system at a certain ratio. During the implementation of the financial service sector's exterior wall, consistent specifications are ensured in the solution. The scale issue of all lines in the financial service sector is addressed by the department according to the length and width of a line.

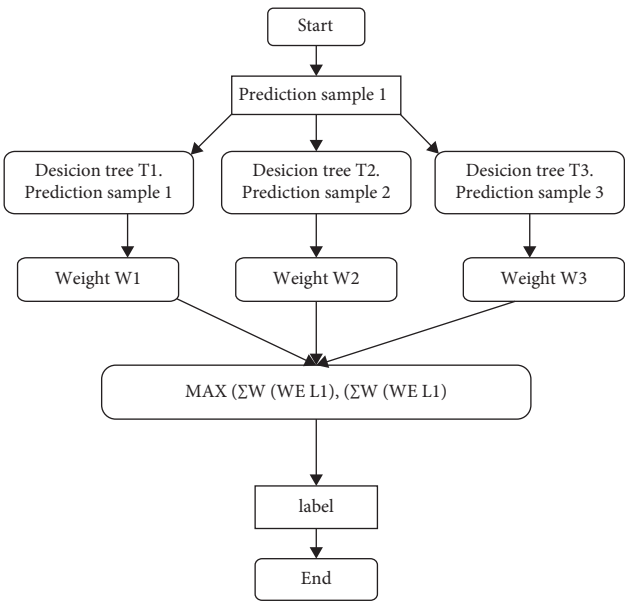


Figure 3: Parallel voting flowchart of weighted random forest.

After establishing the coordinate system in scale, each line in the financial service sector is represented by a geometric entity in the virtual sector through a series of computations.

3. Experiment and Result Analysis

In the cluster based on random forest graph model, the parallel frame is established each in the test for storage by Hadoop, and relevant data are calculated according to the model. Let

$$ITUs_{ijkt} = \alpha + \beta_1 \text{fincol}_{ijkt} + \beta_2 X_{ijkt} + \vartheta_i + \tau_j + \varphi_t + \varepsilon_{ijkt}, \tag{35}$$

where k, i, j, and t are company, sector, region, and year, respectively; $ITUs_{ijkt}$ is the conversion result of the manufacturer; fincol_{ijkt} is the distribution of spatial coordination between the financial service and manufacturing sectors; X_{ijkt} is control variable; α is constant term; ε_{ijkt} is random disturbance item. Further, the fixed effects of sector (ϑ_i), region (τ_j), and time (φ_t) are introduced into the model.

3.1. Variables Are Explained. Variable interpretation: manufacturing model transformation. Based on the viewpoint of the industrial value chain, the conversion and upgrading of manufacturers are mainly manifested in moving towards the high end of the global value chain. On this basis, the upstream degree of each subsector is obtained in the input-output table. Furthermore, the firm-product-grade import and export data is used; the formula for calculating the upstream degree of firm-level import and export is

$$UX_{ft} = \sum_{i=1}^{N} U_i \frac{X_{if}}{X_f}, \qquad UM_{ft} = \sum_{i=1}^{N} U_i \frac{M_{if}}{M_f}. \tag{36}$$

Two differences define the upstream degree of pure exports or the conversion and upgrade effects of manufacturing (ITU):

$$ITU = UM_{ft} - UX_{ft}. \tag{37}$$

Firstly, market needs are analyzed to facilitate the subsequent financial services for new commodities. In this way, firms can understand the market situation comprehensively to meet the demand of customers better. Secondly, the fashion trend is predicted to guide the firms correctly. Fashion trends refer to designs, colors, fabrics with higher quality, and patterns that are popular. Further, the design of new clothes requires designers to have both inspiration and creativity [15]. During the process of spatial recognition of the financial service sector, the knowledge base should be combined with market demand and fashion trend at present. The information on market demand and fashion trend should also be used as the source of design inspiration for spatial identifiers in the financial service sector. According to design patterns, the relevant style is identified, combined with inspiration, and stored in the knowledge base. After spatial recognition of the financial service sector is completed, the financial service sector spatial recognition of new products will be converted into the design knowledge of the individual needs of the financial service sector customers.

3.2. Core Explanatory Variable. The spatial coordination distribution of financial services and manufacturing: In the research to date, the deposit amount of local financial institutions in most regions accounts for the ratio of GDP. Or use the location entropy method to measure the scale of industrial integration and the degree of integration of local finance, but it cannot describe the codistribution features of the financial service sector and the manufacturing sector.

$$\text{cluster}_{ij} = \frac{L_{ij}/L_j}{L_i/L}, \tag{38}$$

where cluster_{ij} represents the location entropy index of sector i (i = mcluster, fcluster) in city j in the country; L_{ij} represents the number of employees in sector i in j city; L_j represents personnel count in manufacturing and financial service industries in city j, $(j = 1, 2, 3, \ldots, N)$; L_i represents personnel count in i sector nationwide; L represents the number of employees in the manufacturing and financial services industries across the country.

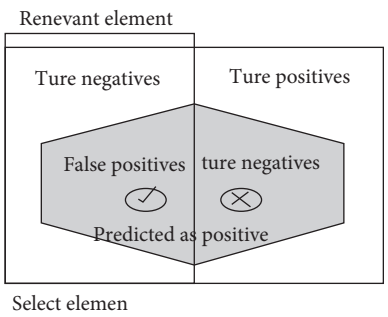


Figure 4: Schematic diagram of classification results.

Table 1: Confusion matrix.

	Positive	Negative
T	TP	TN
F	FP	FN

$$\text{fincol} = \left(1 - \frac{|m\text{cluster} - f\text{cluster}|}{m\text{cluster} + f\text{cluster}}\right) + |m\text{cluster} + f\text{cluster}|. \tag{39}$$

In Figure 4, the attributes obtained based on the classification model are verified in combination with their mathematical relationship, and the performance of the model is assessed by confusion matrix indices. The confusion matrix is shown in Table 1, where T indicates True, F indicates False, TP indicates True Positive, FP indicates False Positive, TN indicates True Negative, and FN indicates False Negative.

The evaluation indices of the confusion matrix are divided into precision and recall.

Veracity:

$$\text{precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}. \tag{40}$$

Recall rate:

$$\text{recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}. \tag{41}$$

Further to this, there is F_1 value, which is a blending value of veracity and recall rate. The F_1 value is defined as

$$F_1 = \frac{2\text{TP}}{2\text{TP} + \text{FP} + \text{FN}}. \tag{42}$$

In the process of constructing the model, the scientific computation visualized aggregation method was used. The prediction of small loans is divided into two types: on-time repayment and overdue. The corresponding values of the type are "0" and "1", respectively, so the value of ClassNumber is set as 2. Set the four parameters according to the greedy algorithm; select the value F_1

$$\begin{cases} \text{max Boxes} = 130 \\ \text{max Depth} = 6 \\ \text{number Decision Trees} = 240 \\ \text{characteristic Number Strategy} = \text{"sqrt"} \end{cases} \tag{43}$$

According to equation, the tree weight is proportional to the value on the out-off-bag data, and 200 weight values for decision tree can be selected to verify the rationality of the tree weight. Figure 5 is the weight map.

For the purpose of testing the recognition capacity of the model put forward in this paper and at the same time comparing with the curve profile offset recognition model, the recognition threshold value based on the random forest mapping model is used as the difference value in the spatial recognition rate for the financial service sector in the experimental samples. In other words, the deviation of the joints in the three consecutive business types will be considered as the business type that can be used to identify the joints when the deviation between the slopes of the fixed points is completed. The financial services are identified based on the curve profile offset identification model and the random forest mapping model in turn. After different experimental threshold values are set, the financial service space is identified accordingly, and the information data on the financial service space are detected in turn. In accordance with Table 2 below, the experimental results suggest that the traditional model can lead to an increase in the recognition volume as the recognition threshold value of the financial service space increases, and the similarity of recognition will also be affected to some extent. Hence, the random forest mapping model is mainly implemented based on the rotation operation so that better recognition capacity can be obtained. Table 3 is shown below.

The proposed method is used in the random forest mapping model for the detection of the financial services space identification, and the detection objects are identified patterns that may be subject to various attacks, as well as the unidentified patterns. The ideal detection model should be able to detect the maximum similarity with the part corresponding to the completely original recognition. It can be observed through the probabilistic theoretical analysis that the algorithm adopted above needs to be associated with the presence of a sequence in the identification of the financial services space. Table 2 below shows the corresponding size of the ms for the different values selected.

In fact, the length of the recognition information is not very small, and the recognition pattern subjected to the ablation attack has no practical application value if the number of valid bits is relatively small. Hence, the minimum value and the maximum length of the identification information bits extracted based on the considered design are set between 25 and 1000. After the above data are interpolated a threshold curve can be plotted based on the similarity threshold value corresponding to each recognition length, as

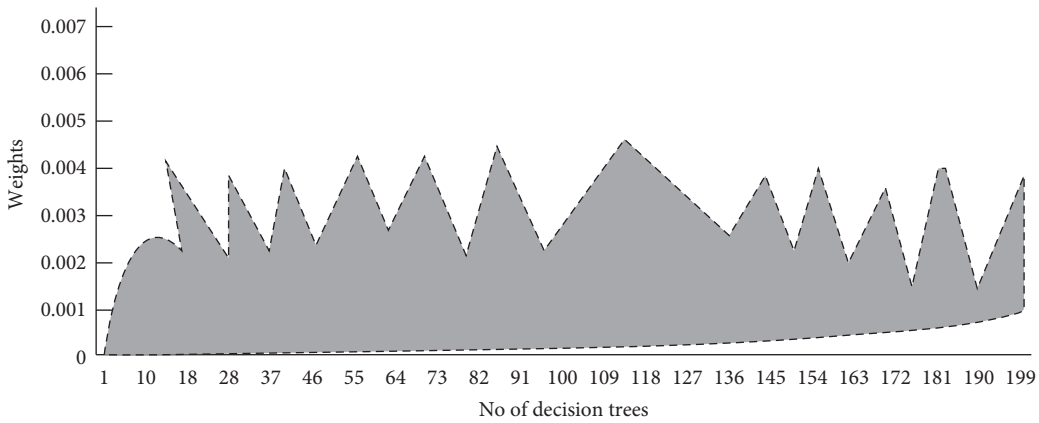


Figure 5: Decision tree weight diagram of weighted random forest.

Table 2: Maximum similarity of the identification with different lengths and 999 random identifications.

L	25	50	100	200	400	800	1000
Ms	0.5	0.499	0.39	0.28	0.23	0.21	0.198

Table 3: Comparison of the recognition capacity of the curve profile offset recognition model and the random forest mapping model.

Threshold	Similarity of recognition	
	Curve profile offset recognition model	Random forest mapping model
0.03	0.45647	0.72135
0.05	0.29183	0.71093
0.09	0.16688	0.68315
0.17	0.09175	0.66406
0.21	0.0748	0.66232
0.31	0.0544	0.6467

shown in Figure 5 above, which can be further used as a reference for the similarity threshold of the recognition information with different lengths during the recognition detection.

4. Conclusion

Various types of data in the traditional financial sector are rich and contain great value. How to effectively use these data and extract useful information to help users make decisions is a major problem faced by people in the financial sector. The random forest map model is used for the scientific computation of spatial recognition of the financial service sector. The random forest map model is used to assess the data model capacity and control the featured resources acquired. The accuracy of scientific computation of spatial recognition is improved by using optimal parameter values based on RFAM, and the spatial recognition and industrial agglomeration analysis of the financial service sector are completed. Finally, the results of example analysis show that accurate and fast spatial recognition scientific computation can be achieved by introducing the model of random forest graph into independent scientific computation of spatial recognition in the financial service sector. At the same time, combined with the rhythm features of the financial service sector, the spatial recognition scientific computation accuracy of the RFAM model of the financial service sector is improved to 67.9%. The visual analysis of scientific computation of spatial recognition of financial service sector based on random forest graph model is realized.

Data Availability

The supporting data can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] M. Daniel, E. Letenah, and Wale, "Account ownership and use of financial services among individuals: evidence from selected sub-saharan african economies," *African journal of economic and management studies*, vol. 42, no. 4, pp. 49–58, 2017.

[2] T. Baker and B. G. C. Dellaert, "Regulating robo advice across the financial service sector," *Erim Report*, vol. 103, no. 2, pp. 713–775, 2017.

[3] A. M. Iddrisu, "Access to financial services via rural and community banks and poverty reduction in rural households in Ghana," *Journal of African Development*, vol. 190, no. 3, pp. 353–358, 2017.

[4] M. Pinedo and Y. Xu, "Operations in financial services: processes, technologies, and risks," *Foundations and Trends® in Technology Information and Operations Management*, vol. 10, no. 2, pp. 223–342, 2017.

[5] A. Freytag and S. Fricke, "Sectoral linkages of financial services as channels of economic development-An input-output analysis of the Nigerian and Kenyan economies," *Review of Development Finance*, vol. 7, no. 1, pp. 36–44, 2017.

[6] J. C. Paradi, H. D. Sherman, and F. K. Tam, "Data envelopment analysis in the financial service sector," *International*, vol. 28, no. 3, pp. 352–371, 2018.

[7] P. Das, R. Verburg, A. Verbraeck, and L. Bonebakker, "Barriers to innovation within large financial services firms: an in-depth study into disruptive and radical innovation projects at a bank," *European Journal of Innovation Management*, vol. 35, no. 3, pp. 102-103, 2017.

[8] J. Varghese and M. Edward, "Relationship between job, orientation and performance of sales people: a financial service sector perspective," *Iim Kozhikode Society & Management Review*, vol. 14, no. 4, pp. 612–618, 2017.

[9] M. Xue, P. Yuqian, and Michael, "Operational risk in financial services: a review and new research opportunities," *Production and Operations Management*, vol. 25, no. 8, pp. 757–760, 2017.

[10] A. R. Ambedkar, A. Gunasekaran, P. Murugesan, T. Natarajan, and A. Gunasekaran, "Brand resonance score for cbbe model: an application in financial services," *Benchmarking: An International Journal*, vol. 34, no. 3, pp. 70–74, 2017.

[11] Armour and John, "Brexit and financial services," *Oxford Review of Economic Policy*, vol. 5, no. 9, pp. 170–173, 2017.

[12] J. P. Miller, "Communication professionals' sensemaking of csr: a case study of a financial services firm," *Business and Professional Communication Quarterly*, vol. 35, no. 1, pp. 73–89, 2020.

[13] K. J. Jang, "The a study on innovative financial services of business models using blockchain technology," *The e-Business Studies*, vol. 18, no. 6, pp. 113–130, 2017.

[14] S. Jecan, D. Benta, L. M. Rusu, and R. Arba, "Elder monitoring workflow system for independent living," *International Journal of Computers, Communications & Control*, vol. 13, no. 1, pp. 62–70, 2018.

[15] T. Abbasi and H. Weigand, "The impact of digital financial services on firm's performance: a literature review," *Papers*, vol. 4, no. 1, pp. 31–45, 2017.

[16] T. Nawaz, "Determinants and consequences of disruptive innovations: evidence from the UK financial services sector," *Journal of Accounting and Management Information Systems*, vol. 12, no. 2, pp. 234–251, 2018.

[17] S.-I. Choi, S. T. Choi, and H. Yoo, "Selective feature generation method for classification of low-dimensional data," *International Journal of Computers, Communications & Control*, vol. 13, no. 1, pp. 24–38, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6706437, 8 pages
https://doi.org/10.1155/2022/6706437

Research Article

Comparative Research on the Game Behavior of the Participants in the Traditional Supply Chain Finance and the Supply Chain Finance on the Blockchain

Yong Luo [1] **and Yanhong Tang** [2]

[1] *School of Business, Changsha Social Work College, Changsha 410004, China*
[2] *Department of Modern Economy and Trade, Hunan Vocational College of Engineering, Changsha 410151, China*

Correspondence should be addressed to Yanhong Tang; tyhtinatang@sina.com

Received 17 May 2022; Revised 18 June 2022; Accepted 22 June 2022; Published 18 July 2022

Academic Editor: Lele Qin

The authors took the financing warehouse in supply chain finance as an example, used the game between capital providers (banks and their entrusted logistics supervision enterprises) and capital demanders (core enterprises of supply chain, upstream suppliers, and downstream dealers) as the research object, and constructed the income matrices, respectively, and the Nash equilibrium of pure decision and mixed decision was calculated. The authors compared the game behavior of the participants in the traditional supply chain finance and the supply chain finance on the blockchain and the difference of the mixed decision Nash equilibrium whether blockchain rewards and punishment were added. When the rewards and punishment were added to encourage the transaction information placing in the blockchain, the Nash equilibrium point would be further away from the origin point, and the capital provider and the capital demander would choose to cooperate with greater probability. When the cost of the blockchain is gradually reduced, the two sides of the game choose to place the transaction information in the chain, which can improve the cooperation of the participants of the supply chain finance, and they can get more profit.

1. Introduction

The authors constructed the income matrices by using chicken game theory and income analysis theory, compared the game behavior of the participants in the traditional supply chain finance and the supply chain finance on the blockchain, and compared the difference of the mixed decision Nash equilibrium whether blockchain rewards and punishment were added. When the rewards and punishment were added to encourage the transaction information placing in the blockchain, the Nash equilibrium point would be further away from the origin point. The distance of the mixed Nash equilibrium point from the origin is much longer, meaning that the possibility of "cooperation" between the capital provider and the capital demander increases from 1/5 to 3/5. The difference of the Nash equilibrium of the mixed decision showed that when the transaction is included in the blockchain, meaning that when the reward or punishment is added, the Nash equilibrium is further away from the origin, and the two parties will cooperate with a greater probability. The research showed that the probability of choosing cooperation is strongly correlated with the degree of reward and punishment trading information in the blockchain. By encouraging trading information to be recorded in the blockchain and improving the sharing degree of trading information, the willingness of both parties to cooperate can be promoted. Therefore, promoting the application of blockchain technology in the field of supply chain finance and strengthening the cooperative behavior of participants will be conducive to the healthy and rapid development of supply chain finance and will better solve the financing problems of SMSE in the supply chain.

China's supply chain finance has developed rapidly since it was piloted in Ping An Bank (formerly Shenzhen Development Bank) in 2006, which has solved the financing problems of many small- and medium-sized enterprises

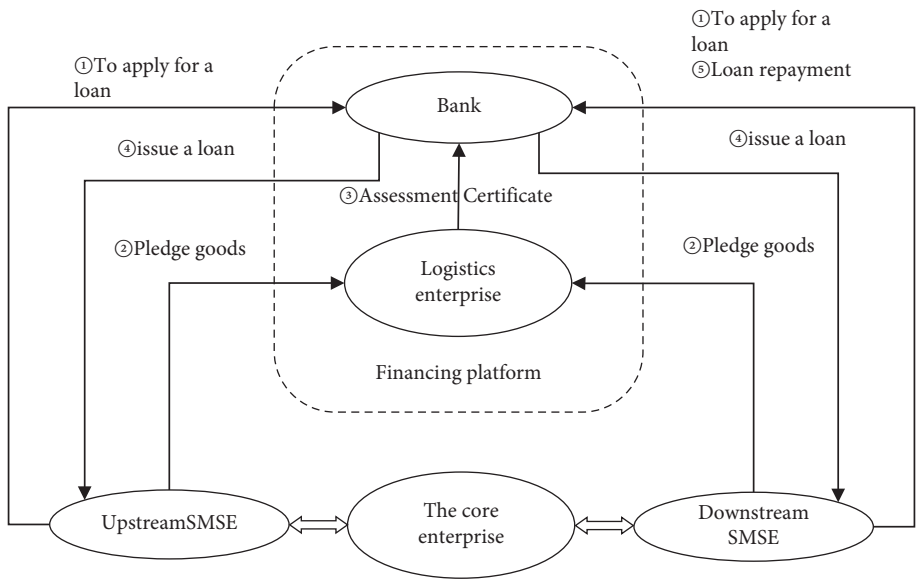


Figure 1: Financing flowchart of financing warehouse.

(hereinafter referred to as SMSE) and greatly promoted the healthy development of the economy. In recent years, blockchain, as a new technology, has been gradually introduced into supply chain finance. As an emerging FinTech, it empowers the supply chain industry. Under this background, the authors took financing warehouse in supply chain finance as an example and analyzed and contrasted game behavior of the participants in supply chain finance whether blockchain reward is added. They wanted to understand the changing rule of the game behavior and to provide the reference for the application scenarios and promotion of supply chain finance in the blockchain.

2. Analysis of Research Status

2.1. Overview of Supply Chain Finance and Its Financing Warehouse. Supply Chain Finance (SCF) [1] refers to a package of services such as financing, settlement, and financial management, which design and provide for different links of the supply chain. It takes the transaction with the core enterprise as the risk control variable on the basis of analyzing the transaction structure within the supply chain and takes current assets such as inventory, work in process, manufactured goods, and accounts receivable in the supply chain as mortgage or pledge. The logistics company will supervise the collateral or pledge.

According to the pledges and their positions in the upstream and downstream of the supply chain, the bank-led supply chain finance [2, 3] can be divided into three financing types: accounts receivable, financing warehouse, and confirmation warehouse. In the supply chain, financing carried out with raw materials, work in process, and finished products as collateral can be called financing warehouse, as shown in Figure 1. The demander of the financing warehouse is the whole supply chain, mainly SMSE, such as upstream suppliers and downstream dealers of the supply chain. The capital provider is the bank and its entrusted logistics supervision enterprises. Banks, the core enterprise supply chain, upstream suppliers and downstream distributors, and logistics enterprises sign the agreement. It takes materials in the supply chain as the pledge. The logistics enterprise is as the pledge mediation, issued the pledge proves after receiving the raw materials, work in process, and finished products as collateral, then the bank provides capital to the demand side according to the certain loan-to-value ratio, and the core enterprise takes its own credit or repurchase pledge as collateral. Financing warehouse is the most common way in supply chain finance. It can partly solve the capital shortage problem of SMSE in the upstream and downstream of the supply chain, realize smooth production of the supply chain, increase product sales in the chain, and improve the collecting reserves and profits of banks in capital.

2.2. Research on the Game Behavior of Supply Chain Finance. Many scholars have discussed the game behavior of the parties involved in supply chain finance from different perspectives, providing a reference for the business development and risk prevention of supply chain finance. Du et al. [4] built a game model to analyze the impact of supply chain finance on the supply chain and the enterprises in the chain and pointed out that supply chain finance, to a certain extent, solved the financing problem of small- and medium-sized enterprises, promoted financial innovation, and improved the ability of supply chain to resist capital chain fracture. Cao and Ma [5] introduced default penalty number and used the game theory method to solve and compare the Nash equilibrium of the traditional accounts receivable financing and supply chain finance accounts receivable financing. They concluded that the supply chain financial accounts receivable financing could achieve Pareto efficient equilibrium, reduce the enterprise financing costs, and increase the lending rate at the same time. Luo and Chen [6]

discussed the game behavior between the capital provider and the capital demander in supply chain finance based on the game theory and calculated the Nash equilibrium of pure decision and mixed decision. Through the example, it was concluded that when the incentives and penalties were added to the financing contract, the Nash equilibrium point was further away from the origin, and the two parties would choose cooperation with greater probability, which could reduce the risk of supply chain finance. Wang and Zhou [7] established an evolutionary game model of banks and SMES in supply chain finance, calculated and analyzed the influence of information sharing factors and blockchain technology factors on the model according to the position of equilibrium points, and then verified the reliability of the calculation results through MATLAB data simulation analysis. The results showed that factors such as information sharing incentive and blockchain incentive would promote banks to choose blockchain supervision, while factors such as information sharing risk and blockchain cost were on the contrary. Finally, some corresponding suggestions were put forward according to the results of the evolutionary game model.

2.3. Research on Supply Chain Finance in the Blockchain. Blockchain was originally built by Nakamoto as a digital currency solution based on a distributed ledger. Blockchain technology provided an imtamable data integrity proof in terms of digital products, permission, finance, and other aspects, which had a profound impact on the work and life of human society in the era of big data and had landed a series of application scenarios [8, 9]. Yermack [10] believed that the low-cost, high liquidity, high accuracy, and high transparency information provided by blockchain would subvert the balance of power among managers, different shareholders, intermediaries, and other participants, forming a new corporate governance mechanism. Sabari et al. [11] believed that the distributed ledger technology in blockchain technology solves the problem of original information asymmetry, making the information among multiple entities recorded and shared on each unit. The consensus mechanism of blockchain made the protocols in the supply chain immutable. No node could unilaterally or privately change the protocols and manipulate the data among only a few subjects. Even if all subjects or a valid percentage of subjects agreed to change the contract or data, the original information would remain intact, and new information would be recorded. Shunzi et al. [12] discussed the application of blockchain technology in cross-border payment and settlement, electronic loan, supply chain finance, asset custody, and other business fields. Chu and Gao [13] introduced the distributed ledger of blockchain, encryption technology, and smart contract into the business link of supply chain finance, which would effectively promote the depth of transaction data acquisition by all parties, accelerate the speed of business identification and settlement, and improve the risk control ability of financial institutions. Bai et al. [14] realized the quantification, transmission, and transaction of contract elements such as credit and reputation in the industrial chain by building a digital system corresponding to logistics and applying a new supply chain finance platform, thus forming a new framework for the development of supply chain finance in the digital economy environment. Guo and Chen [15] believe that blockchain technology should be used to optimize supply chain finance to break through the transmission mechanism of "information island," build industrial alliance, improve supervision and reduce risks, and so on.

2.4. Research Literature Review. The researchers at home and abroad carried out a lot of research on the basic form of supply chain finance, development obstacle, the main risk, and the game behavior of participants in supply chain finance. They thought that the cooperation and information sharing among supply chain participants could reduce the risk of supply chain finance and improve the profit level of each participant. However, there were not many studies on the combination of blockchain and supply chain finance; especially, the game behavior analysis of the participants of supply chain finance on the blockchain was relatively less. Therefore, this paper took the financing warehouse as an example to carry out the research on the game behavior of supply chain finance on the blockchain. It had certain theoretical research value and practical guiding significance for the development of supply chain finance in the new era by comparing the change of the game behavior of the participants in supply chain finance and the supply chain finance on blockchain.

3. Problem Description

As shown in Figure 1, the participants of traditional financing warehouse mainly include capital demanders composed of enterprises in the supply chain whose credit is endorsed by the core enterprise; capital providers composed of banks and the logistics enterprise entrusted by the bank to supervise pledges. The participants of the financing warehouse on the blockchain have increased the blockchain technology provider, but whether to introduce the blockchain technology is mainly decided by the bank, so the blockchain technology provider can be classified as the capital provider, and the game subject can still be simplified as the capital provider and the capital demander. Based on the above definitions, the problems studied in this paper can be described as follows:

Capital providers decide whether to lend based on supply chain credit assessment. By comparing and analyzing the game behavior of participants on traditional financial warehouse and blockchain financing warehouse, people can understand the changes of game behavior and provide reference for the application and promotion strategy of blockchain in the supply chain finance scene.

4. Game Behavior Analysis of Traditional Financing Warehouse and Blockchain Financing Warehouse

4.1. Game Behavior Analysis of Traditional Financing Warehouse

4.1.1. Basic Assumptions of the Game Model

(1) The Game Participants. Banks and logistics supervision enterprises shall be the capital providers. Logistics supervision enterprises shall provide collateral supervision services according to the requirements of banks and be responsible to the banks. Core enterprises of supply chain and their upstream and downstream SMSE are the demanders of capital, which take the pledge of raw materials, products in process, and finished products corresponding to the transaction business of core enterprises as the guarantee for financing. This paper analyzes the game behavior of the participants in the financing position of supply chain finance based on the chicken game. Chicken game, also known as a coward game, is a very important model in game theory. Suppose that there are two people, A and B, who meet on a narrow road and both sit in their cars waiting at the starting line; each party has two options: back and forward. If A retreats, but B does not, and B wins, A is a coward. If Party B also chooses to retreat, then both parties will be in a draw. If A does not choose to retreat and B retreats, then A wins, and B is a coward. If both parties choose to move forward, they will both fail. Therefore, for both Party A and Party B, it is the best result for the opponent to choose to retreat while moving forward.

(2) The Game Behavior. The capital provider is {cooperation, betrayal}, and the capital demander is {cooperation, betrayal}. Cooperation of the capital provider means to strictly supervise that the quantity, quality, storage, and transportation conditions of the pledges of the capital demander meet the requirements of the contract and ensure that the pledge ratio is within a controllable range. Capital demander cooperation refers to that the capital demander guarantees that all the incoming pledges meet the initial requirements of the contract and that the value of the pledges meets the quantity requirements agreed in the contract and will not take concealment or fraud and replace the defective ones with the good ones, leading to increased risk of lending. The probability of capital supply and demand parties to choose each strategy according to their own judgment is as follows: the probability of cooperation of the capital provider is p, the probability of noncooperation is $1-p$, the probability of cooperation of the capital demander is q, and the probability of noncooperation is $1-q$.

(3) Game Benefits. Parameter description: the loan interest rate charged by the capital provider is α_b, the regulatory rate is r_s, the operating cost rate is c_s, the increase income of betrayal is U_s, the probability of choosing cooperation is p, the probability of betrayal is $1-p$, and the income of the capital provider is $\pi_s\pi_s$. The capital provider for each year can be selling more products to the customer and need to increase liquidity through loans D, assuming that the demand increase revenue is Dr_d because of the loan capitals, capitals demand rate of operating cost is c_d, capital demanders earnings of betrayal is U_d, the probability of capital demanders choose cooperation is q, the probability of betrayal is $1-q$, and capital demanders earned is π_d.

The payoff of the game is as follows: First, the payoff of the capital provider $\pi_s = D(\alpha_b + r_s - c_s)\pi_s = D(\alpha_b + r_s - c_s)$. Second, in the financing supply chain, sales opportunities are obtained through loan support, and Dr_d is the gross profit of sales. The total cost expenditure is the sum of operating cost and financial cost expenditure brought by loan, that is, $D(\alpha_b + c_d)$, and income is $\pi_d = Dr_d - D(\alpha_b + c_d) = D(r_d - \alpha_b - c_d)$. Third, to simplify the calculation, if one party cooperates and the other defies, the partner will have no income, and the defector will have an increase in income. Therefore, if the capital provider defies, its income is $\pi_s = D(\alpha_b + r_s - c_s) + U_s\pi_s = D(\alpha_b + r_s - c_s) + U_s$. If the capital demander defies, its income is $\pi_d = D(r_d - \alpha_b - c_d) + U_d$. Fourth, to simplify the calculation, if both parties default, there will be no revenue, and the cost is the operating cost of both parties. Therefore, when both parties betray, the income of the capital provider is $\pi_s = -Dc_s$, and that of the capital demander is $\pi_d = -Dc_d$.

(4) Game Information. The capital provider and the capital demander fully understand and comply with the contract, understand their own behavior, and at the same time are able to judge the other party's basic situation and predict the choice of strategy. The capital provider can judge whether the capital demander is cooperative from the information on the goods in the supervised warehouse and the information of the entry and exit of the warehouse. The capital demander can also judge whether the capital provider is cooperative from the arrangement of the capital provider's supervisors and the seriousness of the supervision process. In other words, the game information is symmetric and complete.

4.2. Construction of the Game Model between Capital Provider and Capital Demander.

According to the above parameters and assumptions, the profit matrix of the capital provider and the capital demander is shown in Figure 2.

4.2.1. The Optimal Response of the Capital Provider.

According to the above parameter description, the probability of the capital provider choosing "cooperation" is "p"; therefore, the probability of choosing "betrayal" is "$1-p$." The probability of the capital demander choosing "cooperation" is "q," and the probability of choosing "betrayal" is "$1-q$." Based on Figure 2, the expected returns of the capital provider and the capital demander in the chicken game are calculated.

Start with the capital providers. The following are the expected benefits of the "cooperation" and "betrayal" of the capital provider.

The expected benefits of the capital provider choosing "cooperation" are as follows:

		Capital demander			
		cooperation q		betrayal $1-q$	
Capital provider	cooperation p	$\pi_s = D(\alpha_b + r_s - c_s)$	$\pi_d = D(r_d + \alpha_b - c_d)$	$\pi_s = 0$	$\pi_d = D(r_d - \alpha_b - c_d) + U_d$
	betrayal $1-p$	$\pi_s = D(\alpha_b + r_s - c_s) + U_s$	$\pi_d = 0$	$\pi_s = -Dc_s$	$\pi_d = -Dc_d$

Figure 2: Profit matrix of capital provider and capital demander.

Table 1: Optimal response strategy of the capital provider.

$q < Dc_s/(Dc_s + U_s)$	Cooperation ($p = 1$)
$q > Dc_s/(Dc_s + U_s)$	Betrayal ($p = 0$)
$q = Dc_s/(Dc_s + U_s)$	Any choice is right (the probability of any choice will be equal to p)

$$D(\alpha_b + r_s - c_s)q + 0(1-q) = D(\alpha_b + r_s - c_s)q. \quad (1)$$

The expected return of the capital provider choosing "betrayal" is as follows:

$$\begin{aligned}&[D(\alpha_b + r_s - c_s + U_s)]q + (-Dc_s)(1-q)\\&= D(\alpha_b + r_s)q - Dc_s + U_s q.\end{aligned} \quad (2)$$

Then, the probability of "cooperation" and "betrayal" of the capital provider was set as "cooperation p" > "betrayal $1-p$," meaning that the probability of cooperation was greater, and this was used as the equation to solve q.

$$\begin{aligned}&D(\alpha_b + r_s - c_s)q < D(\alpha_b + r_s)q - Dc_s + U_s q,\\&(Dc_s + U_s)q < Dc_s,\\&q < D\frac{c_s}{(Dc_s + U_s)}.\end{aligned} \quad (3)$$

This means that when the probability of the capital demander choosing "cooperation" is "$q < Dc_s/(Dc_s + U_s)$," the probability of the capital provider choosing "cooperation" is "$p > 1-p$," meaning that the probability of the capital provider choosing "cooperation p" is 1. On the contrary, when the probability of the capital demander choosing "cooperation" is "$q > Dc_s/(Dc_s + U_s)$," the probability of the capital provider choosing "betrayal $1-p$" is 1, namely, "$p = 0$." When the probability that the capital demander choosing "cooperation" is "$q = Dc_s/(Dc_s + U_s)$," the capital provider can choose all "p" to deal with it. The optimal response strategy of the capital provider is shown in Table 1 after the above three scenarios are summarized.

4.2.2. Optimal Response of Capital Demander. The expected income of the capital demander choosing "cooperation" is

$$D(r_d - \alpha_b - c_d)p + 0(1-p) = D(r_d - \alpha_b - c_d)p. \quad (4)$$

The expected return of capital demander choosing "betrayal" is

$$\begin{aligned}&[D(r_d - \alpha_b - c_d) + U_d]p + (-Dc_d)(1-p)\\&= D(r_d - \alpha_b)p - Dc_d + U_d p.\end{aligned} \quad (5)$$

Then, the probability of "cooperation" and "betrayal" of the capital demander is set as "cooperation q" > "betrayal $1-q$," meaning that the probability of cooperation is greater. And this is taken as the equation to solve p.

$$\begin{aligned}&D(r_d - \alpha_b - c_d)p > D(r_d - \alpha_b)p - Dc_d + U_d p,\\&(Dc_d + U_d)p < Dc_d,\\&q < cD_d/(Dc_d + U_d).\end{aligned} \quad (6)$$

This means that when the probability of the capital provider choosing "cooperation" is "$p < Dc_d/(Dc_d + U_d)$," the probability of the capital demander choosing "cooperation" is "$q > 1-q$," meaning that the probability of the capital demander choosing "cooperation q" is 1. In contrast, when the probability of the provider choosing "cooperation" is "$p > Dc_d/(Dc_d + U_d)$," the probability of the capital provider choosing "betrayal 1-q" is 1; that is, "$q = 0$." When the probability that the capital demander choosing "cooperation" is "$p = Dc_d/(Dc_d + U_d)$," the capital provider can choose all "q" to deal with it. The optimal response of the capital demander is shown in Table 2 after summarizing the above three situations.

4.2.3. The Diagram of the Optimal Reaction. An optimal response diagram is drawn on the basis of parameter assignment in order to clearly show the optimal response of the two parties of the chicken game involved in supply chain finance.

Example 1. In a supply chain finance project, the operating cost rate of the capital provider is $c_s = 4\%$. The betrayal income is the ratio of the capital demander to increase the working capital D as the base, which is 16%. And the operating cost rate of the capital demander is $c_d = 4\%$. The calculation results of Tables 1 and 2 are shown in Table 3.

Table 2: Optimal response strategy of the capital provider.

$p < Dc_d/(Dc_d + U_d)$	Cooperation ($q = 1$)
$p > Dc_d/(Dc_d + U_d)$	Betrayal ($q = 0$)
$p = Dc_d/(Dc_d + U_d)$	Any choice is right (the probability of any choice will be equal to q)

Table 3: Optimal response strategy of game participants.

The optimal response of the capital provider		The optimal response of capital demander	
$q < 1/5$	Cooperation ($p = 1$)	$p < 1/5$	Cooperation ($q = 1$)
$q > 1/5$	Betrayal ($p = 0$)	$p > 1/5$	Betrayal ($q = 0$)
$q = 1/5$	Any choice is right (the probability of any choice will be equal to p)	$p = 1/5$	Any choice is right (the probability of any choice will be equal to q)

According to Table 3, the optimal decision of the supply and demand parties in the chicken game is shown in Figure 3, made by Excel.

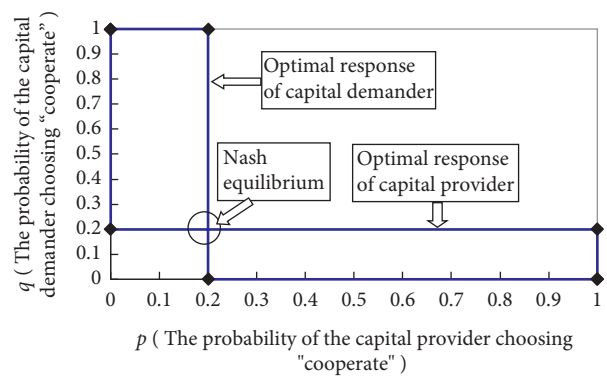


Figure 3: Optimal response strategy of game participants.

4.3. Game Behavior Analysis of Blockchain Financing Warehouse. In Figure 2, Nash equilibriums (dots marked with circles) exist only in "cooperate • betray" and "betray • cooperate" in pure strategy. However, when the range is expanded to include mixed strategies, Nash equilibrium can be achieved "with the probability 1/5 that both parties will cooperate (or betray)." The probability of the capital provider and demander choosing cooperation is very low, and the main reason is to choose the betrayal of income that is higher, meaning that when the trading information of the capital provider and demander is not on the blockchain, asymmetric information, there is no better technology or mechanism constraints default behavior, the cost of betrayal is low, and then the possibility of the game participants choosing cooperation will be very low.

In order to improve the possibility of cooperation, the capital provider timely introduces the new financial technology-blockchain. The capital demander is required to record all transactions on the blockchain. It will give full play to the technology advantages of blockchain such as distributed bookkeeping, nontamper, openness and transparency, privacy protection, and smart contracts. By making information more transparent, the cost of default will be higher for both parties, and the benefits of cooperation will be greater. At this point, it is equivalent to adding cooperation reward and breach penalty to both sides of the game. When the capital provider or the capital demander chooses cooperation, the upper chain reward is added; when choosing to betray, they should be punished. For simplicity of calculation, the amount of the reward is Dc_i, and the penalty for default is Dc_p (both are based on the loan amount D). The profit matrix is shown in Figure 4.

In this case, the calculation shows that when the probability of the capital demander choosing "cooperation" is "$q < (Dc_s + Dc_i + Dc_p)/(Dc_s + U_s)$," the probability of the capital provider choosing "cooperation " is "$p > 1 - p$," meaning that the probability of choosing "cooperation p" is 1. Similarly, when the probability of the capital provider choosing "cooperation" is "$p < (Dc_s + Dc_i + Dc_p)/(Dc_s + U_s)$," the probability of the capital demander choosing "cooperation" is "$q > 1 - q$," meaning that the probability of choosing "cooperation q" is 1. Assuming that the other coefficients in the above example remain unchanged, $c_i = 4\%, c_p = 4\% c_i = 4\%, c_p = 4\%$. Table 4 can be obtained.

According to Table 4, the optimal decision of the supply and demand parties in the chicken game is shown in Figure 5, made by Excel, too.

When the transaction information of the supply chain is recorded in the blockchain, the optimal reaction diagram of reward through cooperation and punishment through betrayal changes greatly compared with the previous one. At this time, the distance of the mixed Nash equilibrium point from the origin is much longer, meaning that the possibility of "cooperation" between the capital provider and the capital demander increases to 3/5. Therefore, in the development of supply chain finance, it can greatly improve the probability of "cooperation" between the supply and demand parties by stipulating in advance the incentive and punishment conditions for the transaction information to be recorded in the blockchain.

5. Analysis of Rewards and Punishment Conditions of Blockchain Supply Chain Finance

5.1. Establishment of Rewards and Punishment Standards for Blockchain Supply Chain Finance. When the capital provider and the capital demander of supply chain finance reach an agreement for a project, the capital provider will generally

		The capital provider	
		cooperation q	betrayal $1-q$
The capital demander	Cooperation p	$\pi_s = D(\alpha_b + r_s - c_s) + Dc_i$ $\pi_d = D(r_d - \alpha_b - c_d) + Dc_i$	$\pi_s = Dc_i$ $\pi_d = D(r_d - \alpha_b - c_d) + U_d - Dc_p$
	Betrayal $1-p$	$\pi_s = D(\alpha_b + r_d - c_d) + U_d - Dc_p$ $\pi_d = Dc_i$	$\pi_s = -Dc_s - Dc_p$ $\pi_d = -Dc_d - Dc_p$

Figure 4: Payoff matrix of game participants of blockchain financing warehouse.

Table 4: Optimal response strategy of game participants of blockchain financing warehouse.

The optimal response of the capital provider		The optimal response of capital demander	
$q < 3/5$	$(p = 1)$	$p < 3/5$	$(q = 1)$
$q > 3/5$	$(p = 0)$	$p > 3/5$	$(q = 0)$
$q = 3/5$	Any choice is right (the probability of any choice will be equal to p)	$p = 3/5$	Any choice is right (the probability of any choice will be equal to q)

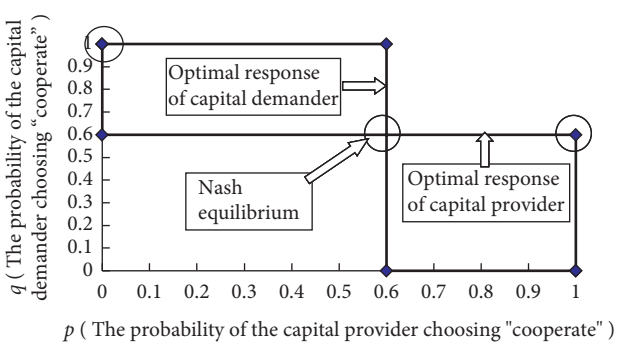


Figure 5: Optimal response strategy of game participants on blockchain.

conduct an overall evaluation of whether the project can introduce blockchain. The competitiveness of the supply chain, the stability of intrachain transactions, the compliance of intrachain enterprises, the performance of logistics supervision enterprises, and the information level of the supply chain will be evaluated. This is the basis for determining the rewards and penalties for adding transactions recorder in the blockchain. Therefore, in the multiparty agreement of the financing warehouse, the evaluation standard of the up-chain project should adopt a relatively systematic, multi-index, and whole-process evaluation method. There are 6 things that should be considered: the loan recovery, interest income, time point of recovery, whether the value of the pledge can always meet the minimum requirements in the process of lending and payment collection, whether the requirement is lower than the minimum pledge rate in the process, and the times of its occurring. Only by evaluating the process and results together can we effectively avoid the risk of the capital provider and reduce the possibility of loss.

5.2. Determination of the Rewards and Punishment Intensity of Blockchain Supply Chain Finance. In order to introduce FinTech blockchain technology into supply chain finance, the optimal reaction diagram of the rewards and punishments on the blockchain added from the above analysis has changed greatly from the previous one. At this time, the distance of the mixed Nash equilibrium point from the origin is much longer, which means that the possibility of both sides of the game choosing "cooperation" has increased. Therefore, in order to motivate the supply chain finance transaction recorded in the blockchain, adding the rewards and punishments in the lending agreement can effectively promote the enthusiasm of both parties, provide power for the application of new science and technology, increase participants' willingness of supply chain finance, and create better conditions for stable economic and social development.

6. Conclusions and Prospects

The authors took the financing warehouse as an example to study the game behavior of the participants in supply chain finance. By calculating examples, they compared and calculated the game behavior of the participants in the traditional supply chain finance and the blockchain supply chain finance. The difference of the Nash equilibrium of the mixed decision showed that when the transaction is included in the blockchain, meaning that when the reward or punishment is added, the Nash equilibrium is further away from the origin, and the two parties will cooperate with a greater probability. The research showed that the probability of choosing cooperation is strongly correlated with the amount of reward and punishment trading information in the blockchain. By encouraging trading information to be recorded in the blockchain and improving the sharing degree of trading information, the willingness of both parties to cooperate can be promoted. Therefore, promoting the application of blockchain technology in the field of supply chain finance and strengthening the cooperative behavior of participants will be conducive to the healthy and rapid development of supply chain finance and will better solve the financing problems of SMSE in the supply chain. In the future, in-depth research can be carried out on the game behavior in

the application scenario of blockchain technology so as to provide more specific guidance for the development of reward and punishment strategies' transaction information in the blockchain.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by Research on Operational Risk Evaluation of Internet Supply Chain Finance Based on Bayesian Network Method, Hunan Natural Science Foundation of Science and Education Joint Project, Project no. 2017JJ5013.

References

[1] "Supply Chain Finance Research Group," *Supply Chain Finance -- New Finance under new Economy*, vol. 1, pp. 26–46, Shanghai Far East Publishing House, Shanghai, 2009.

[2] Y. Luo and Y. Wang, "Discuss simply on the risk and prevention of Internet supply chain finance," *Logistics Engineering and Management*, vol. 1, p. 126, 2017.

[3] Y. Luo, "Analysis on the main modes and operational risks of Internet Supply chain finance," *Logistics Engineering and Management*, vol. 5, pp. 95-96, 2019.

[4] H. Du, J. Li, and J. Liu, "Research on Financing Game of Small and Medium-Sized Enterprises Based on Supply Chain Finance," *China Commerce And Trade*, pp. 115–118, 2011.

[5] W. Cao and C. Ma, "Analysis on financing game of accounts receivable based on supply chain finance," *Business Research*, vol. 3, pp. 168–173, 2013.

[6] Y. Luo and Z. Chen, "Research on the reward and punishment of supply chain finance supervision contract based on game theory," *Journal of East China Jiaotong University*, vol. 2, pp. 35–40, 2015.

[7] X. Wang and Q. Zhou, "Evolutionary game analysis of warehouse receipt pledge between banks and enterprises under blockchain," *Computer Engineering and Application*, 2021, https://kns.cnki.net/kcms/detail/11.2127.TP.20210419.1422.055.html.

[8] M. Andrychowicz and S. Dziembowski, "PoW-based distributed cryptography with No trusted setup based distributed cryptography with No trusted set-up," in *Lecture Notes in Computer Science*, vol. 9216, pp. 379–399, Springer, Berlin, Heidelberg, 2015.

[9] D. Wilson and G. Ateniese, "From pretty good to great: enhancing PGP using bitcoin and the blockchain," *International Conference on Network and System Security*, vol. 9408, pp. 368–375, 2015.

[10] D. Yermack, "Corporate governance and blockchains," *Review of Finance*, vol. 21, no. 1, p. rfw074, 2017.

[11] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," *International Journal of Production Research*, vol. 57, no. 7, pp. 2117–2135, 2019.

[12] J. Shunzi and T. Lei, "The application of blockchain in banks: prospects, challenges and countermeasures," *New Finance*, vol. 7, pp. 36–40, 2017.

[13] X. Chu and B. Gao, "Research on supply chain finance innovation driven by blockchain," *Financial Development Research*, vol. 8, pp. 68–71, 2018.

[14] Y. Bai, D. Zhai, D. Wu, and X. Lin, "Research on optimization strategy of supply chain finance platform based on blockchain," *Research of Financial Economics*, vol. 4, pp. 119–130, 2022.

[15] J. Guo and C. Chen, "Research on supply chain finance development innovation driven by Blockchain Technology," *Journal of Xi'an Jiaotong University*, vol. 3, pp. 46–53, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7005577, 11 pages
https://doi.org/10.1155/2022/7005577

Research Article

Study on the Influence of Reform of Cultural Administrative System on the Upgrading of Urban Industrial Structure

Guangye Che

Zhejiang Zheshang Asset Management Co., Ltd., Hangzhou, China

Correspondence should be addressed to Guangye Che; cheguangye@zsamc.com

Received 13 April 2022; Accepted 2 June 2022; Published 16 July 2022

Academic Editor: Lele Qin

This paper aims at identifying the causal relationship between the reform of the cultural system and the upgrading of industrial structure, revealing the causal relationship between the reform of the cultural system and the upgrading of industrial structure, which is of great significance for promoting the reform of the cultural system and the upgrading of industrial structure. The impact of cultural administrative reform on industrial structure upgrading is empirically tested using panel data from 261 prefecture-level cities in China from 2001 to 2017. The double difference model and PSM-DID method are used. This includes conducting placebo tests and examining the robustness of empirical findings using other methods. The findings indicated that (1) the influence coefficient of the cultural administrative system reform on industrial structure upgrading is positive and passed the significance level test, indicating that the cultural administrative system reform significantly promoted industrial structure upgrading, and on average, it can improve the level of the urban industrial structure by 11.81 percent. (2) Theoretical analysis of the mechanism demonstrates that the innovation level acts as a link between cultural administrative system reform and industrial structure upgrading, implying that cultural administrative system reform promotes industrial structure upgrading by stimulating the innovation level of cultural enterprises. (3) The results of the heterogeneity analysis indicate that the influence of cultural administrative reform on industrial structure upgrading is highly regionally and economically differentiated. The higher the economic level of the local community, the more effective the promotion effect on industrial structure upgrading. The reform of the cultural administrative system has a greater impact on industrial structure upgrading in the eastern region than in the central and western regions. On the basis of the foregoing research findings, this paper makes some policy recommendations for releasing the overall system reform dividend based on the cultural system and promoting regional industrial structure upgrading.

1. Introduction

In May 2021, General Secretary Xi Jinping stressed that "the development potential of local characteristic industries is huge. We should be good at exploiting and making use of local superior resources, strengthen the protection of local high-quality varieties, promote the organic combination of production, education, and research, and coordinate the development of industry, science, and technology, and culture." The "14th Five-Year Plan" emphasizes the importance of improving the cultural management system, as well as the production and operation mechanisms, in order to increase the efficiency of cultural governance. Through its economic permeability and expansion, the industry can not only improve people's quality of life and happiness but also contribute to cultural and economic development [1, 2]. To further support the development of cultural enterprises and institutions, the traditional mode of management by a single administrative order should be abandoned, and cultural enterprises and institutions should be granted independent management authority to compete freely in the market. The State Council initiated the Cultural Administrative System Reform, which aims to boost cultural enterprises' and institutions' capacity for innovation and market participation, as well as to strengthen cultural soft power [3, 4]. China has established three batches of pilot cities for the Reform of Cultural Administrative System since 2003. The cultural administrative system has been reformed from a mode of traditional management to one of scientific development. With the pilot scope of the cultural administrative system

reform continuing to expand, it is critical to scientifically evaluate the policy effect of the cultural administrative system reform on industrial structure upgrading. On the one hand, the reform of the cultural system has promoted the development of the cultural industry in the pilot cities, thus changing the internal structure of the industry; on the other hand, the reform of the cultural system has promoted cultural innovation, which is conducive to providing a high-quality innovation environment for enterprise innovation. To sum up, scientific identification of the relationship between the reform of the cultural system and the upgrading of industrial structure is a new research topic facing the academic circle. The purpose of this paper is to assess the impact of the Cultural Administrative System Reform on industrial structure upgrading and its mechanism, with the goal of answering the following three questions: to begin, how can the impact of the Cultural Administrative System Reform on industrial structure upgrading be quantified? Second, how can the mechanism of cultural administrative system reform be clarified in terms of industrial structure upgrading? Third, how can the spatial heterogeneity of the pilot policy effect of cultural administrative system reform be explored? The answers to the preceding questions serve to summarize the experience of the pilot construction of the cultural administrative system and to provide experience for expanding the reform of the cultural administrative system and promoting high-quality cultural industry development.

Following a review of the existing literature, this paper determines that the existing literature can be classified into the following three categories based on the nature of the research: the first type of research examines the impact of cultural administrative system reform on cultural innovation. Reform of the cultural administrative system is believed to be the primary driver of cultural innovation and economic development [5], and some scholars believe that cultural administrative reform and deregulation can effectively stimulate the market economy's vitality and propel long-term economic growth [6–9]. According to other scholars, loosening the system through cultural administrative reform will directly affect the development of cultural industries, increase economic output, and promote regional economic structure optimization [10, 11]. Additionally, empirical evidence indicates that cultural administrative reform has a significant positive effect on regional economic growth [12] and that the cultural industry cluster can help drive regional tourism economic growth [13]. Second, pay close attention to the mechanism by which cultural industries develop in relation to economic development. According to some scholars, cultural administrative reform results in an innovation-driven effect via the prosperity and development of the cultural industry [14, 15]. However, another type of scholar discovered that culture can influence economic growth by increasing total factor productivity, influencing the allocation of production factors, and influencing the decision-making of micromarket participants [16–18]. Additionally, some studies have discovered that culture can stimulate the growth of cultural industries and related industries, as evidenced by the fact that the development of cultural industries can boost GDP, stimulate the cultural tourism economy, and ultimately promote economic development [15]. From an international trade perspective, it is believed that culture can promote economic development by driving international trade and that cultural output is a critical factor in promoting exports and the economic development levels of countries along the route [19]. Cultural differences can help a country's exports and have a positive effect on export trade [20]. The third category is concerned with the policy implications of the cultural administrative system reform. Certain scholars focus on the policy implications of the cultural administrative system reform and regard it as a quasi-natural experiment. While some scholars are concerned with the causal relationship between cultural administrative system reform and economic growth [12], others are concerned with the impact of cultural administrative system reform on tourism development.

While the existing literature has established a certain research foundation for this study, the following issues remain: to begin, let us consider the endogenous problem of economic variables. It demonstrates primarily that there may be a bidirectional causal relationship between culture and economic growth, as well as endogenous problems caused by missing variables, which complicates deriving the net effect. Cultural development promotes industrial structure upgrade, and industrial structure upgrade improves the environment for cultural innovation. As a result, there is an endogenous problem of reverse causality between the development of cultural industry and industrial structure upgrading. Second, while existing research has examined the impact of cultural administrative system reform on regional economic growth [21, 22], there is no literature on the effect of cultural administrative system reform on industrial structure upgrading. Due to the short duration of existing studies, there is a dearth of in-depth analysis of the long-term dynamic effects of cultural administrative system reform [23]. A portion of the research examines the impact of cultural administrative system reform on the tourism economy, but not the industrial structure [24]. Third, there have been studies on industrial structure upgrading, with a particular emphasis on the impact of high-speed railways [25], civilized city selection [26], the belt and road initiative [27], technology and finance [28], and the China-Europe train [29]. Few scholars have examined its impact on industrial structure modernization from the perspective of cultural administrative system reform.

This paper will construct the research framework from the following three aspects: first, this paper is the first to examine the effect of institutional loosening on industrial structure upgrading through the lens of "cultural administrative system reform" and to theoretically analyze the internal mechanism of cultural administrative system reform on industrial structure upgrading. Second, because the cultural administrative system reform is an exogenous policy shock, it provides ideal conditions for investigating the causal relationship between cultural administrative system reform and industrial structure upgrading. This paper employs the double-difference method to precisely determine the causal relationship between cultural administrative system reform and industrial structure modernization.

Third, the mechanism and regional heterogeneity of the effect of cultural administrative system reform are investigated on industrial structure upgrading.

The rest of this paper is arranged as follows: the second part is the institutional background and theoretical analysis; the third part is the research design and data description. The fourth part is empirical analysis; the fifth part is the influence mechanism analysis, and the sixth part is the research conclusion and policy suggestion.

2. The Institutional Background and Theoretical Analysis

2.1. Institutional Background. The cultural administrative system reform adjusts the original single administrative management mechanism in order to liberate the management vitality of cultural enterprises and institutions, encourage relevant enterprises to compete in the market, and promote the high-quality development of the cultural industry. In other words, the reform of the cultural administrative system abolishes the traditional "imperative" management mode, promotes the modernization of cultural enterprise and enterprise management modes, fosters vital innovation, and ultimately establishes a cultural industry pattern based on the integration of culture, science, and technology. The National Reform of Cultural Administrative System Pilot Work Conference, held in Beijing in June 2003, officially announced the start of China's cultural administrative system reform pilot work. By 2020, three rounds of cultural administrative system reform pilot units would have been launched. The reform of the cultural administrative system is primarily concerned with three aspects: to begin, make full use of financial and tax resources to assist cultural industry development. Pilot areas for cultural administrative reform will increase support for the development of cultural industries and establish special funds to compensate for the deficiencies caused by a lack of development funds. To encourage the development of cultural industries, tax incentives such as discount interest and subsidies are adopted. Second, streamline the approval process and boost cultural enterprises' operational efficiency. The operational efficiency of cultural enterprises can be increased by reducing administrative examination and approval links and simplifying examination and approval procedures. Third, remove financial constraints on cultural enterprises, maximize the financing function of multilevel capital markets, and provide financial support for cultural enterprises' technological innovation.

2.2. Theoretical Analysis. The influence mechanism of cultural system reform on industrial structure upgrading is shown in Figure 1. The cultural administrative system reform modifies the existing and centralized administrative management mode, transforming cultural enterprises into market players capable of self-sufficiency and competition. The benefit of the reform is that cultural enterprises and institutions will be encouraged to innovate by increasing their market competitiveness, thereby promoting industrial structure upgrading. Additionally, reforming the cultural administrative system has the potential to not only absorb multicapital and revitalize the market but also to alter the traditional investment mode of cultural enterprises and optimize their investment and consumption structures [30]. The reform of the cultural administrative system removed barriers to entry, and more enterprises entered the cultural market, which increased market competition in the cultural market, increased the market competitiveness of cultural enterprises, and aided in the enhancement of enterprises' innovation capacity. On the one hand, the entry of cultural enterprises can not only provide capital support for cultural enterprises but also ensure the development of cultural industries. The reform of the cultural administrative system strengthens support for cultural enterprises, alleviates financial constraints on enterprises, encourages technological innovation, and provides technical assistance for industrial structure upgrading. On the other hand, the entry of high-quality cultural enterprises into the market introduces advanced management practices, technology, and business philosophy, which can not only serve as a demonstration effect but also exert competitive pressure on established cultural enterprises, compelling them to transform and upgrade. This paper proposes the following:

Hypothesis 1. Reforming the cultural administrative system has the potential to significantly boost industrial structure upgrading in pilot areas.

The cultural administrative system reform, as the internal driving force of innovation, is the primary force behind industrial structure upgrading and plays a critical role in promoting industrial structure upgrading. As a critical component of promoting cultural enterprise development, reforming the cultural administrative system enables cultural enterprises to overcome entry barriers, thereby facilitating the orderly flow of cultural innovation elements such as capital, talent, and technology and optimizing the allocation of production factors in the field of cultural industries. In the cultural market, innovative elements frequently flow from low- to high-productivity enterprises, and the reform of the cultural administrative system has transformed the efficiency of cultural production elements allocation into a dynamic process of continuous improvement in the direction of higher-level production elements. As a critical carrier and realization subject of knowledge, innovation elements facilitate learning exchange and knowledge sharing between cities via the innovation cooperation platform established by the Cultural Administrative System Reform, which effectively promotes knowledge dissemination and innovation agglomeration. The reform of the cultural administrative system has an effect on the technological advancement of the industrial structure. On the one hand, the reform of the cultural administrative system has resulted in the consolidation of tertiary industry, particularly the cultural industry, into pilot cities that can not only promote technological learning among different enterprises within the industry through cooperative innovation and technology trade, thereby promoting technology diffusion within the industry [31], but

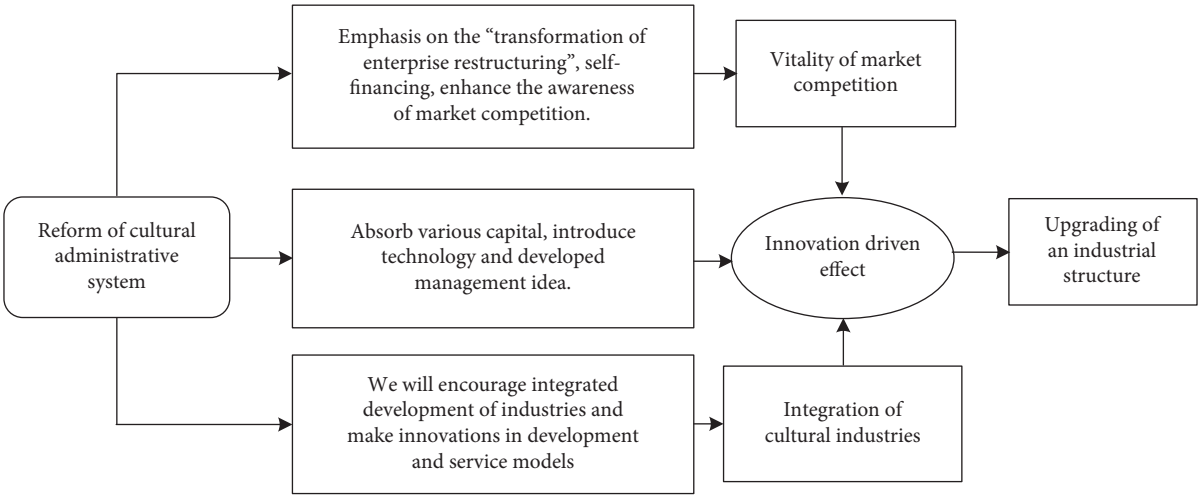


Figure 1: The influence mechanism of reform of cultural administrative system on industrial structure upgrading.

also raise the technological level of the entire industrial chain through the use of technology. On the other hand, technological innovation can contribute to the "win-win" development of cultural industries and the modernization of industrial structures. In terms of cultural industry development, the cultural administrative system reform aims to eliminate institutional and institutional impediments to cultural enterprise development, promote the free flow and optimal allocation of cultural production factors, and reinforce the critical role of technological advancement in improving production efficiency and cultural industry development. In terms of industrial structure modernization, technological advancement is widely regarded as a critical factor in promoting industrial structure modernization [32]. Thus, cultural administrative reform can contribute to industrial structure upgrading by stimulating technological innovation in cultural enterprises; this transmission mechanism is referred to in this paper as the technological innovation effect. On this basis, this paper advances the following research hypotheses:

Hypothesis 2. Reform of the cultural administrative system will promote the upgrading of industrial structure in pilot cities through technological innovation.

3. Research Design and Data Description

3.1. Research Design. According to the list of pilot cities published by the Ministry of Finance, the General Administration of Customs, and the State Taxation Administration of the People's Republic of China, by the end of 2017, 111 prefecture-level cities in China had been piloted in two batches, providing a good quasi-natural experiment for adopting the double-difference method. Due to the long-term nature of industrial structure upgrading, this paper focuses on 89 newly added regions in March 2006. Tianjin, Chaohu, Xiangfan, Xiantao, Wuxue, Wenchang, Baoting Li and Miao Autonomous County, Tongren, Qiandongnan, Dali, Chuxiong, Diqing, Honghe, and Hainan Tibetan Autonomous Prefecture were excluded from the second batch of pilot cities due to a lack of data. As a result, this paper uses 75 prefecture-level cities as the experimental group and 186 prefecture-level cities as the control group to construct policy variables for cultural administrative system reform. The fixed effect model with the double difference is used in this paper to assess the impact of cultural administrative system reform on industrial structure upgrading. The particular model is as follows:

$$\mathrm{Indu}_{it} = \beta_0 + \beta_1 \mathrm{Culreform} + \sum_{N=1}^{N} \gamma_N X_{it} + \eta_t + \mu_i + \varepsilon_{it}, \quad (1)$$

where Induit is the explained variable, which indicates the upgrading level of the industrial structure of the ith city in the t year. This paper selects the added value of the tertiary industry to measure it compared with the added value of the secondary industry. η time fixed effect, μi is the individual fixed effect of each city, X_{it} is the control variable, and Culreform represents the policy variable of the cultural administrative system, which is the core explanatory variable of this paper. $\beta 1$ indicates the net impact of the reform of the cultural administrative system on the upgrading of industrial structure. If $\beta 1$ is positive, it means that the reform of the cultural administrative system helps to promote the upgrading of industrial structure; otherwise, it has an inhibitory effect. The main variables and specific calculation methods are shown in Table 1.

3.2. Sample Data. (1) Variable that can be explained: industrial structure modernization. As the tertiary industry's development reflects its capacity to provide high-quality services, this paper uses the added value of the tertiary industry as a proxy for industrial structure upgrading by examining its historical evolution [33]. (2) The fundamental explanatory variables. The paper's central explanatory variable is the reform of the cultural administrative system. According to the list of pilot cities for cultural administrative reform published by the Ministry of Finance, the General

Table 1: Main variables and specific calculation methods.

	Variable name	Measurement method
Explained variable	Industrial structure upgrading (indu)	Proportion of added value of secondary industry to added value of tertiary industry
Core explanatory variable	Reform of cultural administrative system (Culreform)	Virtual variable (0, 1)
Control variable	Scale of government (lngov)	The local fiscal budget revenue (10,000 yuan) takes logarithm
	Economic development level (lnpergdp)	Logarithmic gdp per capita
	Education expenditure level (lnedu)	Education expenses (10,000 yuan) take logarithm
	Scientific and technological level (lnsci)	Scientific expenses (ten thousand yuan) take logarithm
	Technical level (lnsci)	The total amount of patents granted is logarithmic

Administration of Customs, and the State Taxation Administration of the People's Republic of China, the interactive items of two groups of virtual variables, period and group, are used to quantify the policy variables affecting cultural administrative reform in this paper. Period denotes the fictitious variable of time, which is 0 prior to and following cultural administrative system reform, and 1 following implementation. Between groups, the group represents the virtual variable, and the pilot city for cultural administrative reform is set to 1, while the pilot city for cultural administrative reform is set to 0. (3) Variables under control. According to the existing literature, this paper chooses as control variables for industrial structure upgrading the variables of government scale, economic development level, education expenditure level, scientific research development level, and scientific and technological research and development level. (1) The government scale, which influences industrial structure upgrading by influencing the construction of local industrial infrastructure, is defined as the income in the local financial budget and is treated using the natural logarithm. (2) There is a positive correlation between the level of economic development, the level of economic development, and the upgrading of industrial structure. The per capita GDP is used to quantify it in this paper, and the natural logarithm is used to compute it; (3) the level of education expenditure, which has an effect on industrial structure upgrading through increased human capital, is measured and treated using the natural logarithm. (4) The level of scientific and technological research and development, which fuels the growth of enterprises and industries, is a critical factor in industrial structure upgrading. The expenditure on scientific endeavors is quantified and treated in this paper using the natural logarithm; (5) on a technical level, innovation stimulates industrial vitality, thereby promoting industrial upgrading. This paper quantifies it by examining the total number of patent authorizations. Table 1 details the variable selection and calculation process.

3.3. Data Description. The impact of China's cultural administrative reform on industrial structure upgrading is examined in this paper using panel data from 261 cities in China between 2001 and 2017. The variables used in this paper, such as the size of government, the level of economic development, the level of education spending, the level of scientific research development, and the level of scientific and technological research and development, are all drawn from the China Urban Statistical Yearbook over time. Descriptive statistics of table variables are shown in Table 2.

4. Empirical Results and Robustness Test

4.1. Parallel Trend and Dynamic Effect Test. The premise of double difference estimation is the parallel trend test. A critical assumption for policy evaluation of cultural administrative system reform is that the experimental and control groups follow a parallel trend; in other words, the experimental and control groups' evolution trends are identical when the policy effect is unaffected by the policy. Additionally, with the implementation of the cultural administrative system reform pilot policy and the enhancement of policy supporting measures, the policy's dynamic effect gradually manifests. As a result, it is necessary to test the dynamic effect of cultural administrative system reform, with the objective of analyzing the dynamic effect of cultural administrative system reform on industrial structure upgrading. The parallel trend and dynamic effect are examined in this paper using the event research method [34], and the following regression models are established:

$$\begin{aligned} \mathrm{Indu}_{it} = \theta_0 + \sum_{\tau=-1}^{\tau=-3} \theta_\tau \mathrm{pre} + \theta_1 \mathrm{current}_0 + \sum_{\eta=1}^{\eta=12} \theta_\eta \mathrm{post} \\ + \theta_N \sum_{N=1}^{N} \mathrm{control} + \mu + \gamma + \nu, \end{aligned} \tag{2}$$

where Induit is the explained variable, which indicates the upgrading level of the industrial structure of the ith city in the t year. Pre and post are counterfactual virtual variables of the policy of reforming the cultural administrative system. When the pilot policy of reform of the cultural administrative system was approved in τ years, pre was 1, and when the pilot policy of reform of the cultural administrative system was approved in η years, post was 1, and control was the control variable. In order to analyze the parallel trend of reform of cultural administrative system policy, this paper drew Figure 2. According to Figure 2, we found that the regression coefficient of pre before the implementation of the pilot policy of Reform of Cultural Administrative System is not significant, which shows that there is no significant difference in the industrial structure upgrading between the

Table 2: Descriptive statistics of table variables.

Variable	Sample size	Mean	Standard deviation	Minimum value	Maximum
Indu	4437	0.855	0.435	0.094	5.34
Culreform	4437	0.216	0.412	0	1
Lnpergdp	4437	9.977	0.883	4.595	13.156
Lngov	4437	12.985	1.494	7.193	18.012
Lnedu	4437	9.449	1.745	0.945	15.211
Lnsci	4437	11.347	2.603	1.386	16.082
Lnsci	4437	6.113	1.804	0.693	11.578

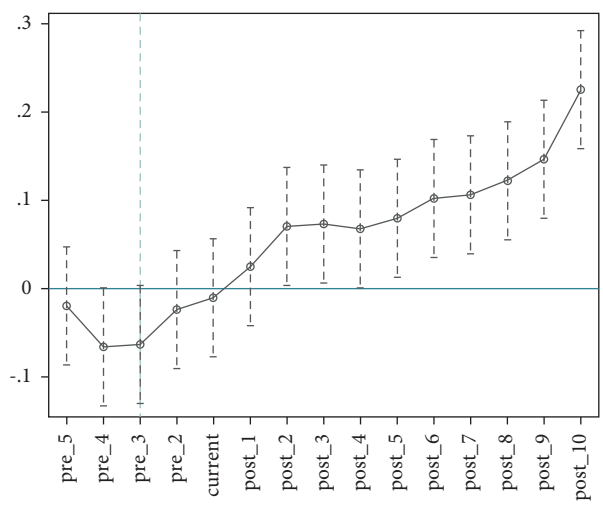


Figure 2: Parallel trend diagram of reform of the cultural administrative system.

experimental group and the control group. In terms of the policy effect's dynamic evolution, the regression coefficient of post was positively significant in the second year following the reform of the cultural administrative system, and the significance level of the regression coefficient increased year by year throughout the sample investigation period, indicating that the reform of cultural administrative system significantly promoted industrial structure upgrading, and it passed the parallel trend test.

4.2. Results of Benchmark Regression. The two-way fixed effect model is used in this paper to assess the effect of cultural administrative system reform on industrial structure upgrading (the regression results are shown in Table 3). In Table 3, models 1 and 2 do not account for the time fixation and individual fixation effects, whereas models 3 and 4 account for the time fixation and individual fixation effects, and model 4 includes control variables. The regression results for model 1 indicate that the influence coefficient of cultural administrative system reform on industrial structure upgrading is 0.1541, which passes the 1% significance level test, indicating that the cultural administrative system reform has significantly facilitated industrial structure upgrading in pilot areas. After controlling for control variables and the time and individual fixing effects, the influence of cultural administrative reform on industrial structure upgrading is reduced. The influence coefficient of the cultural administrative system reform on industrial upgrading decreased from 0.1541 in Model 1 to 0.1181 in Model 4, indicating that other factors were effectively controlled, and the cultural administrative system reform effectively promoted industrial upgrading in pilot areas and the development of service industries characterized by cultural industry. This is largely because the reform of the cultural administrative system revitalizes institutional vitality, unifies the system, and fosters the growth of the cultural industry. As a result, Hypothesis 1 has been established.

4.3. Robustness Test. To ensure the robustness of the effect of cultural administrative reform on industrial structure upgrading, this paper will consider a series of robustness tests, including the province-time joint fixed effect test and the PSM-DID test.

4.3.1. Province-Time Joint Fixed Effect. The impact of cultural administrative reform on industrial structure upgrading is influenced by the heterogeneity of economic development and the heterogeneity of implementation time in cultural reform pilot areas, both of which have a direct effect on the robustness of causality identification (Table 4). After adjusting for province-time fixed effects, the influence coefficient of cultural administrative system reform on industrial structure upgrading is 0.0893, which passes the 1% significance level test. When the province-time combined fixed effect is considered, the regression coefficient for the reform of the cultural administrative system decreases slightly, but there is no discernible difference with the benchmark result, indicating that the research has a high degree of robustness.

4.3.2. PSM-DID Robustness Test. Generally, the pilot area for cultural administrative system reform is not chosen arbitrarily; it is determined by the level of tourism development, scenic spots and historical sites, natural scenery, and other factors in the pilot area. As a result, this paper uses the tendency score matching method to create a treatment group and a control group for the cultural administrative system reform and then computes the average treatment effect between groups. The matching processing variable is whether the city is designated as a pilot city for cultural administrative system reform, and the covariates include government size (lngov), economic development level (lnpergdp), education expenditure level (lnedu), scientific

Table 3: Benchmark regression results.

Explanatory variable	1 model	2 model	3 model	4 model
Culreform	0.1541*** (9.831)	0.1731*** (10.588)	0.1376*** (8.290)	0.1181*** (7.323)
Control variable	Uncontrolled	Control	Uncontrolled	Control
Time fixed effect	Uncontrolled	Uncontrolled	Control	Control
Individual fixation effect	Uncontrolled	Uncontrolled	Control	Control
Constant term	0.8220*** (112.717)	0.8256*** (163.785)	1.8555*** (17.931)	4.1965*** (13.628)
Observed value	4437	4437	4437	4437
R^2	0.021	0.094	0.765	0.786

Note. (1) The standard deviation in brackets, ***, and *** are significant at 10%, 5%, and 1% significance levels, respectively.

Table 4: Results of controlling the fixed effect of province-time.

Explanatory variable	(1)	(2)	(3)
Culreform	0.1731*** (10.588)	0.1181*** (7.323)	0.0893*** (4.729)
Control variable	YES	YES	YES
Time fixed effect	NO	YES	YES
Individual fixation effect	NO	YES	YES
Province x time	NO	NO	YES
Constant term	1.8555*** (17.931)	4.1965*** (13.628)	2.3104*** (15.190)
Observed value	4437	4437	4352
R^2	0.094	0.786	0.528

Note. (1) The standard deviation in brackets, ***, and *** are significant at 10%, 5%, and 1% significance levels, respectively.

Table 5: PSM-DID regression results.

Explained variable	1 model	2 model	3 model	4 model
Culreform	0.1517*** (9.666)	0.1358*** (8.193)	0.1713*** (10.485)	0.1169*** (7.253)
Control variable	NO	NO	YES	YES
Time fixed effect	NO	YES	NO	YES
Individual fixation effect	NO	YES	NO	YES
Constant term	0.8213*** (112.642)	0.8247*** (164.461)	1.8557*** (17.560)	4.2085*** (13.577)
Observed value	4417	4417	4417	4417
R^2	0.021	0.765	0.093	0.786

and technological research and development level (lnsci), and innovation level (lnsci). The paper employs a first-order nearest neighbor matching algorithm based on the Kernel function (see Table 5). According to the regression results in Table 5, the effect of cultural administrative reform on industrial structure upgrading was 0.1169 when control variables were included, and the time fixed effect and individual fixed effect were controlled, passing the 1% significance level test. This research conclusion is consistent with previous regression results, indicating that it is extremely robust.

4.4. Placebo Test. To ensure that the impact of cultural administrative reform on industrial structure upgrading is random, this paper uses the placebo test [3], randomly selects the treatment and control groups, randomly selects 500 times, randomly selects some cities as the experimental group for cultural administrative reform and other cities as the control group, and estimates using the double-difference method. If the influence of cultural administrative system reform on industrial structure upgrading fails the significance test, it means that cultural administrative system reform has an effect on industrial structure upgrading (see Table 6). According to Table 6, we found that there was a significant difference between the results of the placebo test and benchmark regression. As a result, random factors had no effect on industrial structure upgrading, indicating that the reform of the cultural administrative system had a significant effect on industrial structure upgrading.

5. Impact Mechanism and Heterogeneity Analysis

This paper concludes that reforming the cultural administrative system can significantly aid in the upgrading of industrial structure; however, what is the mechanism by which cultural administrative system reform can aid in industrial structure upgrading? Is there spatial heterogeneity in the effect of cultural administrative reform on the upgrading of industrial structure?

5.1. Intermediary Effect Model. According to the theoretical mechanism analysis mentioned above, this paper thinks that the reform of the cultural administrative system has an impact on the upgrading of industrial structure through technological innovation. To verify this mechanism, the empirical test of this paper adopts a four-step method: (1)

Table 6: Placebo test.

Random variable	1 model	2 model	3 model
Random	−0.0463*** (−2.823)	−0.0073 (−0.532)	0.0156 (1.308)
Control variable	NO	YES	YES
Time fixed effect	NO	YES	YES
Individual fixation effect	NO	YES	YES
Province * time	NO	NO	YES
Constant term	3.7765*** (25.680)	4.2764*** (13.845)	2.2253*** (14.707)
Observed value	4437	4437	4352
R^2	0.003	0.783	0.523

Table 7: Analysis of influence mechanism.

Variable	1 model	2 model	3 model	4 model
Culreform	0.1181*** (7.323)	—	—	0.0958*** (6.296)
Index	—	0.0015*** (9.360)	0.0006*** (4.637)	0.0014*** (9.374)
Control variable	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Individual fixation effect	YES	YES	YES	YES
Constant term	4.1965*** (13.628)	4.2273*** (13.577)	0.6324*** (3.194)	4.1667*** (13.401)
Observed value	4437	4437	4437	4437
R^2	0.786	0.796	0.754	0.798

regression of the reform of the cultural administrative system to the upgrading of industrial structure, if the regression coefficient is significantly positive, it indicates that the reform of the cultural administrative system has promoted the upgrading of industrial structure; (2) regression of urban innovation level to industrial structure upgrading. If the regression coefficient is significantly positive, it indicates that the urban innovation level promotes industrial structure upgrading. (3) The reform of the cultural administrative system is used to regress the level of urban innovation. If the regression coefficient is significantly positive, it means that the reform of the cultural administrative system is helpful to improve the level of urban innovation. (4) The influence of the reform of the cultural administrative system and the level of urban innovation on the upgrading of industrial structure is studied by incorporating them into the regression model at the same time. If the regression coefficient of the reform of the cultural administrative system becomes smaller or the significance level decreases or is no longer significant, it proves that the reform of the cultural administrative system promotes the upgrading of industrial structure through the effect of technological innovation. According to the above inspection steps, the mechanism verification model of this paper is set as follows:

$$\begin{aligned}
\mathrm{Indu}_{it} &= \beta_0 + \beta_1 \mathrm{Culreform} + \sum \gamma X_{it} + \eta_t + \mu_i + \varepsilon_{it}, \\
\mathrm{Indu}_{it} &= \beta_0 + \beta_1 \mathrm{Index}_{it} + \sum \gamma X_{it} + \eta_t + \mu_i + \varepsilon_{it}, \\
\mathrm{Index}_{it} &= \beta_0 + \beta_1 \mathrm{Culreform} + \sum \gamma X_{it} + \eta_t + \mu_i + \varepsilon_{it}, \\
\mathrm{Index}_{it} &= \beta_0 + \beta_1 \mathrm{Culreform} + \beta_2 \mathrm{Index}_{it} \\
&\quad + \sum \gamma X_{it} + \eta_t + \mu_i + \varepsilon_{it},
\end{aligned} \tag{3}$$

where Indu represents the upgrading level of industrial structure, Culreform represents the pilot policy of the cultural administrative system, and Index is the level of urban innovation. This paper uses the design idea of the intermediary effect model [3] for reference, measures the level of urban innovation (Index) by using the report of China's urban and industrial innovation published by Fudan University Industrial Development Center, and uses it as an intermediary variable.

The results of mediating effect of reform of the cultural administrative system are shown in Table 7. The result of model 1 shows that the influence coefficient of the reform of the cultural administrative system on the upgrading of industrial structure is 0.1181, and it has passed the significance test of 1%. It shows that the reform of the cultural administrative system promotes the upgrading of industrial structure, and it is an important way to promote the reform of cultural enterprises, which is conducive to breaking the entry barriers of cultural enterprises, thus promoting the orderly flow of cultural innovation factors such as capital, talents, and technology and optimizing the allocation of production factors in the field of cultural industries. The regression result of model 2 shows that the regression coefficient of urban innovation ability to industrial structure upgrading is 0.0015, and it has passed the 1% significance level test, which indicates that urban innovation level promotes industrial structure upgrading. The regression results of model 3 show that the influence of the reform of the cultural administrative system on urban innovation is 0.0006, which has passed the 1% significance level test; (4) the model incorporates urban innovation capability and cultural administrative reform, and the regression coefficient for urban innovation capability is 0.0014, exceeding the 1% significance level. The coefficient of reform of the cultural administrative system decreases from 0.1181 in the benchmark regression to 0.0958 in model 4. This demonstrates that reforming the cultural administrative system promotes industrial structure upgrading through the enhancement of urban innovation capability, thereby validating Hypothesis 2.

Table 8: Heterogeneity regression results.

Explanatory variable	East		Midland		Western part of the country	
	(1)	(2)	(1)	(2)	(1)	(2)
Culreform	0.1920*** (6.694)	0.0912*** (5.144)	0.0497** (2.389)	0.0335* (1.714)	0.1772*** (5.563)	0.0455 (1.313)
Control variable	YES	YES	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES	YES	YES
Individual fixation effect	YES	YES	YES	YES	YES	YES
Province x date	NO	YES	NO	YES	NO	YES
Constant term	3.2109*** (8.071)	2.9182*** (8.645)	5.1768*** (7.886)	3.4141*** (5.195)	1.8406*** (4.726)	2.2753*** (4.708)
Observed value	1683	1632	1649	1649	1105	1071
R^2	0.845	0.911	0.795	0.839	0.761	0.853

5.2. Heterogeneity Analysis. Is the impact of cultural administrative system reform on industrial structure modernization different depending on the spatial location? As a result, this paper will attempt to further explore the heterogeneity of the influence of cultural administrative system reform on industrial structure upgrading. The sample of 261 cities is divided into three regions in this paper: eastern, central, and western, and each region is estimated using the double-difference method (see Table 8). According to Table 8, the effect of cultural administrative system reform on industrial structure upgrading varies by spatial location. Specifically, cultural administrative reform has the greatest effect on upgrading the industrial structure in the eastern region, indicating that the eastern region has a high level of economic development and strong support for cultural industries. Cultural enterprises are receptive to cultural administrative reform and can make comprehensive use of the eastern region's advanced capital, labor, and technology to create the culture and advance the industrial structure. The influence coefficient of cultural administrative reform on industrial structure upgrading is lower in the central region than in the eastern region and greater in the western region. However, the policy effect in the western region is negligible, indicating that the reform of the cultural administrative system has a negligible effect on the upgrading of the western region's industrial structure.

6. Research Conclusions and Policy Recommendations

Using panel data from 261 cities in China from 2001 to 2017, this paper empirically examines the impact of cultural administrative system reform on industrial structure upgrading through the use of the double-difference and PSM-DID methods. It is discovered that the reform of the cultural administrative system has significantly aided in the upgrading of industrial structure, increasing the level of upgrading by an average of 11.81 percent. The analysis of the influence mechanism reveals that by stimulating innovation, the cultural administrative system reform facilitated the upgrading of the industrial structure. The analysis of heterogeneity reveals that the reform of the cultural administrative system has a greater impact on the upgrading of industrial structure in the eastern region than in the central and western regions. In light of the foregoing research findings, this paper makes the following policy recommendations.

To begin, the expansion of the pilot cultural administrative system reform is promoted in order to assist in upgrading the industrial structure. The study's conclusion demonstrates that cultural administrative reform has significantly aided in the upgrading of industrial structure. Thus, cultural administrative reform should be tightly coupled with the endowments of various regions' cultural resources, and historical sites, ethnic cultural traditions, and regional characteristic cultures should be fully utilized to adapt to modern business concepts, allowing various regions to develop cultural industries in accordance with local conditions. The orderly expansion of the pilot program is promoted for the Reform of Cultural Administrative Systems, so that more regions can benefit from the reform dividend associated with the system's loosening. And we should increase the promotion of the cultural industry system reform, strive to overcome the original system constraints of the cultural industry, orderly transform the cultural management system, and give full play to the driving effect of cultural industry upgrading. We should relax the system and mechanism, promote the upgrading of the industrial structure, and make the reform of the cultural administrative system a driving force and economic power.

Secondly, the barriers that exist between cultural industries are dismantled, and the barriers that exist between cultural industries are dismantled. We should give full play to the development potential released by the reform of the cultural administrative system, break the entry threshold of cultural enterprises by simplifying examination and approval, attract enterprises to enter the market, and enhance the competitiveness of enterprises. By increasing support for cultural enterprises, efforts should be made to remove impediments to cultural industry development. As a significant promoter of tertiary industry growth, the industry itself is a typical green industry with a high value-added, which aligns with the country's primary theme of green development today. As a result, we should actively promote the development of a fair, open, and competitive administrative management system and market operation system environment for the cultural industry, in order to accelerate the industry's growth and upgrade its industrial structure.

Thirdly, the reform of the cultural administrative system's pivotal role is emphasized in regional coordinated

development. Give full consideration to the impact of cultural system liberalization on domestic trade, foreign investment, financial services, and other related industries, as well as to the radiation and aggregation synergy of the cultural administrative system reform. Geographical location has an effect on the influence of cultural administrative system reform on industrial structure upgrading. On the one hand, it is necessary to strengthen support for the development of cultural industries and infrastructure in the eastern region's pilot cities, to continue promoting administrative system reform, to spread the economic and institutional benefits of cultural administrative system reform to the central and western regions, to increase the efficiency of cultural resource allocation, and to promote industrial structure upgrading.

Finally, the intermediary role of technological innovation should be emphasized in order to assist in industrial structure upgrading. The mechanism analysis in this paper demonstrates that reforming the cultural administrative system has an effect on industrial structure upgrading by increasing the level of urban innovation. As a result, we should actively encourage market players to innovate and develop independently, loosen the institutional dividend with the help of the cultural system, encourage cultural enterprises to enter the market, improve their competitiveness, and innovate, fully unleash the cultural market's vitality, and stimulate the development of new formats of cultural market development.

This paper takes the cultural system reform as a quasi-natural experiment, solves the causal relationship between the cultural system reform and the upgrading of industrial structure, and reveals the theoretical mechanism of the influence of the cultural system reform on the upgrading of industrial structure. However, due to the limitations of data and methods, the paper did not study the influence of cultural system reform on microenterprises and did not reveal the influence of cultural system reform on total factor productivity and innovation input of enterprises.

Data Availability

All data used in this study can be accessed by request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] E. E. Hagen, "Journal of Social Issues," *How economic growth begins: a theory of social change*, vol. 19, no. 1, pp. 20–34, 1963.

[2] P. Zak and S. Knack, "Trust and growth [j]," *The Economic Journal*, vol. 111, no. 470, pp. 295–321, 2001.

[3] Z. Li, "Sichuan reform of cultural administrative system: challenges and choices [J]," *Economic System Reform*, vol. 1, no. 3, pp. 44–48, 2006.

[4] R. Liu, Yu Mao, and Y. Kang, "System loosening, market vitality stimulation and tourism economic development-Evidence from China's reform of cultural administrative system [J]," *Economic Research*, vol. 55, no. 1, pp. 115–131, 2020.

[5] B. Huo and C. Fu, "The theoretical staging of China's reform of cultural administrative system and the strategic issues of deepening reform of cultural administrative system [J]," *China Soft Science*, vol. 9, no. 8, pp. 23–34, 2007.

[6] K. Yang, T. Ran, and M. Liu, "Deregulation, decentralization and China's economic transition [J]," *China Social Sciences*, vol. 16, no. 3, pp. 4–17, 2003.

[7] F. Li, Z. Dong, and L. Wang, "Classification test of system dominance, factor contribution and economic growth power in China [J]," *Economic Research*, vol. 4, no. 4, pp. 53–65, 2008.

[8] G. Fan, X. Wang, and G. Ma, "The contribution of China's marketization process to economic growth [J]," *Economic Research*, vol. 46, no. 9, pp. 4–16, 2011.

[9] Y. Fang and Y. Zhao, "Looking for institutional instrumental variables: estimating the contribution of property rights protection to China's economic growth [J]," *Economic Research*, vol. 46, no. 5, pp. 138–148, 2011.

[10] D Wynne, *The Culture Industry: The Arts in Urban regeneration[M]*, Avebury, UK and Singapore, 1992.

[11] J. Zhang and W. Wu, "The model of cultural industry driving tourism economy and international experience [J]," *Journal of Tourism*, vol. 30, no. 8, pp. 4–6, 2015.

[12] Y. Xue, "Empirical analysis of the impact of China's reform of cultural administrative system on regional economic growth [J]," *Contemporary Economic Science*, vol. 38, no. 4, pp. 89–97+127, 2016.

[13] Na Tan and W. Huang, "Has the policy of cultural industry agglomeration driven the growth of regional tourism economy? —evidence from the selection of quasi-natural experiments in Wenchuang Park [J]," *China Soft Science*, vol. 95, no. 1, pp. 68–75, 2021.

[14] Ji. Qi, "Research on the new impetus of cultural industry promoting economic growth [J]," *Journal of Shandong University*, vol. 6, no. 3, pp. 42–48, 2017.

[15] Y. Wang and S. Zhang, "Empirical study on the influence of cultural symbols on urban economic growth [J]," *Economics and Management Research*, vol. 38, no. 5, pp. 24–33, 2017.

[16] S. Zheng and X. Ge, "Reform of cultural administrative system and total factor productivity growth of cultural industry [J]," *China Soft Science*, vol. 9, no. 10, pp. 48–58, 2012.

[17] S. Luo and Z. Bai, "Study on the economic growth effect and mechanism of culture [J]," *Jiangxi Social Sciences*, vol. 40, no. 3, pp. 60–71, 2020.

[18] Li Shu, R. Deng, and G. Chen, "The theoretical dimension and practical approach of cultural economics-a summary of the fifth cultural and economic forum [J]," *Economic Research*, vol. 55, no. 1, pp. 204–208, 2020.

[19] W. Pan and Y. Liu, "Empirical study on the influence of cultural output on exports and the economic development level of "the belt and road initiative" [J]," *statistics and decision*, vol. 35, no. 17, pp. 135–138, 2019.

[20] R. Qu and L. Han, "An empirical study on the influencing factors of Chinese cultural commodity trade [J]," *China Soft Science*, vol. 7, no. 11, pp. 19–31, 2010.

[21] M. Ouyang and F. Zhong, "The influence of reform of cultural administrative system on economic growth and its regional heterogeneity-an empirical test based on PSM-DID method [J]," *Journal of Fujian Business University*, vol. 13, no. 2, pp. 26–35, 2021.

[22] R. Dekle and G. Vandenbroucke, "A quantitative analysis of China's structural transformation," *Journal of Economic Dynamics and Control*, vol. 36, no. 1, pp. 119–135, 2012.

[23] J. Li, D. Wang, and Y. Liu, "Has the construction of high-speed railway network promoted the upgrading of China's urban industrial structure? [j]," *Industrial Economics Research*, vol. 2, no. 3, pp. 30–42, 2020.

[24] Z. Liu and C. Liu, "Study on the influence of civilized cities on the upgrading of industrial structure-a quasi-natural experiment from the selection of civilized cities [J]," *Industrial Economics Research*, vol. 19, no. 1, pp. 43–55, 2021.

[25] F. Hui and S. Zhao, "Has the "the belt and road initiative" Initiative promoted the upgrading of China's industrial structure? —double difference test based on 285 cities [J]," *Industrial Economics Research*, vol. 10, no. 1, pp. 29–42, 2021.

[26] Y. Feng and J. Qiu, "Analysis of the effect and heterogeneity of industrial structure upgrading of technology and finance's policy-a quasi-natural experiment based on "the pilot project of combining science and technology with finance" [J]," *Industrial Economics Research*, vol. 12, no. 02, pp. 128–142, 2021.

[27] A. lee, W Yue, and X. Wang, "Can the opening of China-Europe trains promote the upgrading of industrial structure?" *Quasi-natural experimental research from 285 prefecture level cities in China*, vol. 1, no. 3, pp. 69–83, 2021.

[28] A. J. Scott, "Cultural products industries and urban economic development: prospects for Growth and Market Contestation," *Global Context [J]*, vol. 39, no. 4, pp. 461–490, 2004.

[29] Y. Bian, L. Wu, and J. Bai, "Growth, innovation and promotion-empirical evidence from provincial local governments in China [J]," *Scientific Research Management*, vol. 40, no. 8, pp. 53–61, 2019.

[30] C. Tao and Y. Peng, "Population agglomeration, greening level and environmental pollution-spatial heterogeneity analysis based on urban data [J]," *Journal of Jiangxi University of Finance and Economics*, vol. 4, no. 6, pp. 21–31, 2017.

[31] C. Gan, R. Zheng, and D. Yu, "The impact of China's industrial structure change on economic growth and fluctuation [J]," *Economic Research*, vol. 46, no. 5, pp. 4–16, 2011.

[32] C. Liu, "Study on the effect of environmental information disclosure on green development efficiency [J]," *Journal of Shandong University of Finance and Economics*, vol. 33, no. 5, pp. 25–42, 2021.

[33] C. Liu, "Impact of emission trading system on green development efficiency [J]," *Environmental Economic Research*, vol. 6, no. 2, pp. 80–99, 2021.

[34] C. Liu and Q. Ma, "Research on the influence of network infrastructure construction on the growth of total factor productivity-a quasi-natural experiment based on the pilot policy of "Broadband China" [J]," *China Population Science*, vol. 19, no. 3, pp. 75–88, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2987885, 11 pages
https://doi.org/10.1155/2022/2987885

Research Article

Empirical Analysis on the Correlation between Low-Carbon Economy and Marine Industry Development

Jian Yang and Hui Liu

School of Economics and Management, China University of Petroleum (East China), Qingdao 266580, China

Correspondence should be addressed to Hui Liu; huiliu2@yeah.net

Received 23 March 2022; Revised 28 April 2022; Accepted 19 May 2022; Published 16 July 2022

Academic Editor: Lele Qin

In order to analyze the correlation between the low-carbon economy and marine industry development, an empirical analysis method of the correlation between the low-carbon economy and marine industry development is proposed. The decomposition analysis method of marine industry carbon emission structure based on the input-output table is adopted to analyze China's marine industry carbon emission structure and obtain the influencing factors of marine industry carbon emission. The calculation method of total factor productivity of marine low-carbon economy is used to calculate the productivity of all influencing factors of a marine low-carbon economy and analyze the technical effect after the integrated development of low-carbon economy and marine industry. The panel data model is used to analyze the relationship between the transformation and upgrading of the marine industry and the development of the low-carbon economy. The empirical analysis results show that the sustainable development of marine low-carbon economy can only be realized by improving low-carbon technology, and the advanced degree of the marine industrial structure plays the greatest role in the marine low-carbon economy. The marine industry needs to optimize low-carbon technology and improve the advanced degree of industrial structure in order to realize the integrated development of a low-carbon economy and marine industry.

1. Introduction

When China's economic development speed increased, the problem of uneven supply and demand of land resources has gradually become prominent. One of the preconditions for the management of land resource shortage is the rational use of marine resources [1]. The ocean is the focus of global attention, and the competition of coastal countries for the commanding heights of the marine industry is also very fierce [2]. In 2012, after China put forward the strategy of becoming a maritime power, the development speed of the marine economy increased. In 2017, China's marine GDP exceeded 7 trillion yuan, accounting for more than 9% of GDP in 2017 and more than 16% of GDP in coastal areas. The marine economy has become an important blue engine in China's economic development process [3].

In 2016, China's traditional marine industries, such as marine oil and gas industry, fishery, and shipbuilding industry, slowed down, and their economic benefits deteriorated. In 2017, such traditional industries showed a state of restorative development, and the rapid development of marine emerging industries promoted the transformation and upgrading of marine industries [4].

At present, the new goal of China's marine economic development is to complete the green environmental protection and low carbon of the marine industry [5]. Coastal countries around the world follow the standards of resource conservation and environmental protection to develop the marine industry and abandon the extensive development model with serious traditional energy consumption [6]. Therefore, when China puts forward the concept of green development and the strategy of marine power, analyzing the correlation between a low-carbon economy and marine industry has practical significance for promoting the optimization of marine industrial structure [7].

Low carbon economy and low-carbon technology have become hot issues of global concern. China is a developing country with complex energy, industry, and trade structure and more greenhouse gas emissions [8]. With the advent of a low-carbon economy, China must pay attention to the integrated development of the marine industry and low-carbon economy.

Taking the correlation between low-carbon economy and marine industry development as the research content, this paper puts forward an empirical analysis method of the correlation between the low-carbon economy and marine industry development, which provides reference materials for the research on the correlation between the low-carbon economy and marine industry development.

2. Literature Review

At this stage, many scholars have studied the low-carbon economy with a view to the coordinated development of the low-carbon economy and various industries to improve economic benefits. Literature [9] studied the sustainable development process of low-carbon pilot cities, constructed 35 evaluation indicators based on the basic development level of the city and the development level of low-carbon cities, and used the entropy method to evaluate economic development, social progress, and environmental quality. The comprehensive analysis provides reference materials for the development of low-carbon cities, but this method is not comprehensive enough to analyze the relationship between a low-carbon economy and industry. Literature [10] analyzed the impact of energy price, technology, and disaster shocks on my country's energy environment and economic system and constructed a dynamic stochastic general equilibrium (DSGE) model to analyze the impact of energy price, technology, and disaster shocks on China's energy-environment-economy (3E) system impact. It also studies the stylized facts of the system, as well as cointegration and error correction dynamic analysis. The catastrophic shock is modeled as a two-state Markov switching process, but this method is not thorough enough to analyze the carbon emission results, resulting in ineffective analysis. Literature [11] discusses the impact of economic growth and trade openness on urbanization. Taking a large developing economy in India as an example, regression is used to simulate the impact of these variables on carbon emissions. The estimated coefficients of economic growth and energy consumption are positive, and significantly, sustainable and practical energy policies were explored, but the study did not forecast factors of production, leading to problems with the low accuracy of the research methodology. At present, most of the research on the low-carbon development of the economy by domestic and foreign researchers is mainly based on the low-carbon development model, and there are few studies on the correlation between the low-carbon economy and the development of the marine industry.

In response to the above problems, this paper deeply analyzes the correlation between the low-carbon economy and the development of the marine industry.

3. Empirical Analysis Method of Correlation between Low-Carbon Economy and Marine Industry Development

3.1. Decomposition Analysis Method of Carbon Emission Structure of Marine Industry Based on Input-Output Table. Based on the structural decomposition model of the input-output table, this paper decomposes the factors affecting carbon emissions of China's marine industry into direct carbon emissions, indirect carbon emissions, and carbon emissions of imported and exported products.

3.1.1. Decomposition Analysis of Direct Carbon Emission Structure. The calculation method of direct carbon emission is as follows:

$$P_1 = S \times F = [s_1 s_2 \cdots s_n] \times \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1m} \\ f_{21} & f_{22} & \cdots & f_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ f_{n1} & f_{n2} & \cdots & f_{nm} \end{bmatrix}, \tag{1}$$

in the publicity, S and F are the carbon emission coefficient matrix and energy consumption matrix of the marine industry in turn; $s_j \in s_n$ and $f_{ji} \in f_{nm}$ are the carbon emission coefficient of the j sector of the marine industry, followed by class I marine energy consumption of the j sector.

Use the Kaya deformation formula to decompose the structure of F, and the results are as follows:

$$F = FR \times \widehat{F}I \times \widehat{D}R \times Y, \tag{2}$$

in the formula, FR and $\widehat{F}I$ are the energy consumption structure matrix and energy intensity diagonal matrix of the marine industry in turn; $\widehat{D}R$ and Y is the diagonal matrix of marine industrial structure and the total output value of each department in the input-output table.

The decomposition method of direct carbon emission change is as follows:

$$\begin{aligned} \Delta P_1 = {} & \frac{1}{2} S \Delta Y \left(FR_0 * \widehat{F}I_0 * \widehat{D}R_0 + FR_1 * \widehat{F}I_1 * \widehat{D}R_1 \right) + \frac{1}{2} S \left(Y_1 * \Delta FR * \widehat{F}I_0 * \widehat{D}R_0 + Y_0 * \Delta FR * \widehat{F}I_1 * \widehat{D}R_1 \right) \\ & + \frac{1}{2} S \left(Y_1 * FR_1 * \Delta \widehat{F}I * \widehat{D}R_0 + Y_0 * \Delta FR_0 * \Delta \widehat{F}I * \widehat{D}R_1 \right) + \frac{1}{2} S \left(Y_0 * FR_0 * \Delta \widehat{F}I_0 + Y_1 * \Delta FR_0 * \Delta \widehat{F}I_0 \right) \widehat{D}R, \end{aligned} \tag{3}$$

in the formula, subscripts 0 and 1 represent the base period and reporting period, the same below. The total output effect is a; b. C is energy structure effect and energy intensity effect, respectively.

3.1.2. Decomposition Analysis of Indirect Carbon Emission Structure. The calculation method of indirect carbon emission is as follows:

$$P_2 = C' \times \hat{Y} \times DJ, \tag{4}$$

where C' is the transposition of all consumption coefficients in the input-output table; DJ is the carbon emission intensity value.

The structural decomposition method of indirect carbon emissions is as follows:

$$\Delta P_2 = \frac{1}{2}\Delta C'\left(\hat{Y}_1 * DJ_1 + Y_0 * DJ_0\right) + \frac{1}{2}\left(C_1' * \Delta Y * DJ_0 + C_0' * \Delta Y * DJ_1\right) + \frac{1}{2}\Delta\ DJ\left(C_1' * Y_1 + C_0' * Y_0\right). \tag{5}$$

Among them, the change in indirect carbon emission is $\Delta C'$; $\Delta\ DJ$ is the carbon emission intensity effect.

To sum up, the information on industry carbon emission components and influencing factors is shown in Table 1.

3.1.3. Decomposition Analysis of Carbon Emission Structure of Import and Export Products

(1) The calculation method of carbon emission of export products is as follows:

$$P_3 = H\ D\hat{J} * FYR * HFY, \tag{6}$$

in the formula, $H\ D\hat{J}$ is the diagonal matrix of complete carbon emission intensity of each sector; FYR is the column vector of export product structure of the marine industry, and HFY is the total export volume of the marine industry.

The decomposition formula of the change structure of export carbon emissions of the marine industry is as follows:

$$\Delta P_3 = \frac{1}{2}\Delta H\ D\hat{J}\left(FYR_0 * HFY_0 + FYR_1 * HFY_1\right) + \frac{1}{2}\left(H\ D\hat{J}_1 * \Delta FYR_0 * HFY_0 + H\ D\hat{J}_0 * \Delta FYR_0 * HFY_1\right) + \frac{1}{2}\left(H\ D\hat{J}_1 * FYR_1 + H\ D\hat{J}_0 * FYR_0\right). \tag{7}$$

The complete carbon emission intensity is $\Delta H\ D\hat{J}$; ΔFYR is the effect of the export product structure of the marine industry.

(2) The carbon emission calculation formula of imported products of the marine industry is as follows:

$$P_4 = H\ D\hat{J} * JNR * HJN, \tag{8}$$

JNR and HJN is the column vector and import volume of imported products of marine industry.

The structural decomposition method of import carbon emission change is as follows:

$$\Delta P_4 = \frac{1}{2}\Delta H\ D\hat{J}\left(JNR_0 * HJN_0 + JNR_1 * HJN_1\right) + \frac{1}{2}\left(H\ D\hat{J}_1 * \Delta FYR * HJN_0 + H\ D\hat{J}_0 * \Delta JNR * HJN_1\right) + \frac{1}{2}\left(H\ D\hat{J}_1 * JNR_1 + H\ D\hat{J}_0 * JNR_0\right)\Delta HJN. \tag{9}$$

The structure effect of imported products is ΔJNR.

The summary information of import and export factors is shown in Table 2.

3.2. Calculation of Total Factor Productivity of Marine Low-Carbon Economy. After analyzing the carbon emission structure of China's marine industry in Section 3.1, this section uses the measurement method of total factor productivity of the marine low-carbon economy. After the integrated development of the low-carbon economy and marine industry, the total factor productivity of marine low-carbon economy can reflect the technical structure after the integrated development of low-carbon economy and marine industry.

3.2.1. Research Methods. When evaluating the efficiency of marine low-carbon economy, in order to analyze the causes of productivity changes, the directional distance function is usually used to decompose the Malmquist-Luenberger productivity index into technical progress index and

Table 1: Information on industry carbon emission components and influencing factors.

Carbon emission type	Influencing factors (code)
Direct	Total output ($a1$)
	Energy-resource structure ($a2$)
	Energy intensity ($a3$)
	Industrial structure ($a4$)
Indirect	Complete consumption coefficient ($b1$)
	Sector output ($b2$)
	Carbon emission intensity ($b3$)

Table 2: Summary of import and export factors.

Carbon emission type	Influencing factors (code)
Export	Complete carbon emission intensity ($c1$)
	Export product structure ($c2$)
	Total exports ($c3$)
Import	Complete carbon emission intensity ($d1$)
	Structure of imported products ($d2$)
	Total imports ($d3$)

technical efficiency index so as to achieve the consistent change of "expected" output and "unexpected" output [12].

(1) Directional Distance Function. The core of the development of the marine low-carbon economy is to reduce carbon dioxide emissions (not belonging to the expected output) and increase marine economic benefits (belonging to the expected output) [13]. Undesired outputs can be described by directional distance function $\overline{E}_o$:

$$\overline{E}_o(H, Z, F, X, D; f) = \sup\{\alpha\colon\ (X, D) + \alpha f\}, \tag{10}$$

in the formula, H, Z, F, X, D and f are capital input, labor input, energy input, GDP, carbon dioxide emission, and direction vector in turn. The increase of X can increase the economic benefits of the marine industry, which belongs to the expected output. D is unexpected output; the bigger, the better. X and D all belong to outputs.

According to the variable size of unexpected parameters, the direction distance function must set the direction vector of difference. This paper analyzes the following two states:

State a: set the direction vector to $f = (X, 0)$ and do not analyze the role of unexpected output D. In this state, the binding force of carbon emission does not need to be analyzed.

State b: the direction vector is set to $f = (X, -D)$, and the unexpected output D has the characteristics of unexpected output. In this state, it is necessary to analyze the binding force of carbon emission.

If $\overline{E}_o$ value is 0, the production technology of the marine industry in this area is effective. Otherwise, the technology is invalid [14].

(2) Malmquist-Luenberger Productivity Index. Taking state B as an example, the productivity index is as follows:

$$\begin{aligned} N_t^{t+1} &= \left\{ \frac{1+\overline{E}_o^t(H^t, Z^t, F^t, X^t, D^t; X^t, -D^t)}{1+\overline{E}_o^t(H^{t+1}, Z^{t+1}, F^{t+1}, X^{t+1}, D^{t+1}; X^{t+1}, -D^{t+1})} \times \frac{1+\overline{E}_o^{t+1}(H^t, Z^t, F^t, X^t, D^t; X^t, -D^t)}{1+\overline{E}_o^{t+1}(H^{t+1}, Z^{t+1}, F^{t+1}, X^{t+1}, D^{t+1}; X^{t+1}, -D^{t+1})} \right\}^{1/2} \\ &= \frac{1+\overline{E}_o^t(H^t, Z^t, F^t, X^t, D^t; X^t, -D^t)}{1+\overline{E}_o^t(H^{t+1}, Z^{t+1}, F^{t+1}, X^{t+1}, D^{t+1}; X^{t+1}, -D^{t+1})} \times \left\{ \begin{array}{c} 1+\overline{E}_o^{t+1}(H^t, Z^t, F^t, X^t, D^t; X^t, -D^t) \\ 1+\overline{E}_o^t(H^t, Z^t, F^t, X^t, D^t; X^t, -D^t) \times \times \dfrac{1+\overline{E}_o^{t+1}(H^{t+1}, Z^{t+1}, F^{t+1}, X^{t+1}, D^{t+1}; X^{t+1}, -D^{t+1})}{1+\overline{E}_o^t(H^{t+1}, Z^{t+1}, F^{t+1}, X^{t+1}, D^{t+1}; X^{t+1}, -D^{t+1})} \end{array} \right\}^{1/2}, \end{aligned} \tag{11}$$

t stands for the period. Formula (2) is decomposed to obtain the technical efficiency index FE and technical progress index HF:

$$N_t^{t+1} = FE \times HF. \tag{12}$$

If the value of FE is greater than 1, the technical efficiency is higher, and if the value of FE is less than 1, the technical efficiency is lower. If the value of HF is greater than 1, the technological progress index is larger; if the value of HF is less than 1, the technological progress index is smaller.

3.2.2. Index Selection and Data Description. In order to fully evaluate the development of China's marine low-carbon economy, this paper uses the data of 11 coastal areas, Yangtze River Delta, Pearl River Delta, and Bohai Rim, from 2011 to 2020. The three input variables used in the empirical analysis are marine capital stock, marine employment, and marine economic energy consumption, and the two output variables are marine GDP and marine economic carbon emissions. The data are extracted from the China Ocean statistical yearbook.

(1) *Input Variable*

(a) Marine capital stock H

When calculating the total factor productivity of marine low-carbon economy, the paper adopts the capital factor input index. Because there is no statistical data on 14 coastal regions at present, this paper first calculates the overall implementation of each coastal region in China and then modifies the implementation of coastal regions according to the proportion of marine GDP in the GDP of coastal regions to obtain the final results.

(b) Labor input Z

Labor input is set as Z.

(c) Energy input F

Put F of marine economy in equation (10). Since energy consumption is one of the influencing factors of economic growth, its binding force is large. Because the energy consumption data of the marine economy cannot be extracted directly, according to the conversion coefficient of energy, this paper converts all kinds of energy in 14 coastal regions into standard coal to obtain the overall energy consumption of each region [15]. Finally, according to the proportion of marine GDP in the GDP of coastal areas, the needs F of the marine economy are calculated.

(2) *Output Variable*

(a) Gross marine product X

X of the coastal area belongs to the expected output, which can describe the marine economic output of each province in the coastal area [16].

(b) Carbon dioxide emissions D

The unexpected output in the development of marine economy in coastal areas is carbon dioxide emission D, which can describe the reduction value of ineffective loss of energy in the development of marine low-carbon economy [17]. Because the current carbon dioxide emission data of the marine economy is not in the statistical yearbook, this paper uses the Kaya equation to calculate D:

Table 3: Energy emissions coefficient.

Types of energy	Emission coefficient
Coal	0.7477
Petroleum	0.5826
Natural gas	0.4436
Hydropower and nuclear power	0

$$CO_2 = \frac{CO_2}{FM} \times \frac{FM}{G\ DP} \times \frac{G\ DP}{QOQ} \times QOQ = DC_i \times \widehat{F}I_i \times XY_i \times QP_i. \quad (13)$$

FM, $G\ DP$ and QOQ are primary energy consumption value, DC_i, $\widehat{F}I_i$, XY_i and QP_i are carbon dioxide emissions per unit of energy consumption, energy intensity, per capita GDP, and total population. Energy emission factors are shown in Table 3.

Because the influence of DC_i, $\widehat{F}I_i$, XY_i and QP_i on carbon dioxide emission is analyzed by calculus in the past, there will be an imbalance on both sides of the equation due to the influence of residuals. Therefore, this paper optimizes the Kaya equation and obtains the improved Kaya equation as follows:

$$\Delta CO_2 = \Delta CO_2(t) - \Delta CO_2(0) = DC_{af} + \widehat{F}I_{iaf} + XY_{af} + QP_{af}, \quad (14)$$

ΔCO_2 is the result of the overall change of carbon dioxide emissions after t years from year 0.

Such changes can continue to be decomposed into DC_{af}, $\widehat{F}I_{iaf}$, XY_{af} and QP_{af} which describe the action value of emission intensity effect, energy intensity effect, economic effect, and population effect.

(3) Decomposition of Total Factor Productivity of Marine Low-Carbon Economy. This paper assumes two kinds of situations: one is to calculate the total factor productivity HGQ of the conventional marine economy without analyzing carbon emissions and only analyzing the expected output. One is to analyze carbon emissions, set carbon dioxide as an unexpected output with weak disposability, and calculate the total factor productivity DHGQ in the marine low-carbon economy.

3.3. Correlation Analysis between Marine Industry Transformation and Upgrading and Low-Carbon Economy Based on Panel Data Model

3.3.1. Explained Variable Setting. Low carbon economy is inseparable from energy, but the development degree of a low-carbon economy cannot be judged simply by the total energy consumption [18]. In order to increase the persuasiveness of this analysis, this paper uses carbon emission intensity DJ as an index to judge the development degree of China's low-carbon economy. It can describe economic development and has significant practical economic significance. When DJ value is small, indicating that the emission per unit output is small and the economic development model is close to a low-carbon economy [19]. After calculating the coastal area ΔCO_2, the carbon emission intensity value can be obtained:

$$DJ = \frac{\Delta CO_2}{SK_{it}}, \quad (15)$$

SK_{it} is the real gross marine product.

3.3.2. Setting of Explanatory Variables. The explanatory variables are set as advanced marine industrial structure $E1$, rationality of marine industrial structure $E2$, and efficiency of marine industrial structure $E3$. When setting the detailed description mode of explanatory variables, this paper sets the natural logarithm $LnE1$, $LnE2$ and $LnE3$ of $E1$, $E2$ and $E3$ as the explanatory variable.

3.3.3. Model Construction. The model is constructed as follows:

$$DJ = \delta_1 LnE1 + \delta_2 LnE2 + \delta_3 LnE3 + \varepsilon_i + \gamma_{it}, \quad (16)$$

ε_i, γ_{it} is the unobservable effect and random error value. δ_1, δ_2 and δ_3 are the coefficients of $LnE1$, $LnE2$ and $LnE3$ in turn.

Carbon emission intensity is not only affected by the adjustment of marine industrial structure. In order to fully analyze the influence of other factors and take into account the subjectivity of the setting of control variables, equation (16) is optimized as follows:

$$DJ = \delta_1 LnE1 + \delta_2 LnE2 + \delta_3 LnE3 + \delta_4 (DJ \times LnE1) + \delta_5 (DJ \times LnE1) + \delta_6 (DJ \times LnE1) + \delta_7 DJ(-1)\varepsilon_i + \gamma_{it}, \quad (17)$$

δ_n is the coefficient of other factors.

3.3.4. Estimation Method Setting. When implementing the regression research of the panel data dynamic model, this paper uses the differential generalized moment estimation method to deal with the endogenous problem of the dynamic model and avoid the error of the fixed-effect estimator [20]. In this paper, the residual sequence obtained by estimation is detected by autocorrelation to judge whether the random error term has a second-order sequence correlation problem so as to evaluate the rationality of the result of differential generalized moment estimation [21].

4. Results

4.1. Decomposition Analysis Results of China's Carbon Emission Structure. The decomposition analysis results of the direct carbon emission structure of China's marine industry are shown in Table 4.

Table 4: Decomposition analysis results of direct carbon emission structure.

Influence factor	Contribution value (10000 tons of carbon)	Contribution rate (%)
$a1$	105627.25	286.7
$a2$	−2597.09	−6.86
$a3$	−48832.68	−128.9
$a4$	−16151.18	−48.7
Direct carbon emission change	37913.59	100

According to the data in the analysis table, the output and change of each department of the marine industry can promote the change in direct carbon emissions, with a contribution rate of 286.7%. The change of energy structure, energy intensity, and industrial structure can curb the change of direct carbon emissions of the marine industry, with a contribution rate of −6.86%, −128.9%, and −48.7%. Because of this, the output and drive of each department of the marine industry can lead to an increase in direct carbon emissions. The change in energy intensity and industrial structure can control the increase of carbon emissions. The energy consumption structure has no significant effect on the change in carbon emissions. The optimization of low-carbon energy technology and the increase of energy utilization can effectively control the direct carbon emission without increasing it. The adjustment of industrial structure is the core entrance to reducing the direct carbon emission.

The decomposition analysis results of indirect carbon emission structure of the marine industry are shown in Table 5.

According to the data in the analysis table, the changes in output effect and complete consumption coefficient effect of the marine industry sector can promote the changes in indirect carbon emission, with a contribution rate of 181.6% and 43.4%, and the contribution rate of carbon emission intensity effect is - 125.4%, which has a restraining effect. If the output effect and complete consumption coefficient effect of the marine industry sector become larger, the indirect carbon emission will become larger.

The change decomposition results of influencing factors of carbon emission from import and export products of the marine industry are shown in Tables 6 and 7.

It can be seen from Table 6 that the change in carbon emission intensity is the core factor among the influencing factors of carbon emission of marine industry export products, and its contribution rate is as high as 108.4%. The change in export product structure and total export volume has little effect on the carbon emission of marine industry export products. The utility of export product structure can promote the carbon emission of export products. If there are more export products, the carbon emissions will increase, and the total export effect of the marine industry does not promote the carbon emissions of export products.

According to the analysis of Table 7, the change in carbon emission intensity and the change in import structure of the marine industry have a positive effect on the carbon emission of imported products, with a contribution rate of 379% and 83.4%, respectively. The total import effect of the marine industry has a restraining effect on the carbon emission of imported products, with the contribution rate of −361.4%

4.2. Calculation Results of Total Factor Productivity of Marine Low-Carbon Economy. Table 8 shows the analysis results of HGQ and DHGQ indexes of the marine low-carbon economy.

Based on the analysis from the national perspective, without analyzing carbon emissions, the HGQ index of China's traditional marine economy is 1.046, representing the average annual growth of the HGQ index from 2011 to 2020 is 46%, and the contribution rate of technological progress is 6.0%. This shows that the HGQ index increases

Table 5: Decomposition analysis results of indirect carbon emission structure of the marine industry.

Influence factor	Contribution value (10000 tons of carbon)	Contribution rate (%)
$b1$	404408.6	181.6
$b2$	87272.9	43.4
$b3$	−245966	−125.4
Indirect carbon emission change	245716.5	100

Table 6: Decomposition results of influencing factors of carbon emission of marine industry export products.

Influence factor	Contribution value (10000 tons of carbon)	Contribution rate (%)
$c1$	−38499.6	108.4
$c2$	−13073.5	36.9
$c3$	16016.5	−46
Export carbon emission change	−35556.7	100

mainly due to the increase in the technological progress rate.

Under the condition of analyzing carbon emissions, the average annual growth of the DHGQ index from 2011 to 2020 is 1.021, which is less than the HGQ index without analyzing carbon emissions, which means that the calculation results of the traditional HGQ index are not in line with the actual marine economic efficiency. In the DHGQ index, the contribution rate of the technological progress index is 2.4%. Therefore, after analyzing the carbon emission conditions, the contribution rate of the technological progress index decreases rapidly, so in the low-carbon economy, the contribution rate of the technological progress index decreases, and the technology needs to be optimized.

Table 9 shows the decomposition results of total factor productivity of marine low-carbon economy in coastal areas.

Based on the analysis from the regional perspective, the HGQ index of coastal areas except Liaoning has positive growth (the index is greater than 1) without analyzing carbon emissions. Under the condition of analyzing carbon emission, the provinces with negative growth of DHGQ index (index less than 1) are Liaoning, Hebei, Shandong, Guangxi, and Bohai Rim. The marine industrial structure of such provinces has obvious "2, 3, and 1" structural characteristics and the high-carbon consumption level of marine chemical industry and coastal industry in the secondary industry is high, which obviously interferes with the development of marine low-carbon economy in their respective provinces. After analyzing the carbon emission conditions, the total factor productivity of the marine low-carbon economy in Jiangsu Province becomes smaller and larger, which means that the cost of resources and the environment becomes more, and the growth rate of technological progress and technical efficiency also becomes significantly smaller during the economic development of Jiangsu Province. The increase in total factor productivity of the marine low-carbon economy in Zhejiang and Guangdong is mainly due to the synchronous growth of technical efficiency and technological progress. However, the technological changes in Tianjin and Fujian are small because the growth rate of technological progress is also lower. The increase in the total factor productivity of the marine low-carbon economy in Shanghai is more obvious. The total factor productivity of the marine low-carbon economy in the Bohai Rim region has negative growth. After analyzing the carbon emission constraints, there is no obvious difference in the change in technical efficiency in each province and city, but the change in the technological progress index is more significant in Hebei, Shandong, and Hainan. Without analyzing the constraints of carbon emissions, the technological progress index is not less than 1, but under the constraints of carbon emissions, the technological progress index is not more than 1, which means that there is no increase but a decrease in cutting-edge technologies. The governments of such provinces must pay attention to this problem and improve low-carbon technologies in order to realize the sustainable development of the marine low-carbon economy.

Table 7: Change decomposition results of influencing factors of carbon emission of imported products of the marine industry.

Influence factor	Contribution value (10000 tons of carbon)	Contribution rate (%)
$d1$	−35848.2	379
$d2$	−7895.6	83.4
$d3$	34260.4	−361.4
Import carbon emission change	−9482.8	100

Table 8: Analysis results of HGQ and DHGQ indexes of marine low-carbon economy.

Time	Do not analyze carbon emission constraints			Analyze carbon emission constraints		
	HGQ	FE	HF	DHGQ	FE	HF
2011~2012	1.030	0.989	1.043	1.032	1.002	1.073
2012~2013	1.079	1.020	1.059	1.040	1.009	1.031
2013~2014	1.090	0.936	1.165	1.070	0.997	1.023
2014~2015	1.085	1.024	1.060	1.064	1.004	1.065
2015~2016	1.038	0.984	1.056	1.040	0.999	1.061
2016~2017	1.060	0.991	1.071	1.012	0.992	1.042
2017~2018	0.984	0.962	1.024	0.958	0.991	1.021
2018~2019	1.074	0.994	1.081	1.045	1.006	0.968
2019~2020	0.974	0.989	0.986	0.931	1.005	0.928
Mean value	1.046	0.988	1.060	1.021	1.000	1.024

4.3. Results of Correlation Analysis between Transformation and Upgrading of Marine Industry and Low-Carbon Economy

4.3.1. Stability Test and Cointegration Test of Panel Data. Before regression analysis, the unit root test is performed on the panel data through the unit root test method and the PP Fisher test method. This operation can prevent the

Table 9: Decomposition results of total factor productivity of marine low-carbon economy in coastal 14 areas.

Region	Do not analyze carbon emission constraints			Analyze carbon emission constraints		
	HGQ	FE	HF	DHGQ	FE	HF
Tianjin	1.056	0.986	1.072	1.035	0.996	1.040
Hebei	1.009	0.972	1.039	0.995	1.016	0.981
Liaoning	0.992	0.938	1.058	0.945	0.996	0.950
Shanghai	1.104	1.001	1.104	1.080	1.001	1.080
Jiangsu	1.075	1.003	1.072	1.032	1.001	1.032
Zhejiang	1.049	1.000	1.030	1.050	1.007	1.044
Fujian	1.044	0.987	1.058	1.029	0.990	1.040
Shandong	1.022	0.976	1.048	0.991	1.001	0.991
Guangdong	1.045	1.002	1.053	1.049	1.002	1.068
Guangxi	1.013	0.974	1.041	0.992	0.981	1.012
Hainan	1.055	1.014	1.040	1.012	1.013	0.998
Changjiang delta	1.086	1.005	1.082	1.054	1.003	1.048
Pearl river delta	1.042	0.994	1.048	1.030	0.997	1.012
Circum Bohai sea	1.020	0.968	1.054	0.992	1.002	0.998
Mean value	1.047	0.988	1.060	1.020	1.000	1.020

occurrence of pseudoregression problems. The test results are shown in Table 10.

In Table 10, DJ, LnE1, LnE2, and LnE3 all belong to zero order single integration and meet the cointegration test standard.

The panel cointegration test was performed using the Kao test method, and the results are shown in Table 11.

In Table 11, there is no abnormality in the cointegration test of DJ, LnE1, LnE2, and LnE3.

4.3.2. Regression Result Analysis. Table 12 shows the regression results of the impact of marine industrial structure adjustment on a low-carbon economy.

In Table 12, model 1 is a static model, and only the regression results of LnE1, LnE2, and LnE3 are given. According to the Hausman test results, the fixed-effect model is selected for regression analysis. In order to judge the stability of model 1, model 2 introduces control variables and AR model. Model 3 is a dynamic model. According to the exogenous test results, the use of tool variables is effective. According to the autocorrelation test results of residual sequence in Table 13, the difference in generalized moment estimation does not reject the original hypothesis and meets the consistency condition, so the result of the difference generalized moment estimation is reasonable.

The regression results show that the explanatory variables are different in the static model and dynamic model, which indicates that the adjustment of China's marine industrial structure has an impact on the low-carbon development of the marine economy to a certain extent. LnE1, LnE2, LnE3, and DJ all have a negative correlation, which means that the more significant the efficiency and efficiency level of marine industrial structure, the lower the carbon emission intensity. The higher the development level of marine industrial structure, the faster the development of marine service industry and high-tech industry, which

Table 10: Unit root test.

Variable	Unit root test	PP Fisher test	Stable?
DJ	0.0000	0.0002	Yes
LnE1	0.0000	0.0000	Yes
LnE2	0.0000	0.0004	Yes
LnE3	0.0458	0.0000	Yes

Table 11: Panel cointegration test results.

Inspection method	Unit root
T statistic	−2.638
P value	0.0043

improves the level of economic development, the proportion of low-energy consumption industry, and the development of the low-carbon economy. Due to the improvement of scientific and technological level, the advanced level of machinery and equipment has also been improved. Under these conditions, the social labor productivity increases, the resource allocation efficiency of the marine industry increases, and the industrial resources will develop into high-efficiency departments in low-efficiency departments. Energy resources belong to industrial resources, and the utilization rate of energy resources can also be increased.

LnE2 and DJ have a positive correlation, which means that the greater the rationality of marine industrial structure, the smaller the carbon emission intensity, which has a positive impact on the development of a low-carbon economy. China's resource consumption is large, and the traditional extensive development model of the marine economy has not been completely abandoned. In the energy consumption of the marine industry, traditional energy accounts for a large proportion. Even though our government has used many methods to reduce the pressure of carbon emission, the total amount of carbon emission continues to increase. Therefore, while ensuring the stable growth of the marine economy, high-tech industries with low-energy consumption also need to develop rapidly, reduce carbon emissions and complete the development of a low-carbon economy.

By analyzing the values of LnE1, LnE2, and LnE3-coefficients, it can be seen that in the static model, the efficiency of marine industrial structure has a positive effect on carbon emission intensity. In the dynamic model, the efficiency of the industrial structure has a significant positive effect on carbon emission intensity. The "3, 2, 1" structure of the marine industry is more suitable for the development of the low-carbon economy.

By analyzing the meaning of LnE1, LnE2, and LnE3 coefficients, it can be seen that the elastic coefficients of the advanced, reasonable, and efficient level of marine industrial structure on carbon emission intensity are 1.019, 0.796, and 0.842, respectively. When the advanced level of marine industrial structure increases by 1%, the carbon emission intensity decreases by 1.019 units, and when the rationality level of marine industrial structure increases by 1%, the carbon emission level decreases by 0.842 units. Then the high-level degree of marine industrial structure has the most

Table 12: Regression results of the impact of marine industrial structure adjustment on low-carbon economy.

Explanatory variable	Model 1	Model 2	Model 3
D	4.663*** (0.27)	2.599*** (0.178)	
LnE1	−0.656*** (0.098)	−0.248*** (0.088)	−1.019*** (0.287)
LnE2	0.225*** (0.082)	0.494*** (0.058)	0.796** (0.322)
LnE3	−0.662*** (0.082)	−0.566*** (0.067)	−0.842*** (0.206)
DJ ∗ LnE1		0.126*** (0.037)	0.363*** (0.182)
DJ ∗ LnE2		−0.215** (0.033)	−0.247*** (0.093)
DJ ∗ LnE3		0.198*** (0.022)	0.174* (0.092)
AR(1)		0.951 (0.001)	
AR(2)		−0.164(0.112)	
DJ(−2)			0.137* (0.074)
Exogenous test observations	89	67	67

Note: ***, **, and * describe the inspection degree of 1%, 5%, and 10% in turn, with significance. The values in the brackets of regression coefficient belong to standard error, and the values in the brackets of AR and Sagan test results are p values.

significant interference on the low-carbon economy, the second significant degree of rationality of marine industrial structure, and the least obvious effect of high-efficiency of marine industrial structure.

Table 13: Autocorrelation test results of residual series.

Variable	AR(1)	AR(2)
Coefficient	1.843	8.248
Prob.	0.0656	0.0000

5. Discussion

Under the influence of a marine low-carbon economy, China needs to keep pace with the times. Under the development mode of a low-carbon economy, we should set up appropriate strategies, give full play to our advantages, and achieve rapid economic development and low-carbon integration. Moreover, "low-carbon" must be placed in the national development strategy. It is necessary to set the marine low-carbon economy as the strategic core and balance the development of sea and land. In the existing research, all focus on the marine industry, analyze the structure of the industry, the enterprise level, the product level, etc., and the analysis of the low-carbon economy is not deep enough, which leads to limitations in the conclusions drawn by the research. For example, the research mainly focuses on relevant theories. In terms of the analysis of China's marine economy and the discussion of the low-carbon development model of the marine economy, there are few studies on the correlation between the marine industry and the low-carbon level of the marine economy. Quantitative analysis of the contribution rate of the marine industry to economic growth, using grey correlation analysis method to measure and empirically analyze the low carbonization level of marine industry clusters and marine economy. There is less analysis of the carbon economy. Compared with the existing research, the research in this paper is more comprehensive and specific, and it has carried out an in-depth analysis of the low-carbon economy, and at the same time, it has given specific development suggestions. Specific recommendations are as follows:

(1) With the goal of sustainable development and under the construction of marine low-carbon civilization, the overall planning of sea and land will be set as the development path. In detail, we need to set the scientific outlook on development as the value core of marine low-carbon economic development, take sustainable development as the goal, and realize the integrated development of the sea and land economy. The ocean and path are inseparable. The overall planning of sea and land is mainly to realize the unified planning of sea and land industrial development, sea and land infrastructure construction, sea and land environmental management, and the allocation of sea and land production factors.

(2) Set China's basic national policies as resource conservation and environmental protection. Under the guidance of the development objectives of China's marine development plan, set up the development strategy of marine low-carbon economy, and take the development of the marine low-carbon economy as one of the hot issues concerned by the country. Based on the perspective of sustainable development, we should set up the development path of a marine low-carbon economy and obtain the path of combining a low-carbon economy with a national development strategy.

(3) We will focus on energy conservation and emission reduction in the development of a marine low-carbon economy and include the development and use of Shanghai Ocean renewable resources in China's marine energy development and construction plan. The last resource treasure house of the Earth is the ocean. Based on the analysis of technical and economic feasibility, tidal energy in marine energy can obtain very valuable returns through mature technology. Both marine wind energy and tidal energy are very important.

(4) Establish a marine low-carbon economy demonstration area. In order to promote the development of a marine low-carbon economy, a marine low-carbon economy demonstration zone can be established so as to further adjust industrial structure

and optimize the economic development model. We should also strengthen the management of pollutants discharged into the sea, protect marine ecological security, and realize the double progress of marine environmental protection and economic development under the influence of marine low-carbon economy demonstration areas.

6. Conclusion

After the empirical analysis of the correlation between a low-carbon economy and the development of the marine industry, this paper mainly draws the following conclusions:

(1) The optimization of low-carbon energy technology and the increase of energy utilization can effectively control the direct carbon emissions without increasing them. The adjustment of industrial structure is the core entrance to reducing direct carbon emissions. The output effect and complete consumption coefficient effect of the marine industry sector become larger and the change in import and export carbon emission intensity is the core factor in the influencing factors of carbon emission of export products.

(2) In a low-carbon economy, the contribution rate of the technological progress index becomes smaller, and technology needs to be optimized. Provinces with a low total factor productivity index of the marine low-carbon economy must improve low-carbon technology in order to realize the sustainable development of the marine low-carbon economy.

(3) The higher the efficiency level of marine industrial structure, the lower the carbon emission intensity; The greater the rationality of marine industrial structure, the smaller the carbon emission intensity. The high degree of marine industrial structure has the most significant interference on the low-carbon economy, the rationality of marine industrial structure is significant, and the high efficiency of marine industrial structure is the least significant.

(4) This paper fully analyzes the decomposition results of China's carbon emission structure, calculates the total factor productivity of the marine low-carbon economy, and fully confirms the correlation between the transformation and upgrading of the marine industry and the low-carbon economy.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This paper was supported byShandong Province Natural Science Foundation Subject (ZR2020MG070): Research on the Perfect Eco-compensation Mechanism of Marine Oil and Gas Resources Development-Take Shandong Province in China as an Example.

References

[1] I. Mafruhah, S. Supriyono, N. S. Mulyani, and N. Istiqomah, "Causality between tourism industry development and the ecological sustainability in marine environment: a convergence and divergence among stakeholder with mactor analysis," *International Journal of Energy Economics and Policy*, vol. 10, no. 4, pp. 85–92, 2020.

[2] L. Airoldi, M. W. Beck, and L. B. Firth, "Emerging solutions to return nature to the urban ocean," *Annual Review of Marine Science*, vol. 13, no. 1, pp. 1–33, 2020.

[3] K. Kijima, S. Novani, S. Novani, R. Widiana, Y. Palumian, and C. Cintyawati, "What influences tourist' visit decision to coastal area? A lesson learned from southern beaches of west java," *The Asian Journal of Technology Management*, vol. 13, no. 1, pp. 63–81, 2020.

[4] Y. Li, X. Yang, Q. Ran, H. Irfan, M. Ahmad, and M. au, "Energy structure, digital economy, and carbon emissions: evidence from China," *Environmental Science and Pollution Research*, vol. 28, no. 45, pp. 64606–64629, 2021.

[5] L.-F. Chen, "Green certification, e-commerce, and low-carbon economy for international tourist hotels," *Environmental Science and Pollution Research*, vol. 26, no. 18, pp. 17965–17973, 2019.

[6] W. Wu, "Modern urban planning and design based on low carbon economy concept," *Open House International*, vol. 44, no. 3, pp. 108–111, 2019.

[7] D. R. Lugo-Morin, "Global future: low-carbon economy or high-carbon economy?" *World*, vol. 2, no. 2, pp. 175–193, 2021.

[8] N. Keough and G. Ghitter, "Pathways to sustainable low-carbon transitions in an auto-dependent Canadian city," *Sustainability Science*, vol. 15, no. 1, pp. 203–217, 2020.

[9] T. Peng and H. Deng, "Research on the sustainable development process of low-carbon pilot cities: the case study of Guiyang, a low-carbon pilot city in south-west China," *Environment, Development and Sustainability*, vol. 23, no. 2, pp. 2382–2403, 2021.

[10] S. Zhang, T. Hu, J. Li et al., "The effects of energy price, technology, and disaster shocks on China's Energy-Environment-Economy system," *Journal of Cleaner Production*, vol. 207, no. 1-1180, pp. 204–213, 2019.

[11] S. Basu, M. Roy, and P. Pal, "Exploring the impact of economic growth, trade openness and urbanization with evidence from a large developing economy of India towards a sustainable and practical energy policy," *Clean Technologies and Environmental Policy*, vol. 22, no. 4, pp. 877–891, 2020.

[12] X. J. Du, F. J. Shao, and R. C. Sun, "Simulation study on eutrophication assessment of marine water," *Computer Simulation*, vol. 036, no. 005, pp. 377–380, 2019.

[13] J. Xu, Q. Feng, C. Lv, and Q. Huang, "Low-carbon electricity generation-based dynamic equilibrium strategy for carbon dioxide emissions reduction in the coal-fired power enterprise," *Environmental Science and Pollution Research*, vol. 26, no. 36, pp. 36732–36753, 2019.

[14] X. Teng, L. C. Lu, and Y.-H. Chiu, "Energy and emission reduction efficiency of China's industry sector: a non-radial directional distance function analysis," *Carbon Management*, vol. 10, no. 4, pp. 333–347, 2019.

[15] B. Chen, C. Wu, X. Liu et al., "Seasonal climatic effects and feedbacks of anthropogenic heat release due to global energy consumption with CAM5," *Climate Dynamics*, vol. 52, no. 11, pp. 6377–6390, 2019.

[16] J. Tian, Q. Xia, and P. Wang, "Comprehensive management and coordination mechanism of marine economy," *Mathematical Problems in Engineering*, vol. 2021, no. 5, 9 pages, Article ID 6616412, 2021.

[17] C. Kesarat and I. Rinthaisong, "Structural equation model of conflict management between the government and citizens regarding marine and coastal areas development projects in southernmost provinces of Thailand," *Kasetsart Journal - Social Sciences*, vol. 40, no. 3, pp. 727–734, 2019.

[18] H. Xiao, Z. Ma, P. Zhang, and M. Liu, "Study of the impact of energy consumption structure on carbon emission intensity in China from the perspective of spatial effects," *Natural Hazards*, vol. 99, no. 3, pp. 1365–1380, 2019.

[19] K. U. Ehigiamusoe and H. H. Lean, "Effects of energy consumption, economic growth, and financial development on carbon emissions: evidence from heterogeneous income groups," *Environmental Science and Pollution Research*, vol. 26, no. 22, pp. 22611–22624, 2019.

[20] S.-S. Jiang and J.-M. Li, "Do political promotion incentive and fiscal incentive of local governments matter for the marine environmental pollution? Evidence from China's coastal areas," *Marine Policy*, vol. 128, no. 2, Article ID 104505, 2021.

[21] W. Hua, D. Li, H. Sun, and P. Matthews, "Stackelberg game-theoretic model for low carbon energy market scheduling," *IET Smart Grid*, vol. 3, no. 1, pp. 31–41, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1252885, 8 pages
https://doi.org/10.1155/2022/1252885

Research Article

The Characterization of Substructures of c-Anti Fuzzy Subgroups with Application in Genetics

Kalaichelvan Kalaiarasi,[1] **P. Sudha**,[1] **Nasreen Kausar**,[2] **Sajida Kousar**,[3] **Dragan Pamucar**,[4] **and Nasr Al Din Ide**[5]

[1]*Research Department of Mathematics, Cauvery College for Women (Affiliated to Bharathidasan University), Tiruchirappalli 620018, Tamil Nadu, India*
[2]*Department of Mathematics, Faculty of Arts and Science, Yildiz Technical University, Esenler, Istanbul 34210, Turkey*
[3]*Department of Mathematics & Statistics, Faculty of Basic and Applied Sciences, International Islamic University Islamabad, Islamabad, Pakistan*
[4]*Faculty of Organizational Sciences, University of Belgrade, Belgrade, Serbia*
[5]*Department of Mathematics, University of Aleppo, Aleppo, Syria*

Correspondence should be addressed to Nasr Al Din Ide; ide1112002@yahoo.ca

Received 12 May 2022; Revised 7 June 2022; Accepted 21 June 2022; Published 15 July 2022

Academic Editor: Lele Qin

Fuzzy and anti fuzzy normal subgroups are the current instrument for dealing with ambiguity in various decision-making challenges. This article discusses γ-anti fuzzy normal subgroups and γ-fuzzy normal subgroups. Set-theoretic properties of union and intersection are examined and it is observed that union and intersection of γ-anti fuzzy normal subgroups are γ-anti fuzzy normal subgroups. Employee selection impacts the input quality of employees and hence plays an important part in human resource management. The cost of a group is established in proportion to the fuzzy multisets of a fuzzy multigroup. It was a good idea to introduce anti-intuitionistic fuzzy sets and anti-intuitionistic fuzzy subgroups, as well as to demonstrate some of their algebraic features. Product of γ-anti fuzzy normal subgroups and γ-fuzzy normal subgroups is defined, the product's algebraic nature is analyzed, and the findings are supported by presenting γ-anti typical sections with blurring and γ-ordinary parts with the weirdness of well-defined and well-established groups of genetic codes.

1. Introduction

The algebraic theory contains various applications not only in theocratical and applied mathematics such as algebraic geometry, cryptography, game theory, and harmonic analysis but also in other scientific fields like physics, genetics, and engineering. The algebraic structures are conventionally defined on a nonempty set by employing binary operations. The simplest among them is groupoid, precisely a non-vain set endowed with a bipartite action. With the inclusions of different properties, the groupoid can be transformed into semigroup and monoid group. The group is a central algebraic structure and serves as a baseline for various algebraic structures such as ring, field, vector space, and module. Significate research has been carried out for deep analysis of algebraic properties and applications ranging from mathematics to DNA structure, cars moving on the road to aircraft flying in the air, and wristwatches to complicated computing systems. Uncertainty, imprecision, and ambiguity are the common factors associated with real-life decision-making problems or any kind of experimental data. The classical probability theory is sometimes not enough to handle all such cases. In 1965, Zadeh [1] laid the notation of blurry place as an ideal framework to incorporate the uncertainty fragment in logic. The set is formalized by defining a map called membership responsibility through a nonempty set to the interval $[0, 1]$, where the images of elements under this function are called degree or grade of membership. The

concept was so inspiring that it grabbed the attention of researchers from every field of knowledge. Several new theories are established parallel to the classical ones by considering the fuzzy sets and logic.

Rosenfeld [2] sought to incorporate fuzzy ideas in group theory in 1970 and labeled the results as a fuzzy subgroup. Rosenfeld looked at the basic group theocratic aspects of the newly discovered algebra. Algebraists later studied the structural features of fuzzy subgroups. Anthony [3, 4] refined Rosenfeld's concept by enhancing the need for pictures of elements and their inverses. They are less expensive to design, cover a broader variety of operating situations, and are more easily adaptable to plain language concepts. Fuzzification is the process of transforming a crisp input value into a fuzzy value through the application of knowledge base information. Zadeh relates the ordinary sets and fuzzy sets using level sets. Level sets are seen in fuzzy groups, and it is demonstrated that a flexible selection of a subgroup G is a hazy subgroup if and only if all of the applied principles are constituents G (see [5, 6]). Liu [7] established flexible resilient parts and fuzzy ideals in 1982. Mukherjee et al. [8–10] suggested an association connecting fuzzy normal subgroups, fuzzy cosets, and group-theoretic analogs. Kumar et al. [11] solved the problems of sensitive ordinary groupings and flexible quotients. Tarnauceanu [12] also introduced the idea of curved typical counterparts for the group of limited groups. Choudhary et al. and Addis [13, 14] explored feature sustaining bridges and elementary presented in this research theorems. Malik et al. [15] and Mishref [16] developed fuzzy normal series to enhance the theory of group nilpotency and solubility.

An intuitionistic blurry set [17] is an induction of an unclear set endowed with two functions from a nonempty adjust to the interval $[0, 1]$ known as membership and non-integration function. The idea is not identical to the occurrence and non-occurrence of an event in classical probability theory as in this case the quantity of the grades of integration and non-integration could be real in any number between 0 and 1. In 2017, Al-Husban et al. [18] described a complex intuitionistic fuzzy normal subgroup. As defined by Rosenfeld, a blurry subdivision of a category G is a blurry subdivision if the degree of membership of the product of two elements is greater than or equal to the minimum of their individual degrees. The replacement of minimum by maximum defines a new type of fuzzy-subgroups called anti fuzzy subgroups [19]. Onasanya [20] investigated existing fuzzy group-theoretic properties for anti fuzzy subgroups. α-anti blurry subdivisions and α-blurry subdivisions are depicted by Sharma [21, 22]. Shuaib et al. [23, 24] manifested some characterizations and properties of o-fuzzy subgroups.

Most recently, several generalizations of fuzzy sets and subgroups [25–31] are developed not only for the sake of new algebraic structures but also to utilize them for wide range of applications [32–34]. Advancements in fuzzy sets are introduced mainly in search of a better and more efficient tool to deal with uncertainties more accurately and effectively. Ultimately algebraic structures are also upgraded but conducting analysis in the generalized fuzzy environment. In this article, the authors aim to study group theocratic concepts in an advanced manner by employing the impulse of γ-anti blurry sets. Normal subgroups and their analytic behavior are examined; also group homomorphisms are used to define fuzzy extension rules.

2. Preliminaries

Definition 1 (see [14]). A fuzzy set constructed from either a nonempty set A is a technique η: $A \longrightarrow [0, 1]$.

Definition 2 (see [14]). A grouping $(L, \star)$ is a semiset L minus a discrete activity L that meets the following properties:

(i) *Closure*. for all $a, b \in L$, the element $a \star b$ is a uniquely defined element of L

(ii) *Associativity*. We have $a \star (b \star c) = (a \star b) \star c$ for every $a, b, c \in L$

(iii) *Identity*. for any $a \in L$, there exists an identity element e such that $e \star a = a$ and $a \star e = a$

(iv) *Inverse*. There exists an inverse element $a^{-1} \in L$ for each $a \in L$ such that $a \star a^{-1} = e$ and $a^{-1} \star a = e$

Definition 3 (see [19]). Assume M is a fuzzy subset (FSS) of a group L. Then, M is a fuzzy subgroup (FSG) if $M(a^{-1}b) \geq \min\{A(a), A(b)\}$ for all $a, b \in L$ where $A(a), A(b)$ are fuzzy membership functions.

Definition 4 (see [21]). Assume M is a FSS of a group L. Then, M is an AFSG (anti fuzzy subgroup) if $M(a^{-1}b) \leq \max\{A(a), A(b)\}$, for all $a, b \in L$ where $A(a), A(b)$ are fuzzy membership functions.

Definition 5 (see [32]). A function t^*: $[0, 1] \times [0, 1] \longrightarrow [0, 1]$ is said to be a t-conorm on $[0, 1]$ if and only if t^* satisfies the following properties for all $u, v, w, s \in [0, 1]$:

(i) $t^*(u, v) = t^*(v, u)$

(ii) $t^*(u, t^*(v, w)) = t^*(t^*(u, v), w)$

(iii) $t^*(u, 0) = t^*(0, u) = u, t^*(1, 1) = 1$

(iv) If $u \leq w$ and $v \leq s$ then $t^*(u, v) \leq t^*(w, s)$

Definition 6 (see [32]). Let S_p: $[0, 1] \times [0, 1] \longrightarrow [0, 1]$ be the algebraic sum t-conorm on $[0, 1]$, then it is defined by $S_p(a, b) = a + b - ab, \quad 0 \leq a \leq 1, 0 \leq b \leq 1$.

Tuning is the most laborious and tedious part of building a fuzzy system. It often involves adjusting existing fuzzy sets and fuzzy rules. With appropriate examples, the composition of the fuzzy relations is described in two ways: max-min composition and max-product composition. This study also introduces the composition features of fuzzy relations.

3. γ-Anti FSS (γ AFSS) and Their Attributes

This section deals with the definition of γ-anti fuzzy subset and some results based on this definition.

Definition 7 (see [3]). Let M be a nonempty set and H be an FSS of M and $\gamma \in [0,1]$. Then, the FSS is called the γ-anti FSS (γ AFSS) of M if

$$H_\gamma(a) = S_p\{H(a), 1-\gamma\}, \quad \text{for all } a \in M. \tag{1}$$

Remark 1

(i)

$$\begin{aligned} H_1(a) &= S_p\{H(a), 1-1\} \\ &= H(a) - H(a)\cdot(0) \\ &= H(a). \end{aligned} \tag{2}$$

(ii)

$$\begin{aligned} H_0(a) &= S_p\{H(a), 1-0\} \\ &= S_p\{H(a), 1\} \\ &= H(a) + 1 - H(a)\cdot 1 \\ &= 1. \end{aligned} \tag{3}$$

Theorem 1. *Let H and K be two arbitrary FSS of M. Then,*

(i) $(H \cup K)_\gamma = H_\gamma \cup K_\gamma$

(ii) $(H \cap K)_\gamma = H_\gamma \cap K_\gamma$

Proof. Consider

(i)

$$\begin{aligned} (H\cup K)_\gamma(a) &= S_p\{(H\cup K)(a), 1-\gamma\} \\ &= S_p\{\max\{H(a), K(a)\}, 1-\gamma\} \\ &= \max\{S_p\{H(a), 1-\gamma\}, S_p\{K(a), 1-\gamma\}\} \\ &= \max\{H_\gamma(a), K_\gamma(a)\} \\ &= H_\gamma(a) \cup K_\gamma(a), \quad \text{for all } a \in M \\ &= (H_\gamma \cup K_\gamma)(a). \end{aligned} \tag{4}$$

Hence, we have

$$(H\cup K)_\gamma(a) = (H_\gamma \cup K_\gamma)(a). \tag{5}$$

(ii)

$$\begin{aligned} (H\cap K)_\gamma(a) &= S_p\{(H\cap K)(a), 1-\gamma\} \\ &= S_p\{\min\{H(a), K(a)\}, 1-\gamma\} \\ &= \min\{S_p\{H(a), 1-\gamma\}, S_p\{K(a), 1-\gamma\}\} \\ &= \min\{H_\gamma(a), K_\gamma(a)\} \\ &= H_\gamma(a) \cap K_\gamma(a), \quad \text{for all } a \in M \\ &= (H_\gamma \cap K_\gamma)(a). \end{aligned} \tag{6}$$

Hence, we have

$$(H\cap K)_\gamma(a) = (H_\gamma \cap K_\gamma)(a). \tag{7}$$

□

Definition 8. Suppose $f: M \longrightarrow N$ be a category M to column N component. If H and K are flexible sections (FSS) of M and N, alternately, then $f(H)$ and $f^{-1}(K)$ are now the portrait of soft set H and the inverse image of fuzzy rules K, respectively, defined as

$$f(H)(b) = \begin{cases} \operatorname{Sup}\{H(a): a \in f^{-1}(b)\}; & \text{iff}^{-1}(b) \neq \phi, \\ 1; & \text{iff}^{-1}(b) = \phi, \end{cases} \tag{8}$$

for every $b \in K$ and $f^{-1}(K)(a) = K(f(a))$, for every $a \in H$.

Theorem 2. *Let $f: M \longrightarrow N$ be a mapping and H and K be two FSS of M and N, respectively, then*

(a) $f^{-1}(K_\gamma) = (f^{-1}(K))_\gamma$

(b) $f(H_\gamma) = (f(H))_\gamma$

Proof.

(a)

$$\begin{aligned} f^{-1}(K_\gamma)(a) &= K_\gamma(f(a)) \\ &= \max\{K(f(a)), 1-\gamma\} \\ &= \max\{f^{-1}(K)(a), 1-\gamma\} \\ &= (f^{-1}(K))_\gamma(a). \end{aligned} \tag{9}$$

Hence, we have

$$f^{-1}(K_\gamma)(a) = (f^{-1}(K))_\gamma(a), \quad \text{for all } a \in H. \tag{10}$$

(b)

$$\begin{aligned} f(H_\gamma)(b) &= Sup\{H_\gamma(a): f(a) = b\} \\ &= \operatorname{Sup}\{\max\{H(a), 1-\gamma\}: f(a) = b\} \\ &= \max\{\operatorname{Sup}\{H(a): f(a) = b\}, 1-\gamma\} \\ &= \max\{f(H)(b), 1-\gamma\} \\ &= (f(H))_\gamma(b). \end{aligned} \tag{11}$$

Hence, we have

$$f(H_\gamma)(b) = (f(H))_\gamma(b), \quad \text{for all } b \in K. \tag{12}$$

Thus, we have proved that the union and intersection of two γ-FSS are also a γ-FSS. □

4. Mathematical Dominion of γ-Anti FSGs (γ AFSGs)

In this section, we have discussed the γ-anti fuzzy subgroups (γ-AFSGs) and some results based on γ-AFSG.

Definition 9. Let L be a group and M be a FSS of L and $\gamma \in [0,1]$. Then, M is called γ-APFSG of L if

(i) $M_\gamma(ab) \le \max\{M_\gamma(a), M_\gamma(b)\}$, for all $a, b \in L$
(ii) $M_\gamma(a^{-1}) = M_\gamma(a)$

Theorem 3. *Let M: $L \longrightarrow [0,1]$ be a μ-APFSG of a group L, then*

(i) $M_\gamma(a) \ge M_\gamma(e)$, $\forall a \in L$ *and* $e \in L$
(ii) $M_\gamma(ab^{-1}) = M_\gamma(e)$

Proof. (i)

$$\begin{aligned} M_\gamma(e) &= M_\gamma(aa^{-1}) \\ &\le \max\{M_\gamma(a), M_\gamma(a^{-1})\} \\ &= \max\{M_\gamma(a), M_\gamma(a)\} \\ &= M_\gamma(a) \end{aligned} \tag{13}$$

Hence, $M_\gamma(e) \le M_\gamma(a)$.

This implies that $M_\gamma(a) \ge M_\gamma(e)$.

(ii)

$$\begin{aligned} M_\gamma(a) &= M_\gamma(ab^{-1}b) \\ &\le \max\{M_\gamma(ab^{-1}), M_\gamma(b)\} \\ &= \max\{M_\gamma(e), M_\gamma(b)\} \\ &= M_\gamma(b) \end{aligned} \tag{14}$$

Hence, $M_\gamma(a) \le M_\gamma(b)$

Similarly, $M_\gamma(b) \le M_\gamma(a)$.

This implies that $M_\gamma(a) = M_\gamma(b)$. □

Theorem 4. *Every APFSG of a group L is a γ-APFSG of a group L.*

Proof. Let M be an APFSG of a category L and let a and b be two elements in L. Since M is an APFSG of a group L, then we have

$$M(a^{-1}b) \le \max\{A(a), A(b)\}, \quad \text{for all } a, b \in L. \tag{15}$$

To prove

(i) $M_\gamma(ab) \le \max\{M_\gamma(a), M_\gamma(b)\}$, for all $a, b \in L$
(ii) $M_\gamma(a^{-1}) = M_\gamma(a)$, for all $a \in L$

(i) Consider

$$\begin{aligned} M_\gamma(ab) &= S_p\{M(ab), 1-\gamma\} \\ &\le S_p\{\max\{M(a), M(b)\}, 1-\gamma\} \\ &= \max\{S_p\{M(a), 1-\gamma\}, \\ &\quad \cdot S_p\{M(b), 1-\gamma\}\} \\ &= \max\{M_\gamma(a), M_\gamma(b)\} \end{aligned}$$

Hence, $M_\gamma(ab) \le \max\{M_\gamma(a), M_\gamma(b)\}$, for all $a, b \in L$. (16)

(ii) Consider

$$\begin{aligned} M_\gamma(a^{-1}) &= S_p\{M(a^{-1}), 1-\gamma\} \\ &= S_p\{M(a), 1-\gamma\} \\ &= M_\gamma(a). \end{aligned} \tag{17}$$

Therefore, M is μ-APFSG of L. □

Note 1. The converse of Theorem 4 might not be true.

Theorem 5. *Union of two γ-APFSGs of a group L is also γ-APFSG of L.*

Proof. Authorize H and K be two γ-APFSGs of a category L. Let us assume that $a, b \in L$.

$$\begin{aligned} (H \cup K)_\gamma(ab) &= (H_\gamma \cup K_\gamma)(ab) \\ &= \max\{H_\gamma(ab), K_\gamma(ab)\} \\ &\le \max\{\max\{H_\gamma(a), H_\gamma(b)\}, \\ &\quad \cdot \max\{K_\gamma(a), K_\gamma(b)\}\} \\ &= \max\{\max\{H_\gamma(a), K_\gamma(a)\}, \\ &\quad \cdot \max\{H_\gamma(b), K_\gamma(b)\}\} \\ &= \max\{(H \cup K)_\gamma(a), \\ &\quad (H \cup K)_\gamma(b)\} \end{aligned} \tag{18}$$

Hence, $(H \cup K)_\gamma(ab) \le \max\{(H \cup K)_\gamma(a), \cdot (H \cup K)_\gamma(b)\}$.

Consider

$$\begin{aligned} (H \cup K)_\gamma(a^{-1}) &= (H_\gamma \cup K_\gamma)(a^{-1}) \\ &= \max\{H_\gamma(a^{-1}), K_\gamma(a^{-1})\} \\ &= \max\{H_\gamma(a), K_\gamma(a)\} \\ &= (H_\gamma \cup K_\gamma)(a) \\ &= (H \cup K)_\gamma(a). \end{aligned} \tag{19}$$

Therefore, $H \cup K$ is γ-APFSG of L. □

Example 1. Let $L = Z$, the set of integers be the group under the binary operation "+."

Let us assume the two FSS H and K of Z as

$$H(a) = \begin{cases} 0.3, & \text{if } a \in 3Z, \\ 0.7, & \text{otherwise.} \end{cases} \quad K(a) = \begin{cases} 0.2, & \text{if } a \in 2Z, \\ 0.5, & \text{otherwise.} \end{cases} \tag{20}$$

Let us take $\gamma = 1$. Obviously, H and K are 1-APFSG of Z. Now, $(H \cup K)(a) = \max\{H(a), K(a)\}$.

To prove: association of two γ-APFSG of Z is not a γ-APFSG of Z.

Therefore, $(H \cup K)(a) = \begin{cases} 0.3, & \text{if } a \in 3Z, \\ 0.2, & \text{if } a \in 2Z - 3Z, \\ 0.7, & \text{otherwise.} \end{cases}$ Let $a = 9$ and $b = 2$. Then,

$$\begin{aligned} (H \cup K)(9) &= 0.3 \\ (H \cup K)(2) &= 0.2 \\ (H \cup K)(9-2) &= (H \cup K)(7) \\ \max\{(H \cup K)(a), (H \cup K)(b)\} &= \max\{0.3, 0.2\} \\ &= 0.3. \end{aligned} \tag{21}$$

Therefore, $(H \cup K)(a-b) \rangle \max\{(H \cup K)(a), (H \cup K)(b)\}$. Hence, $H \cup K$ is not a 1-APFSG of Z. Therefore, union of two 1-APFSG of Z is not a 1-APFSG of Z.

Definition 10. Let H and K be two γ-APFSGs of groups L_1 and L_2, respectively. Then, product of μ-APFSGs of H and K is defined as

$$H_\mu \times K_\mu = \max\{H_\mu(a), K_\mu(b)\}, \quad \text{for all } a \in L_1, b \in L_2. \tag{22}$$

Theorem 6. *Let H and K be two γ-APFSGs of groups L_1 and L_2, respectively. Then $H_\mu \times K_\mu$ is μ-APFSG of $L_1 \times L_2$.*

Proof. Let $a_1, a_2 \in L_1$ and $b_1, b_2 \in L_2$, then $(a_1, b_1), (a_2, b_2) \in L_1 \times L_2$,

$$\begin{aligned} & H_\mu \times K_\mu\left((a_1, b_1)\left(a_2^{-1}, b_2^{-1}\right)\right) \\ &= H_\mu \times K_\mu\left(a_1 a_2^{-1}, b_1 b_2^{-1}\right) \\ &= \max\left\{H_\mu\left(a_1 a_2^{-1}\right), K_\mu\left(b_1 b_2^{-1}\right)\right\} \\ &\le \max\left\{\max\left\{H_\mu(a_1), H_\mu\left(a_2^{-1}\right)\right\}, \max\left\{K_\mu(b_1), K_\mu\left(b_2^{-1}\right)\right\}\right\} \\ &\le \max\left\{\max\left\{H_\mu(a_1), H_\mu(a_2)\right\}, \max\left\{K_\mu(b_1), K_\mu(b_2)\right\}\right\} \\ &= \max\left\{\max\left\{H_\mu(a_1), K_\mu(b_1)\right\}, \max\left\{H_\mu(a_2), K_\mu(b_2)\right\}\right\} \\ &= \max\left\{H_\mu \times K_\mu(a_1, b_1), H_\mu \times K_\mu(a_2, b_2)\right\}. \end{aligned} \tag{23}$$

Hence, $H_\mu \times K_\mu((a_1, b_1)(a_2^{-1}, b_2^{-1})) \le \max\{H_\mu \times K_\mu(a_1, b_1), H_\mu \times K_\mu(a_2, b_2)\}$. With appropriate examples, the composition of the fuzzy relations is described in two ways: max-min composition and max-product composition. This study also introduces the composition features of fuzzy relations. □

Definition 11. Let H be a γ-APFSG of a group L and $\gamma \in [0, 1]$. For any $a \in H$, the γ-AFLCS of H in L is represented by $aH_\gamma(g) = S_p\{H(m^{-1}), \gamma\}$, for all $a, g \in L$. The γ-AFRCS is defined as

$$(Ha)(g) = S_p\{H(ga^{-1}), \gamma\}, \quad \text{for all } a, g \in L. \tag{24}$$

Definition 12. Let H be a γ-APFSG of a group L and $\gamma \in [0, 1]$. Then, H is said to be μ-APFNSG of L if and only if $aH = Ha$, for all $a \in H$.

Theorem 7. *Every APFNSG of a category L is a γ-APFNSG of L.*

Proof. Let H be an APFNSG of a category L. Then, for any $a \in H$,

$$\begin{aligned} aH &= \text{Ha} \\ \Rightarrow (aH)(g) &= (\text{Ha})(g) \text{ for all } g \in L. \end{aligned} \tag{25}$$

Hence, we have

$$\begin{aligned} H\left(a^{-1}g\right) &= H\left(ga^{-1}\right) \\ \Rightarrow S_p\{H\left(a^{-1}g\right), \gamma\} &= S_p\{H\left(ga^{-1}\right), \gamma\} \\ \Rightarrow aH_\gamma(g) &= H_\gamma a(g) \\ \Rightarrow aH_\gamma &= H_\gamma a, \quad \text{for all } a \in L. \end{aligned} \tag{26}$$

Hence, H is a γ-APFNSG of L. □

Remark 2. The contrary of the accompanying hypothesis is not really true.

Example 2. Let $L = D_3 = \langle u, v\colon u^3 = v^2 = e, vu = u^2 v\rangle$ be the dihedral group. Let us define the FSG of D_3 as

$$H(a) = \begin{cases} 0.6, & \text{if } a \in \langle v \rangle, \\ 0.4, & \text{otherwise,} \end{cases} \tag{27}$$

To prove: H is not a APFNSG of L. Let us take $\gamma = 0$, then we have

$$\begin{aligned} \left(aH_\gamma\right)(g) &= S_p\{H\left(a^{-1}g\right), 1-\gamma\} \\ &= S_p\{H\left(a^{-1}g\right), 1\} \\ &= H\left(a^{-1}g\right) + 1 - H\left(a^{-1}g\right) \\ &= 1 \\ \left(H_\gamma a\right)(g) &= S_p\{H\left(ga^{-1}\right), 1-\gamma\} \\ &= S_p\{H\left(ga^{-1}\right), 1\} \\ &= H\left(ga^{-1}\right) + 1 - H\left(ga^{-1}\right) \\ &= 1 \\ \Rightarrow aH_\gamma &= H_\gamma a. \end{aligned} \tag{28}$$

Therefore, H is a o-APFNSG of L.

Now,

$$\begin{aligned} H\left(u^2(uv)\right) &= H\left(u^3v\right) \\ &= H(ev) = H(v) = 0.6, \\ H\left((uv)u^2\right) &= H(u(uv)u) = H(u(vu)u) = H\left(u\left(u^2v\right)u\right) \\ &= H\left(\left(u^3v\right)u\right) = H((ev)u) = H(vu) \\ &= 0.4 \\ \Rightarrow H\left(u^2(uv)\right) &\neq H\left((uv)u^2\right). \end{aligned} \tag{29}$$

$\Rightarrow H$ is not γ-APFNSG of L.

Theorem 8. *Let H be γ-APFNSG of a group L. Then, $H_\gamma(b^{-1}ab) = H_\gamma(a)$ or $H_\gamma(ab) = H_\gamma(ba)$ for all $a, b \in L$.*

Proof. Let H be a γ-APFNSG of a group L.

$$\begin{aligned} \Rightarrow aH_\gamma &= H_\gamma a, \quad \text{for all } a \in L \\ \Rightarrow \left(aH_\gamma\right)\left(b^{-1}\right) &= \left(H_\gamma a\right)\left(b^{-1}\right),\ b^{-1} \in L \\ \Rightarrow S_p\left\{H\left(a^{-1}b^{-1}\right), 1-\gamma\right\} &= S_p\left\{H\left(b^{-1}a^{-1}\right), 1-\gamma\right\}. \\ \Rightarrow H_\gamma(ba) - 1 &= H_\gamma(ab) - 1 \\ \Rightarrow H_\gamma(ba) &= H_\gamma(ab); \end{aligned} \tag{30}$$

[As His a γ − AFSG of L so $H_\gamma(g^{-1}) = H_\gamma(g)$ for all $g \in L$]. □

5. Application

A conventional genetic sequence is made of three base pairs, and the organization among those DNA bases or RNA is precise. Mathematically, these genetic codes can be interpreted and analyzed by defining appropriate algebraic structures. The two main types of nucleic acids are DNA and RNA which are long chains of repeating nucleotides. In RNA, the base thymine (A, C, G, T in DNA) replaces with uracil (U). RNA is formed by the transcription process of DNA and is mostly involved in protein synthesis. This entire process commits to encoding the codons (triplets). These triplets are called standard genetic code SGC [35]. It is a domain transformation of crisp into fuzzy inputs that are used to establish the degree of truth for each rule premise. The mathematical explanation of gene mutation is provided by group automorphism, making it simple to identify the mutation. Different mathematical models suggested binary interpretation of the GC of the DNA bases. These binary representations suggested that there must exist some partial order on the codon set. The partial order on GC is defined by using chemical Base classes (codon and heterocyclic) and protonated values. Numerous algebraic structures for genetic code (GC) have been presented to investigate the consequence of the significant link between the mutational process and the coding apparatus on protein-coding regions [36]. Mathematically, a GC is identical to a cube enclosed in 3D space, as a result of steady phylogenetic analyses of DNA protein-coding regions. Sanchez and Barreto proposed that GC may be characterized as such linear average of treatment in order elliptic groups and suggested that it can be quite logical to extend it to the whole genome defined on the GC, where population's GA in the alike steer to the similar canonical decomposition into p-groups [37]. The four-base Boolean lattice is constructed by considering that bases with the same hydrogen bond number in the DNA molecule and with separate chemical types must be supportive elements in the lattice. By using this complementary behavior of DNA bases, Sanchez et al. [38–40] define two dual Boolean codon lattices of GC. The boolean lattice of the GC is presumed to be the direct product of three copies of the four-base two dual Boolean lattices. Here, we will construct γ-anti fuzzy subgroups and γ-fuzzy subgroups for the DNA base. We proceed in the following manner. Let $L = \{A, C, G, U\}$ define a binary operation L as follows:

$$\begin{array}{ccccc} \cdot & A & C & G & U \\ A & A & C & G & U \\ C & C & A & U & G \\ G & G & U & A & C \\ U & U & G & C & A \end{array}. \tag{31}$$

Define blurring subset μ of G as

$$\mu(x) = \begin{cases} 1, & \text{if } x = A, \\ 0.5, & \text{if } x = C \text{ or } x = G, \\ 0.3, & \text{if } x = U. \end{cases} \tag{32}$$

Then, $\mu(ab) \geq \min\{\mu(a), \mu(b)\}$ and $\mu(a^{-1}) = \mu(a)$ for all $a, b \in G$ imply μ is a fuzzy subgroup of L. Let the fuzzy set η of L be defined by

$$\eta(x) = \begin{cases} 0.9, & \text{if } x = A, \\ 0.7, & \text{if } x = C \text{ or } x = G, \\ 0.8, & \text{if } x = U. \end{cases} \tag{33}$$

then η is γ-APFSG of L as $\eta_\gamma(ab) \leq \max\left\{\eta_\gamma(a), \eta_\gamma(b)\right\}$ and $\eta_\gamma(a^{-1}) = \eta_\gamma(a)$ for all $a, b \in L$. Consider

$$\begin{aligned} \eta_\gamma(AC) &= S_p\{\eta(AC), 1-\gamma\} \\ &\leq S_p\{\max\{\eta(A), \eta(C)\}, 1\} \\ &= \max\left\{S_p\{\eta(A), 1\}, S_p\{\eta(C), 1\}\right\} \\ &= \max\left\{S_p\{0.9, 1\}, S_p\{0.7, 1\}\right\} \\ &= \max\{0.9 + 1 - 0.9, 0.7 + 1 - 0.7\} \\ &= \max\{1, 1\} \\ \eta_\gamma(AC) &= 1, \\ \max\left\{\eta_\gamma(A), \eta_\gamma(C)\right\} &= \max\left\{S_p\{\eta(A), 1\}, S_p\{\eta(C), 1\}\right\} \\ &= \max\left\{S_p\{0.9, 1\}, S_p\{0.7, 1\}\right\} \\ &= \max\{1, 1\} \\ &= 1. \end{aligned} \tag{34}$$

This implies that

$$\eta_\gamma(AC) \leq \max\{\eta_\gamma(A), \eta_\gamma(C)\}. \tag{35}$$

The sixty-four codon system is

$$\begin{aligned} L^3 = \{&AAA, AAC, AAG, AAU, ACA, ACC, ACG, ACU, AGA, AGC, AGG, AGU, AUA, AUC, \\ &AUG, AUU, CAA, CAC, CAG, CAU, CCA, CCC, CCG, CCU, CGA, CGC, CGG, CGU, \\ &CUA, CUC, CUG, CUU, GAA, GAC, GAG, GAU, GCA, GCC, GCG, GCU, GGA, GGC, \\ &GGG, GGU, GUA, GUC, GUG, GUU, UAA, UAC, UAG, UAU, UCA, UCC, UCG, UCU, \\ &UGA, UGC, UGG, UGU, UUA, UUC, UUG, UUU\}. \end{aligned} \tag{36}$$

Using Definition 10, we compute γ-APFSG of the sixty-four codon system as follows:

$$\eta(xyz) = \begin{cases} 0.9, & \text{if } x, y \text{ or } z = A, \\ 0.7, & \text{if } x, y \text{ and } z = C \text{ or } x, y \text{ and } z = G, \\ 0.8, & \text{if } x, y \text{ or } z = U. \end{cases} \tag{37}$$

The groups L and L^3 are Abelian groups so the γ-APFSG is γ-AFNSG.

6. Conclusion

The goal of this study is to study anti fuzzified normative segments (γ-AFNSG and γ-FNSG). As per mathematical logic, the convergence of any assembly of subdivisions of a category G is also the division of G. However, the union of subgroups generally does not obey this rule. However, the union of any two γ-APFNSG is also a γ-APFNSG. The product of two γ-APFNSG of two different groups can be determined by taking the cross product of the groups under consideration with a componentwise binary operation. The cosets are also introduced which can be further used to define quotient structure in anti fuzzy subgroups. The work provides essential information about normal subgroups in γ-fuzzy and anti fuzzy subgroups. Nilpotent and soluble groups are governed by defining normal series, precisely, the chains of normal subgroups. In the future, nilpotent and soluble γ-fuzzy and anti fuzzy subgroups can be defined with the help of the results presented in this article. γ-AFNSG and γ-FNSG are constructed for the dihedral groups. The group automorphisms provide the mathematical description of gene mutation [41]. The dihedral group is the best example of finite non-Abelian groups generated by reflections and rotations of a regular polygon and plays an important role in group theory, geometry, and chemistry. Group automorphisms are observed as the algebra behind gene mutation here γ-AFNSG and γ-FNSG are established for the DNA base and codon system. It is a domain transformation of crisp into fuzzy inputs to determine the truth's degree for each rule premise. The group automorphism provides the mathematical description of gene mutation, so it will be easy to identify the mutation. In future, the automorphism for γ-AFNSG and γ-FNSG can be established by considering the extension principle of fuzzy sets and group homomorphism to analyze its impact to identify gene mutations.

Data Availability

The work is a contribution to theoretical fuzzy algebra so no data are required for the validity of the results obtained.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

This publication was developed in consultation with all the contributors.

References

[1] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338–353, 1965.

[2] A. Rosenfeld, "Fuzzy groups," *Journal of Mathematical Analysis and Applications*, vol. 35, no. 93, pp. 512–517, 1971.

[3] J. M. Sherwood and H. Sherwood, "Fuzzy groups redefined," *Journal of Mathematical Analysis and Applications*, vol. 69, no. 1, pp. 124–130, 1979.

[4] J. M. Sherwood and H. Sherwood, "A characterization of fuzzy subgroups," *Fuzzy Sets and Systems*, vol. 7, no. 3, pp. 297–305, 1982.

[5] P. Bhattacharya, "Fuzzy subgroups: some characterizations," *Journal of Mathematical Analysis and Applications*, vol. 128, no. 1, pp. 241–252, 1987.

[6] P. S. Das, "Fuzzy groups and level subgroups," *Journal of Mathematical Analysis and Applications*, vol. 84, no. 1, pp. 264–269, 1981.

[7] W. J. Liu, "Fuzzy invariant subgroups and fuzzy ideals," *Fuzzy Sets and Systems*, vol. 8, no. 2, pp. 133–139, 1982.

[8] N. Ajmal and A. S. Prajapati, "Fuzzy cosets and Fuzzy normal subgroups," *Information Sciences*, vol. 64, no. 1-2, pp. 17–25, 1992.

[9] N. P. Mukherjee and P. Bhattacharya, "Fuzzy normal subgroups and fuzzy cosets," *Information Sciences*, vol. 34, no. 3, pp. 225–239, 1984.

[10] N. P. Bhattacharya and P. Bhattacharya, "Fuzzy groups: some group-theoretic analogs," *Information Sciences*, vol. 39, no. 3, pp. 247–267, 1986.

[11] I. Kumar, P. K. Yadav, and P. Yadav, "Fuzzy normal subgroups and fuzzy quotients," *Fuzzy Sets and Systems*, vol. 46, no. 1, pp. 121–132, 1992.

[12] M. Tarnauceanu, "Classifying fuzzy normal subgroups of finite groups," *Iran J. Fuzzy Syst.*vol. 12, no. 2, pp. 107–115, 2015.

[13] F. P. Choudhury, A. B. Khare, and S. S. Khare, "A note on fuzzy subgroups and fuzzy homomorphism," *Journal of Mathematical Analysis and Applications*, vol. 131, no. 2, pp. 537–553, 1988.

[14] G. M. Addis, "Fuzzy homomorphism theorems on groups," *Korean J. Math*, vol. 26, no. 3, pp. 373–385, 2018.

[15] D. S. Malik, J. N. Mordeson, and P. S. Nair, "Fuzzy normal subgroups in fuzzy subgroups," *Journal of the Korean Mathematical Society*, vol. 29, pp. 1–8, 1992.

[16] M. Atif Mishref, "Normal fuzzy subgroups and fuzzy normal series of finite groups," *Fuzzy Sets and Systems*, vol. 72, no. 3, pp. 379–383, 1995.

[17] K. T. Atanassov, "Intuitionistic fuzzy sets," *Fuzzy Sets and Systems*, vol. 20, no. 1, pp. 87–96, 1986.

[18] R. Al-Husban, A. R. Ahmad, and A. Ahmad, "Complex intuitionistic fuzzy normal subgroup," *International Journal of Pure and Apllied Mathematics*, vol. 115, no. 3, pp. 199–210, 2017.

[19] R. Biswas, "Fuzzy subgroups and anti fuzzy subgroups," *Fuzzy Sets and Systems*, vol. 35, no. 1, pp. 121–124, 1990.

[20] B. O. Onasanya, "Review of some anti fuzzy properties of some fuzzy subgroups," *Anal. Fuzzy Math. Inform*, vol. 11, no. 6, pp. 899–904, 2016.

[21] P. K. Sharma, "α- Anti Fuzzy subgroups," *International Review of Fuzzy Mathematics*, vol. 7, pp. 47–58, 2012.

[22] P. K. Sharma, "α-Fuzzy subgroups," *International Journal of Fuzzy Mathematics and Systems*, vol. 3, pp. 47–59, 2013.

[23] U. Shuaib, M. Shaheryar, and W. Asghar, "On Some characterizations of o-fuzzy subgroups," *International Journal of Mathematics and Computer Science*, vol. 13, no. 2, pp. 119–131, 2018.

[24] U. Shuaib and M. Shaheryar, "On some properties of o-anti fuzzy subgroups," *International Journal of Mathematics and Computer Science*, vol. 14, no. 1, pp. 215–230, 2019.

[25] X. Yang and Y. Yang, "Some results for Pythagorean fuzzy sets," *International Journal of Intelligent Systems*, vol. 30, no. 11, pp. 1133–1160, 2015.

[26] S. Bhunia and G. Ghorai, "A new approach to fuzzy group theory using (α, β)-pythagorean fuzzy sets," *Songklanakarin Journal of Science and Technology*, vol. 43, 2021 In press.

[27] A. K. Ray, "On product of fuzzy subgroups," *Fuzzy Sets and Systems*, vol. 105, no. 1, pp. 181–183, 1999.

[28] I. Silambarasan, "Implication operators on Pythagorean fuzzy set," *International Journal of Scientific & Technology Research*, vol. 8, no. 8, pp. 1505–1509, 2019.

[29] I. Silambarasan, "Some algebraic properties of picture fuzzy sets," *World Scientific News*, vol. 150, pp. 78–91, 2020.

[30] I. Silambarasan, "New operators for Fermatean fuzzy sets," *Annals of Communications in Mathematics*, vol. 3, no. 2, pp. 116–131, 2020.

[31] I. Silambarasan, "Fermatean fuzzy subgroups," *Journal of the International Mathematical Virtual Institute*, vol. 11, no. 1, pp. 1–16, 2021.

[32] M. M. Qi and J. Qi, "Theory of T-norms and Fuzzy inference methods," *Fuzzy Sets and Systems*, vol. 40, no. 3, pp. 431–450, 1991.

[33] H. Liu, Y. Pan, J. Cao, Y. Wang, and H. Wang, "Positivity and stability analysis for fractional-order delayed systems: a T-S fuzzy model approach," *IEEE Transactions on Fuzzy Systems*, vol. 29, no. 4, pp. 927–939, 2021.

[34] H. Liu, S. G. Li, H. X. Wang, and G. J. Li, "Adaptive fuzzy synchronization for a class of fractional-order neural networks," *Chinese Physics B*, vol. 26, no. 3, Article ID 030504, 2017.

[35] C. Liczner, K. Duke, G. Juneau, M. Wilds, and C. J. Wilds, "Beyond ribose and phosphate: selected nucleic acid modifications for structure-function investigations and therapeutic applications," *Beilstein Journal of Organic Chemistry*, vol. 17, pp. 908–931, 2021.

[36] R. Grau and R. Grau, "A novel algebraic structure of the genetic code over the galois field of four DNA bases," *Acta Biotheoretica*, vol. 54, no. 1, pp. 27–42, 2006.

[37] R. Sanchez and J. Barreto, *Genomic Abelian Finite Groups*, 2021.

[38] R. Sanchez, E. Morgado, and R. Grau, "The Genetic Code Boolean Lattice," 2004, https://arxiv.org/pdf/q-bio/0412034.

[39] R. Sanchez, E. Grau, and R. Grau, "A genetic code Boolean structure. I. The meaning of Boolean deductions," *Bulletin of Mathematical Biology*, vol. 67, no. 1, pp. 1–14, 2005.

[40] R. Grau and R. Grau, "A genetic code Boolean structure. II. The genetic information system as a Boolean information system," *Bulletin of Mathematical Biology*, vol. 67, no. 5, pp. 1017–1029, 2005.

[41] E. Fimmel, M. Strüngmann, and L. Strüngmann, "Circular tessera codes in the evolution of the genetic code," *Bulletin of Mathematical Biology*, vol. 82, no. 4, p. 48, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4384657, 13 pages
https://doi.org/10.1155/2022/4384657

Research Article

Preliminary Study on Construction of China's Overseas Investment Insurance System Based on Comparative Analysis of Investment Insurance Systems of the US, Japan, Germany, and MIGA

Qu Xia

School of Economics and Management, Beijing Jiaotong University, Beijing, China

Correspondence should be addressed to Qu Xia; 13113119@bjtu.edu.cn

Received 28 March 2022; Revised 5 May 2022; Accepted 19 May 2022; Published 11 July 2022

Academic Editor: Lele Qin

With the advancement of the *Belt and Road* strategy, China's foreign direct investment has grown rapidly, and the political risks faced by Chinese enterprises in overseas investment are also increasing. It is a common practice in the world's major capital exporting countries to prevent overseas investment risks by establishing an overseas investment insurance system. Among them, the insurance systems of the United States, Japan, Germany, and the Multilateral Investment Guarantee Agency (MIGA) are the most representative, and they are also models for countries to follow. At present, China has not yet established a legal system for overseas investment insurance. China Export & Credit Insurance Corporation is the only operating institution that provides overseas investment insurance in China, and its overseas investment insurance business only accounts for a small proportion and has not played its due role in safeguarding overseas investment. This paper, on the basis of comparative analysis of foreign experience, combined with China's actual problems and needs, selects the most worthy reference systems of various countries and proposes specific ideas for establishing and improving China's overseas investment insurance system.

1. Introduction

In recent years, China's foreign direct investment has developed rapidly, especially the investment along the "Belt and Road" has increased significantly. Based on "2020 Statistical Bulletin of China's Outward Foreign Direct Investment" released by Ministry of Commerce, PRC, in the year 2020, China's direct investment in countries along the "Belt and Road" reached US$ 22.54 billion, a year-on-year increase of 20.6%, accounting for 14.7% of China's total foreign direct investment during the same period.

Compared with domestic investment, foreign direct investment faces greater risks, especially the political risks of the host country. In particular, countries along the "Belt and Road" have increased political risks, due to their complex geopolitics, frequent regime changes, complex social structures, racial and religious conflicts, single economic structures, and inadequate legal systems. According to the "Report of Country-Risk Rating of Overseas Investment from China (2020)" by the Chinese Academy of Social Sciences, in addition to Singapore, Israel, Czech Republic, Poland, and other 11 countries in the 65 countries along the "Belt and Road," the other 54 countries are medium-risk or high-risk areas, and the percentage of countries with medium to high risk takes up to 83%. However, China's overseas investment is dominantly concentrated in industries that are easily affected by political factors, such as mining, energy, power, and infrastructure [1]. In addition, enterprises' own risk awareness and risk prevention and control capabilities are generally weak, thus facing higher political risks.

According to the "Report on Chinese Enterprises Globalization (2014)," 65% of the 120 failed overseas investment cases of Chinese enterprises from 2005 to 2014 were caused by political risks in the host country [2]. There are countless examples of Chinese companies losing money in overseas investments due to political risk. In 2009, Sinohydro

Corporation's investment in Myanmar's Myitsone Hydropower Station was stopped by the Myanmar government [3]; in 2011, the Libya war caused serious damage to more than 50 projects invested by 75 Chinese companies in the local area, with losses reaching US$18.8 billion; in 2015, the Sri Lankan government changed, which has caused $1.4 billion Colombo Port City project invested by China Bank of Communications to be shelved, suffering heavy losses. Political risks are often closely related to the sovereign behavior of the host country, are mandatory and overall, are more destructive than ordinary commercial risks, and are difficult to predict and control by enterprises themselves.

Therefore, diversifying risks through overseas investment guarantees has become the most common choice for investors in various countries. All major capital exporting countries in the world have established overseas investment insurance systems to protect the interests and safety of their investors' overseas investment. Among all the capital exporting countries, the United States, Japan, and Germany are recognized as the most outstanding countries for their overseas investment insurance practice. These three countries, listed in the biggest or earliest capital exporters, have created and promoted comprehensive overseas investment guarantee systems, especially the insurance systems, which have been playing influential roles in facilitating and supporting outbound investments, and have become worthy examples followed by other countries.

The United States is the first to create overseas investment insurance system, by initiating "bilateral mode" of legislation, establishing Overseas Private Investment Corporation (OPIC) as the only official agency providing overseas investment insurance, and pioneering "subrogation right" for the insurance agencies to claim compensation from the host countries after making compensation, which could be very enlightening for us.

Japan is one of the few countries that apply "unilateral mode" of legislation, which means insurance could be underwritten even for those overseas investments in host countries with which Japan has not signed BITs. The "unilateral mode" simplifies the process of application and claim settlements and thus may provide more protection for Japanese investors. Besides, Japan has innovated "loss reserve" policy for overseas energy investments or overseas engineering contracting, as a supplement of insurance system, to resist overseas investment risks for Japanese investors. China has gone through similar process as Japan in its overseas investment and focuses on similar sectors and industries when investing abroad, so it may learn from Japanese precedent.

Germany, same as China, is one of the countries which has signed the most BITs with other countries and applies blend mode combining "bilateral" and "unilateral" modes. The signing of a BIT with the host country is not a legal condition for German agency to underwrite overseas investment insurance, but in practice, in order to ensure the effectiveness of domestic insurance, it generally provides guarantees to investment projects in the host country that has signed a BIT with Germany. The German blend mode might be a good reference for China at the stage of exploration of overseas investment insurance.

Multilateral Investment Guarantee Agency (MIGA), a member of the World Bank Group, is the most influential international overseas investment insurance agency and is well known for its relaxed insurance conditions, wide range of guarantees, and smart claim settlement process, which will be a good example for Chinese practice.

Thus, this paper, on the basis of comparative analysis of the most representative overseas investment insurance systems such as those of the US, Japan, Germany, and MIGA, combined with China's actual problems and needs, will select the worthiest reference systems of various countries and propose specific ideas for establishing and improving China's overseas investment insurance system.

2. Literature Review

2.1. Overseas Investment Guarantee System. The review starts with a general issue of overseas investment guarantee system. Some authors such as Ni and Zheng sorted out overseas investment risks faced by Chinese investors and analyzed on essentials of establishing Chinese outbound investment security and protection scheme, including signing bilateral investment treaty (BIT) and establishing overseas investment insurance system, etc [4].

Other authors including Hu further compared the practices of the United States, the European Union, and Japan in their overseas investment guarantee measures of financial support, multilateral and bilateral investment environment, overseas investment guarantee legislation, and overseas investment authorities and, on the basis of that, suggested improving Chinese overseas investment guarantee system [5].

More authors suggested to establish overseas investment guarantee systems, in particular legal systems, based on references from specific countries or focused on some sectors or industries. Korean practice of overseas investment guarantee has been studied as a good example, including its overseas investment approval, overseas investment insurance, BIT negotiation, and signing, for the purpose of providing reference for Chinese legislation [6, 7]. The experience of the United States, Japan, France, and Germany in overseas investment guarantee legislation in industries of mining, energy, and retail has also been analyzed, and advice has been given accordingly on making and improving overseas investment supporting laws for specific sectors or industries [8, 9].

The above research studies mainly focused on general overseas investment guarantee system, centered on legal system. The overseas investment insurance system has only been slightly involved as a component of the general guarantee system.

2.2. Overseas Investment Insurance System. The review then narrows down to the issue of overseas investment insurance system. Most studies on overseas investment insurance system were concentrated in legal issues. Some of them covered legal nature, legal definition, legal subjects and legal identification of political risks, and so on [10], and some went through status and problems of Chinese overseas investment insurance and provided references for Chinese

practice in detailed issues of underwriting categories, underwriting conditions, qualified investor, and qualified investment, by learning from the United States, Japan, and Germany modes [11]. The above studies have constituted the legal theoretical basis for overseas investment insurance.

More studies, based on the background of "One Belt One Road" (OBOR), suggested reconstructing Chinese overseas investment insurance legal system in terms of legislative mode, insurance underwriter, underwriting categories, operation mode, financing mode, qualified investors, and claim settlement [12, 13] or viewed from the perspective of financial institutions and investigated measures to prevent overseas investment risks by means of cooperation with international insurance agencies, insurance product innovation and reinsurance plan, and so on [14].

Some research studies started from prevention of political risks in overseas investment, figured out the status and problems faced by Chinese investors during their overseas investments, and then suggested improving Chinese overseas investment insurance system [2].

The available studies of overseas investment insurance are mainly centered around legal system, or based on the background of OBOR, or from the perspective of specific institution or certain kinds of investment risks, so they can neither capture the full essentials of overseas investment insurance system nor meet the needs of Chinese practice.

2.3. International Comparative Study of Overseas Investment Insurance System. The review further narrows to a more specific topic of international comparative study of overseas investment insurance system. There are existing studies of overseas investment insurance which have covered most of the typical capital exporting countries such as the United States, Japan, and Germany, including issues of underwriting conditions, underwriting categories, underwriting terms, and claims settlement [15, 16]. However, these studies were made more than 30 years ago, and there is a lack of updates of overseas investment insurance of these countries, so they might be outdated for Chinese practical needs.

In recent research studies, experiences of the United States, Japan, and Germany in general guarantee system of overseas investment have been analyzed from the perspective of overseas investment risk prevention. The overseas investment insurance system has been roughly mentioned as a point of the general guarantee system without detailed analysis [4, 5, 17].

Additional studies focused on financial supporting or tax incentive policies of overseas investment and provided valuable references by comparing practices of the United States, Japan, Germany, and France in measures of overseas investment loans, subsidies, tax preference, and insurance, without detailed analysis on overseas investment insurance systems or policies of the above countries [18–22].

3. Research Gap and Research Topic

It can be concluded from the above literature review that there are only few studies in the overseas investment insurance domain, especially in the comparison of different countries' practices, and this lack of updated international comparative studies has been identified as a viable research gap to be addressed.

Existing studies mainly cover the general guarantee system of overseas investment, in which the overseas investment insurance has been briefly mentioned as a point of the general system. Recent research studies on overseas investment insurance are concentrated in legal system, or based on the background of OBOR, or on the perspective of specific institutions or risks, and thus they are not comprehensive enough. Those comparative studies among experience of major capital exporting countries were made years ago, and they lack recent updates, while recent comparative analysis mainly focuses on general guarantee system or prevention of overseas investment risks, including financial supporting policies or tax preferences in specific countries, but not involving full-scale comparison on detailed insurance rules and policies of major capital exporters.

To address the above research gap, this paper will compare detailed insurance rules, policies, and practice of the United States, Japan, Germany, and MIGA, in light of the status and needs of Chinese overseas investment, and then propose measures to establish Chinese overseas investment insurance system, including legislative mode, legislative system, underwriting categories, underwriting conditions, insurance terms, insurance amount, insurance premium rate, venture fund or loss reserve, SME supporting plans and cooperative mechanism, etc., aiming at providing some useful references for Chinese practice.

4. Research Method

4.1. Literature Review. The author has reviewed all the studies related to promotion, guarantee, and insurance of overseas investments and made a comparison, conclusion, and analysis thereof, for the purpose of finding out the research gap and determining the research topic of this paper.

4.2. Comparative Study. The author has also compared overseas investment insurance systems of the United States, Germany, Japan, and MIGA in order to find out the difference and similarity among them and to provide good references for China on establishing overseas investment insurance system and protecting overseas investment interests of Chinese enterprises.

4.3. Category Induction. The author has sorted out the main contents and components of overseas investment insurance system, including legislative models, legislative models, underwriting categories and underwriting conditions, etc., and further categorized and analyzed on these contents and components of different countries or organization to refine enlightenment experience for Chinese practice.

5. An Overview of the Overseas Investment Insurance System

5.1. Concept and Characteristics of Overseas Investment Insurance System. The overseas investment insurance system is a system in which the capital exporting country provides guarantees or insurance for the political risks that overseas investors of their own countries may encounter abroad, and after the domestic insurance institution compensates for the losses, it will then seek compensation from the host country by subrogation [23].

The overseas investment insurance system is in essence a government guarantee, which is different from general commercial insurance. Its characteristics are as follows: the category of insurance is limited to political risks, and the underwriting items are limited to foreign direct investment. The underwriting agencies are generally government departments or state-owned companies, which are not profit-seeking and have both prevention and post-event compensation functions to relieve investors from worries [24].

5.2. The Origin and Development of the Overseas Investment Insurance System. The overseas investment insurance system first originated in the United States. After World War II, the United States implemented the "Marshall Plan" to revive Europe. In order to dispel investors' concerns and encourage American investors to invest in Europe, the United States introduced the "Economic Cooperation Act" in 1948 and created the first overseas investment insurance system. The initial categories of insurance were limited to foreign exchange insurance only. In the following ten years, insurance agencies have changed several times, and the Economic Cooperation Agency, the Common Security Agency, the Overseas Affairs Administration, the International Cooperation Bureau, and the International Development Agency are in charge of overseas investment insurance affairs in turn [25]. In 1969, the "Overseas Aid Law" was revised again, and the Overseas Private Investment Corporation (OPIC) was established accordingly and became an insurance institution specializing in providing overseas investment guarantees, and the coverage was also expanded to foreign exchange insurance, expropriation insurance, and war insurance. Japan followed the United States and created an overseas investment (original) insurance system in 1956, then added overseas investment profit insurance in 1957, and finally merged the two insurances. In order to encourage Japanese investors to participate in overseas mineral energy development, Japan established an overseas mineral energy investment insurance system in 1972 [26]. In 2001, Nippon Export and Investment Insurance (NEXI) was specially established to be responsible for underwriting overseas investment insurance. Since then, major capital exporting countries such as Germany, France, Britain, and the Netherlands have followed suit and established their own overseas investment insurance systems. Among them, the practices of the United States, Japan, and Germany are the most representative and have become models for countries to learn from.

In addition to the overseas investment insurance systems of various countries, some regional or international organizations are also gradually exploring the establishment of overseas investment guarantee systems. Generally speaking, the number of regional overseas investment insurance institutions is limited, and they only guarantee investments in specific regions, and thus it is difficult to play their functions in a wider range. Among the international overseas investment insurance agencies, the most influential one is the Multilateral Investment Guarantee Agency (MIGA), a member of the World Bank Group. MIGA has been increasingly recognized by its wide range of guarantees, relaxed insurance conditions, and flexible operation mechanism and has also become the focus of research on overseas investment insurance systems in recent years.

5.3. Core Issues of the Overseas Investment Insurance System. The right of subrogation is the core issue of overseas investment insurance, and it is also the link for the overseas investment insurance system to operate. Different from the domestic insurance system, the subrogation right in overseas investment insurance cannot be realized only by domestic law and must be exercised by obtaining the validity of international law. According to the different legislative models of various countries, the international legal basis for the exercise of the right of subrogation can be divided into two categories, one is the bilateral investment treaty (BIT) signed by the home country of investment and the host country, and the other is the international law's general principles of diplomatic protection. The former is represented by the United States and Denmark. Insurance institutions sign a BIT with the host country as a prerequisite for underwriting; after the insurance agency compensates investors for losses, they can directly obtain subrogation rights in accordance with the subrogation rights clause of the BIT. Therefore, the subrogation rights obtained in this way have stronger legal effect. The latter is represented by Japan and France. Insurance institutions are not premised on the signing of bilateral investment agreements with host countries. After making compensation, the insurance agency can only make a request to the host country in accordance with the relevant diplomatic protection principles of international law. During this period, they may face many defenses such as "exhaustion of local remedies" and "continuation of nationality" proposed by the host country government, thus hindering the realization of the right of compensation. Therefore, even though some countries (such as Germany) have stipulated a "unilateral model" similar to the United States, in practice, they still take signing a BIT with the host country as an important condition for underwriting in order to ensure the subrogation rights of insurance agencies.

6. International Comparison of Overseas Investment Insurance System

6.1. Using the Law to Guide Insurance Practice Starts with Legislation. Basically, all countries follow the path of legislation first, clarifying the establishment purpose, legal status, insurance coverage, insurance qualifications,

insurance conditions, and the right to claim compensation of insurance institutions in the form of legal systems, providing legal basis and guidelines for the operation of overseas investment insurance agencies. Legislation is the primary basis for the smooth implementation of overseas investment insurance.

The United States first established the overseas investment insurance system through the Economic Cooperation Act in 1948 and has continuously improved and refined the system in the multiple revisions of the Foreign Aid Act and the Common Security Act, and finally became the current mature overseas investment insurance system. Japan launched the Export Insurance Law in 1956 and revised it in 1978, which clearly stipulated the scope of insurance, insurance institutions, qualified investors, qualified investments, insurance period, insurance amount, and premium rate. German laws on the foreign investment insurance system include the Federal Budget Act, the Foreign Economic Act, and the Regulations on Guarantee for Foreign Direct Investment. In particular, the Regulations on Guarantee for Foreign Direct Investment clearly stipulate that the government is obliged to provide guarantees for the overseas investment of German companies that need support. Not only countries guide overseas investment with legislation, the Multilateral Investment Guarantee Agency Convention (also known as the "Seoul Convention") was also formulated before the establishment of the Multilateral Investment Guarantee Agency and became the main basis for MIGA's guarantee activities.

6.2. Bilateral and Unilateral Legislative Models. From the perspective of legislative mode, the overseas investment insurance system of various countries can be divided into two categories: "bilateral mode" and "unilateral mode." The former is represented by the United States, and investment insurance can only be obtained by investing in the host country that signed the BIT. The subrogation right clause in the BIT directly grants OPIC the right of subrogation to claim compensation from the host country after making compensation. This domestic and international system connection ensures the smooth acquisition of the right of claim. The signing of a BIT with the host country is not a legal condition for Germany to underwrite overseas investment insurance, but in practice, in order to ensure the effectiveness of domestic insurance, it generally provides guarantees to investment projects in the host country that signs a BIT with Germany, which is essentially a "bilateral model." The latter is represented by Japan, and insurance agency only provides guarantees based on a country's domestic and overseas investment insurance system. After making compensation, the insurance agency can only claim the right of subrogation against the host country in accordance with the principle of diplomatic protection in international law, and it is very likely that the subrogation cannot be achieved due to the host country's various defenses based on international law and domestic law.

6.3. Two Types of Legislative System, Integrated System and Separated System. In terms of legislative modes, the legislative practice of countries can be divided into two categories: one is the integration of the overseas investment insurance approval agency and the business operation agency, and the other is the separation of the approval agency and the operating agency.

The former is still represented by the United States, and OPIC is responsible for the approval and underwriting of overseas investment insurance in the United States. OPIC has both public and private attributes. On the one hand, OPIC is directly under the leadership of the State Council, the legal capital is allocated by the US treasury, and the company's directors are appointed by the president; on the other hand, OPIC, as an independent legal entity, operates independently and is responsible for its own profits and losses. The US way of legislation system is designed to allow OPIC to "serve as a bridge between foreign governments and US investors, enabling political issues to be resolved commercially," and thus "avoid direct government-to-government confrontation" [27]. In 2018, OPIC was merged into the United States International Development Finance Corporation, and the functions of OPIC were inherited by it. Japan at first also implemented the integrated system. The Enterprise Bureau of the Ministry of International Trade and Industry of Japan is responsible for the approval of insurance, and the Long-term Export Insurance Section under the bureau is responsible for underwriting insurance. Under the integrated system, investors and insurance institutions are not only equal contractual subjects but also administrative subjects between managers and managed subjects.

The latter is represented by Germany. The decision-making committee composed of representatives of the German Ministry of Economic Affairs, the Ministry of Finance, and the Ministry of Foreign Affairs, together with the advisory committee composed of representatives of the Federal Bank and the Accounting Audit Office, is responsible for approval. Hermes Kreditversicherungs AG and Treuarbeit AG are responsible for the underwriting. Japan established Nippon International Insurance Co. Ltd. (NEXI) in 2001 to undertake overseas investment insurance business, and the underwriting responsibility has transitioned from government departments to state-owned enterprises, showing a trend of the separation system. Under the separation system, investors apply to the approval agency for insurance, and after being approved by the approval agency, they sign an insurance contract with the operating agency and pay the premium. When a risk occurs and they suffer losses, they can directly claim to the operating agency according to the insurance contract. The relationship between the investor and the insurance institution is an insurance contract, and the relationship between the investor and the approval institution is a vertical manager-managed relationship. Under the separation system, the legal relationship is clear, the rights and responsibilities of each subject are clearly defined, and each party performs its own duties, which helps to prevent corruption.

Table 1: Comparison of overseas investment insurance coverage in different countries.

	United states	Japan	Germany	MIGA
Expropriation insurance	(i) Time requirement: requires the expropriation to last more than one year	(i) Including indirect expropriation: including the forced transfer of shares held by Japanese investors due to the nationalization of joint ventures	(i) Includes indirect expropriation	(i) Includes indirect expropriation: government legislative or administrative action that actually has the effect of expropriation, causing investors to lose ownership, control, or be deprived of the main benefits of their investment
War risk insurance	(i) Terrorism insurance included	(i) Force majeure insurance, including the risk of loss due to war, civil disorder, and natural disasters		(i) Includes losses caused by the investor's inability to use transportation lines for a certain period of time due to war or civil unrest
Foreign exchange insurance	(i) Includes non-payment insurance	(i) Includes non-payment insurance and transfer insurance	(i) Includes non-payment insurance and transfer insurance	(i) Includes non-payment insurance and transfer insurance
Other insurances	(i) Terrorism insurance can also be used as an independent insurance (ii) Business interruption insurance (iii) Export or business license cancellation insurance	(i) Government default insurance (included in expropriation insurance) (ii) Delayed performance insurance (only in the field of resource development)	(i) Stop/delay payment insurance (ii) Currency devaluation insurance	(i) Government default insurance (ii) Insurance of non-fulfillment of sovereign financial obligations

6.4. Underwriting Categories. The underwriting categories of overseas investment insurance in various countries mainly include expropriation insurance, war risk insurance, and foreign exchange insurance. In terms of insurance categories and their contents, countries are different, as shown in Table 1.

In expropriation insurance, various countries basically include direct expropriation and indirect expropriation, and the insurance sets out that the government expropriation behavior cannot be attributed to the investor's own fault or improper behavior. The United States also regards contract rights as the object of expropriation and sets a corresponding time limit for expropriation (lasting more than one year); Japan confirms that the nationalization of joint ventures leading to the forced transfer of shares held by Japanese investors is also expropriation; MIGA stipulates that as long as it is the government's legislative or administrative action that actually has the effect of expropriation, causing investors to lose ownership, control, or be deprived of the main investment income, these behaviors are all considered as expropriation behaviors.

In the war risk insurance, countries normally exclude the conflicts and disturbances caused by general economic conflicts and labor disputes and require that there be an inevitable and direct connection between damage and war. With the continuous escalation of political risks, some countries have gradually updated the connotation of this type of insurance. After the 9/11 incident, the United States developed the terrorism insurance included in the war risk into an independent insurance. Japan has extended the risk of war to force majeure, including the risk of war and civil disturbance and the risk of losses due to natural disasters such as earthquakes, floods, and tsunamis.

In foreign exchange insurance, all countries exclude losses due to normal changes in exchange rates or foreign exchange controls that have been or may be implemented by the host country at the time of signing the insurance contract. The difference of countries is that the United States only includes non-payment insurance, while Japan, Germany, and MIGA include not only non-payment insurance but also transfer insurance.

In addition to the above three traditional risk insurances, many countries have added government default insurance, and use investors have exhausted local judicial remedies as a precondition for claiming default insurance. In addition, the United States also underwrites business interruption insurance, Japan underwrites delayed performance insurance (applicable to the field of resource development only), Germany underwrites stop or delay payment insurance and currency devaluation insurance, and MIGA underwrites non-performance sovereign financial obligation insurance.

6.5. Underwriting Conditions. Underwriting conditions usually include three aspects: qualified investor, qualified investment, and qualified host country.

As far as qualified investors are concerned, most countries follow the "nationality plus capital control principle," including natural or legal persons of their own nationality, or foreign legal persons who are not nationalized but controlled by their own nationals. Qualified investors in the US include US citizens, US legal persons, and foreign legal persons actually controlled by US citizens or legal persons (holding more than 95% of the shares). Japan also has similar regulations, while Germany

Table 2: Comparison of underwriting conditions of overseas investment insurance in various countries.

	United states	Japan	Germany	MIGA
Qualified investor	(1) US citizen (2) US legal person (US citizens or legal persons hold more than 51% of the shares) (3) A foreign legal person actually controlled by a US citizen or legal person (holding more than 95% of the shares)	(1) Japan nature person (2) Japan legal person.	(1) German citizen or legal person (2) Have residence in Germany	(1) Natural or legal persons of MIGA member countries other than the host country (2) Domestic investors of the host country, whose investment properties originate outside the host country, and jointly invest with foreign investors
Qualified investment	(1) New investments and "investments in the expansion, modernization, and development of existing enterprises" (2) The form of investment includes equity investment or non-equity investment (3) The US government agrees to guarantee investments in underdeveloped countries/ regions and investments in countries that have signed BITs with the US approved by foreign governments	(1) New investment and expansion of existing projects (2) Investment forms include equity investment, long-term loans related to equity investment, direct investment in real estate, and long-term loans for the purpose of developing input resources [28] (3) In line with Japan's national interests and contributes to the economic development of the host country	(1) New investment or capital increase of existing projects (2) Investment forms include equity investment, investment in the establishment of overseas branches, and equity-related loans. (3) In line with the national interests of Germany, has a positive effect on Germany, complies with the laws of the host country and meets appropriate environmental standards, and is economically feasible and reasonable	(1) New investment and additional investment or reinvestment (2) Investment forms include equity investment or non-equity investment (3) Contribute to the economic development of the host country
Qualified host country	(1) Respects human rights and workers' rights (2) The per capita income is below a certain limit (3) Established friendly relations with the United States (4) Signed a BIT with the United States	(1) BIT host country does not need to sign BIT with Japan	(1) Host country has relevant laws and measures to protect foreign investors	(1) Developing countries only

requires investors to have a residence in Germany in addition to nationality requirements, as shown in Table 2.

Qualified investment includes three aspects: investment time, investment form, and investment significance. In terms of project time, countries usually require new projects and capital increase in existing projects; in terms of investment forms, it includes not only equity investment but also non-equity investments such as loans, leases, technical assistance agreements, and license agreements; in terms of investment significance, all countries require the investment to meet the interests of the home country and must contribute to the economic development of the host country, in line with the laws of the host country or approved by the host country government. Different countries have slightly different priorities. The United States focuses on the impact of investment projects on the environment, balance of payments, and labor employment. In addition to the above requirements, Germany also requires that investment projects are economically feasible and reasonable.

In terms of qualified host countries, in addition to whether to sign a BIT, all countries basically require the host country to be a developing country. On the one hand, the investment risk of developing countries is higher than that of developed countries, and it is more necessary to provide investment guarantees; on the other hand, the purpose of most countries encouraging overseas investment is to obtain international resources, develop emerging markets, and promote the economic development of developing countries. Obligated international organizations, in particular, aim to promote developing countries, and MIGA's guarantee is limited to investments in developing countries only. In contrast, the United States has the most stringent requirements, and the host country must meet four conditions: respect for human rights and workers' rights, per capita income below a certain percentage, maintaining friendly relations with the United States, and signing a bilateral investment protection agreement.

6.6. Insurance Term, Insurance Amount, and Insurance Premium Rate. In terms of insurance terms, considering the long period of most overseas investment projects, the insurance period in most countries can be as long as 15 years, and the longest can be as long as 20 years. Germany can provide up to 15 years insurance for equity investments and 20 years insurance for investments in production equipment manufacturing; the MIGA Convention stipulates that the insurance period is no less than 3 years, up to 15 years, and

Table 3: Comparison of overseas investment insurance term, insurance amount, and insurance premium rates of various countries.

	United States	Japan	Germany	MIGA
Insurance term	(i) Up to 20 years	(i) 5–15 years generally (ii) Can exceed 15 years based on investment and construction needs	(i) Equity investment up to 15 years (ii) Term for investment in production equipment manufacturing is 20 years	(i) 3–20 years
Insurance amount	(i) 90% of the investment loss; the total compensation does not exceed 100 million US dollars	(i) 90% of the equity or loan claim	(i) The insured bears 80%–95% of the loss	(i) Equity investment: 90% (ii) Loan investment: 95% (iii) Other protocol investment: 95%
Insurance premium rates	(i) Foreign exchange insurance: 0.3% (ii) Expropriation insurance: 0.4–0.8% (iii) War risk insurance: 0.6% (iv) Comprehensive insurance: 1.5%	(i) Comprehensive insurance: 0.55% (ii) Investment in resource development: 0.7%	(i) Insurance period within 5 years: 0.6% (ii) Insurance period within 5–10 years: 1% (iii) Insurance period within 15–20 years: 1.5%	(i) Guaranteed amount less than $25 million: $5,000 (ii) Guaranteed amount over $25 million: $10,000

can be extended to 20 years in special circumstances. In terms of the insurance amount, overseas investment insurance in most countries provides insufficient insurance, and the insurance amount is only a part of the investment amount, and the specific proportion is roughly the same, basically 90%–95%. In terms of insurance premium rates, in order to encourage overseas investment, the premium rates set by various countries are generally not high, and they vary by type of insurance, investment industry, scale, and the risk environment of the host country, as shown in Table 3.

6.7. Venture Fund or Reserve System. Overseas investment projects are usually large-scale and high-risk; therefore, providing overseas investment guarantees to back them up requires a large amount of capital. In addition to the government providing financial support, establishing risk funds, and absorbing private insurance funds, countries are also actively exploring new ways to expand risk reserves. Among them, Japan's overseas loss reserve system is a major innovation to expand capital reserves and resist overseas investment risks. This system is currently only applicable to overseas investments in energy such as oil, natural gas, coal, metal minerals, and timber. According to this system, the insured pays the reserve according to the investment ratio before the project is implemented, and the reserve ratio varies according to the different stages of mineral energy development. When an enterprise's overseas investment is damaged, in addition to applying for overseas investment insurance claims, it can directly obtain compensation from the reserve; if there is no loss, the reserve can be accumulated for a certain year (usually 5 years) and divided into a certain fraction (usually 5 copies), which are consolidated into the taxable income for taxation year by year, thereby reducing the tax burden on investors. The loss reserve system, to some extent, can be regarded as an investor's preexisting capital reserve to defend against the risks that may be brought about by overseas investment. On the one hand, it reduces the pressure of government claims settlement, and on the other hand, it is combined with the overseas investment insurance system to increase the channels for investors to obtain compensation, alleviate the impact of investment losses on enterprises, and help enterprises resist investment risks.

6.8. SME Support System. SMEs play an irreplaceable role in the economic activities of countries, including overseas investment activities. Therefore, the overseas investment guarantee systems of various countries usually set up special preferential support policies for small and medium-sized enterprises. Taking the United States as an example, the US overseas investment insurance system requires OPIC to give priority to underwriting overseas investment projects of small and medium-sized private investors, provide additional insurance types for SMEs, increase the underwriting ratio, provide premium discounts, and give priority to protecting the interests of SMEs in overseas investment. German guarantee agencies provide diversified services for SMEs, provide consulting for SMEs overseas investment, and negotiate insurance coverage on a case-by-case basis to meet the specific insurance needs of SMEs. MIGA even launched the Small Investment Program (SIP), which offers SMEs more favorable rates and faster insurance procedures.

6.9. Flexible and Diverse Cooperation Mechanisms. To enhance the vitality and applicability of the overseas investment guarantee mechanism and give full play to its role in guaranteeing, countries are actively developing flexible and diverse cooperation mechanisms. The Japanese government requests to cooperate with the government of the host country and entrusts the local insurance agency of the host country to accept the insurance application of the Japanese-funded enterprise, and the Japanese insurance agency will reinsure the reinsurance business of the local insurance agency. In the event of a government risk, the Japanese-

funded enterprise will receive compensation from the Japanese insurance institution. Through this "co-insurance" and "reinsurance" to bind benefit, the local insurance agencies in the host country are motivated to protect the investment rights and interests of Japanese companies, and the political risks faced by Japanese companies in the host country are reduced. US law also encourages OPIC to "co-insure" and "reinsure" with private investment guarantee agencies to meet market needs to the greatest extent possible [29]. MIGA actively cooperates with guarantee agencies of various countries to provide reguarantee for the overseas investment projects it has already underwritten.

7. Current Situation and Problems of China's Overseas Investment Insurance

In the 1980s and 1990s, the People's Insurance Company of China and the Export-Import Bank of China took the lead in obtaining the qualification to operate overseas investment insurance business. In 2001, China Export & Credit Insurance Corporation ("SINOSURE" for short) was established, replacing the above-mentioned agencies as the only agency providing overseas investment insurance in China. Since 2003, it has officially launched overseas investment guarantee business.

Judging from the legal basis, China has not yet established a legal system for overseas investment insurance. SINOSURE undertakes overseas investment insurance business, mainly guided by a series of regulations in the form of notices by relevant departments. Among them, the normative document with the highest legislative level is the "Notice on Issues Concerning the Establishment of a Risk Protection Mechanism for Key Overseas Investment Projects" ("Notice") jointly issued by the National Development and Reform Commission and SINOSURE in 2005 [3]. The "Notice" briefly stipulates the key projects supported by risk insurance, the subject of application for insurance, and the content of insurance scope. The Supreme People's Court also issued relevant judicial interpretations in 2013, clarifying the application of law in the trial of overseas investment insurance contract disputes by the people's courts. In addition, the normative documents issued by the Ministry of Commerce, the Ministry of Finance, the Ministry of Science and Technology, etc. are also slightly involved with overseas investment insurance, But the normative documents issued by these departments are not systematic and merely touch on. At present, the main basis for guiding overseas investment insurance business is still the "Guidelines for Overseas Investment Insurance" ("Guide to Insurance") formulated by SINOSURE. In terms of nature, the "Guide to Insurance" is only a guide for the business handling of SINOSURE, not a legal document, and does not have common legal binding force [24]. In general, the legislative level and effectiveness of China's legal system related to overseas investment insurance are low. The content of those legal documents is too general and principled, and it lacks operability and does not play the due role of legislation to protect and promote overseas investment insurance.

In terms of legislative model, the "Guide to Insurance" describes qualified investment as "should comply with policies in terms of foreign policy, foreign trade, industry, fiscal and financial sectors, comply with the laws and policies of the host country of the investment project, and obtain approvals related to the investment project" [29]. It is clear that China adopts the "unilateral model," which may make it difficult for insurance agencies to seek compensation from the host country after settlement of claims. In terms of the form of legislation, SINOSURE is solely responsible for the approval and underwriting of insured projects, which is the mode that the approval agency and the operating agency are integrated. However, SINOSURE is only a policy-based financial agency, not the subject of administrative evaluation and approval, and it lacks a clear legal basis to act as an evaluation and approval institution. In terms of insurance types, SINOSURE covers expropriation insurance, exchange restriction insurance, war and political riot insurance, and default insurance. These types are mainly designed for the characteristics of political risks of overseas investment in the 1960s and 1970s. The types and their contents are generally traditional, and they do not cover the emerging insurance types in recent years, and their specific connotations are not clear enough and lack operability. In terms of underwriting conditions, qualified investments stipulated in the "Guide to Insurance" include domestic legal persons in China, overseas legal persons actually controlled by Chinese legal persons, and domestic and overseas financial institutions that provide financing for the project, excluding natural person investors; qualified investment projects shall comply with China's national interests and obtain project-related approvals and shall be in line with the laws of the host country; the form of investment is limited to direct investment, including equity investment, shareholder loans, shareholder guarantees, and loans from financial institutions. The insurance period and insurance amount are roughly the same as those of other countries, but the average insurance rate of 4% is generally higher than the average rate of 0.5%–2% in major capital exporting countries such as the United States, Japan, and Germany, which, to some extent, inhibits the enthusiasm of investors to purchase insurance, as shown in Table 4.

Judging from the data of the past five years, the overseas investment insurance underwritten by SINOSURE has increased year by year. In 2019, the underwriting amount reached 61.33 billion US dollars, which was five times higher than that in 2010, but the proportion of the total underwriting amount of SINOSURE was still limited. It reached the highest level in history, but only accounted for 10.06% of the total insurance coverage. Compared with the stock funds of foreign direct investment in China in the same period, the insurance coverage rate is only 2.92%, which is still far from the international average of 10%–15% [2]. Moreover, the structure of the insured is extremely unreasonable. State-owned enterprises account for the vast majority, and the share of central enterprises is as high as 2/3 [30]. To sum up, the overseas investment insurance business of SINOSURE has not been fully developed, and it is far from playing its due role in protecting the overseas investment of enterprises. The main reason lies in the lack of legislation and the lack of clear and systematic legal norms in insurance practice, which greatly restricted the business development.

Table 4: 2015–2019 SINOSURE overseas investment insurance business and insurance coverage statistics.

Year	Covered amount of overseas investment insurance (100 million USD)	Total covered amount (100 million USD)	Proportion of overseas investment insured amount (%)	Stock funds for overseas investment (100 million USD)	Insurance coverage rate (%)
2015	409.4	4713.2	8.69	10978.6	3.73
2016	426.5	4730.7	9.02	13573.9	3.14
2017	488.9	5246	9.32	18090.4	2.7
2018	581.3	6122.3	9.49	19822.7	2.92
2019	613.3	6097.9	10.06	20994	2.92

8. Some Ideas on Establishing and Perfecting China's Overseas Investment Insurance System

Based on the legislative experience of the United States, Japan, Germany, and MIGA, this paper proposes the following ideas for the construction of China's overseas investment legal system.

The United States has founded US Model BIT through numerous negotiations and inserted "subrogation" term into BITs signed with other countries, to provide international legal basis for domestic insurance agency to claim compensation from the host countries after making compensation. Moreover, the United States has protected the interests of small and medium-sized private investors in overseas investment by giving priority to SMEs in their overseas investment insurance. Such practice could be a worthy example for China.

Japan, same as China, is one of the major economies in Asia, which has faced similar circumstances and has gone through similar development process in overseas investment compared with China [31]. Japan has achieved notable success by a raft of overseas investment promoting and supporting measures, especially the "loss reserve" policy for overseas investments in sectors of energy, electricity, and infrastructure. These will be very enlightening and might meet the needs of Chinese investors who are involved in the same location and sectors or industries in their overseas investments.

Germany and China are the countries which signed the most BITs with other countries. German blend legislative mode combining "bilateral" and "unilateral" modes, and the legislative system in which approving agency is separated from operating agencies, might be more suitable for Chinese practice.

MIGA has been recognized as the most efficient and influential overseas investment insurance agency in the world, for its flexible and effective insurance rules and policies, especially the rules of underwriting categories and underwriting conditions and terms, and may provide valuable references to China.

On the above basis, the author would like to suggest the following approaches of establishing Chinese overseas investment insurance system.

8.1. Developing Legal System for Overseas Investment Insurance in a Timely Manner. First, laws related to overseas investment insurance should be formulated in a timely manner to provide norms and guidelines for overseas investment insurance practices. At this stage, the "Overseas Investment Insurance Regulations" can be formulated to clarify the purpose and objectives of the overseas investment insurance system, the nature and status of insurance agencies, the scope of insurance, insurance conditions, insurance procedures, insurance amount, duration and rate, loss compensation, and other matters. In particular, the subrogation rights of insurance institutions should be clarified. When conditions and time are ready, the regulation can be upgraded to the "Overseas Investment Insurance Law" or integrated into the "Overseas Investment Law" and lay out the institutional foundation for overseas investment insurance.

8.2. Establishing "Bilateral Model" Investment Guarantee System. China's Credit Insurance has only been established for 20 years, and the operating time of overseas investment insurance business has not been long. Compared with the US's tens of billions of US dollars of registered capital, China Credit Insurance's 4 billion registered capital has weaker anti-risk capabilities. It is necessary to ensure subrogation through the subrogation clause of BIT to prevent risks. Furthermore, China has signed BITs with more than 130 countries around the world and basically covers the 20 countries with the most concentrated foreign investment. Among the 65 countries along the "Belt and Road," China has signed BITs with 56 countries, most of which contain subrogation clauses [29] and have established the basis for the establishment of a "bilateral-based" legislative model. Therefore, China should adopt a "compromising" legislative model, that is, to take the bilateral model as principle and the unilateral model as exception when necessary. Specifically, a BIT signed by China and the host country should be the premise for insurance; on this basis, China should leave some room for key investment projects encouraged by the state, which can be free from the restrictions of signing a BIT, so as to protect investors' investment rights and regulate the focus and direction of overseas investment.

8.3. Establishing a Legislative System That Separates Approval Institutions from Operating Agencies. China's overseas investment insurance system should establish a legislative system that separates the approval institution from the operating agency, with a specialized institution directly under the State Council as the approval institution for overseas

investment projects and SINOSURE as the only operating agency for overseas investment insurance business.

At this stage, the Ministry of Commerce can perform the approval duties concurrently, with the active cooperation of the Ministry of Finance, the Ministry of Foreign Affairs, and other departments. When conditions and time are ready, representatives of the above departments can be formed to set up a special "underwriting approval committee." Among them, the Ministry of Commerce is responsible for the evaluation and review of investors and investment projects, the Ministry of Finance is responsible for paying investors in advance after risks occur, and the Ministry of Foreign Affairs is responsible for the communication and negotiation with the host country government when risks occur, and to claim against the host country on behalf of the country after the Ministry of Finance makes the payment to the investors.

SINOSURE has accumulated rich experience in overseas investment insurance business. As the sole underwriting institution, it will continue to perform its underwriting duties. When conditions are ready, the overseas investment insurance business can be separated from its business, and an independent overseas investment insurance company can be established to undertake the business and clarify the legal status of the institution in the form of law.

8.4. Expanding Insurance Coverage Appropriately and Relaxing Insurance Conditions. In terms of underwriting types, the types and their contents should be further expanded and updated in accordance with overseas investment practices and needs. Specifically, transfer insurance and losses caused by discriminatory exchange rates adopted by the host country should be supplemented in the foreign exchange insurance; terrorism insurance should be added to war and political riot insurance; expropriation insurance should include both direct violent expropriation or seizure and indirect "cannibalizing expropriation"; and government default insurance should cover the violation or non-performance of relevant investment agreements by the central government, local governments, and state-owned enterprises, and the premise of applying for compensation is limited to the investor being unable or unable to obtain judicial relief in the host country in a timely manner. In addition, necessary insurance types such as delay or stop payment insurance and business interruption insurance should be added to strengthen the protection of overseas investment rights.

In terms of qualified investors, we should learn from common international practices and clarify that qualified investors include Chinese natural person or juridical person and foreign enterprises actually controlled by Chinese natural or juridical person, so as to enhance the enthusiasm of investors for insurance. In terms of qualified investment, first of all, it should be clarified that the investment project must conform to the national interests of China and be approved by the competent authorities and must comply with the laws and regulations of the host country or be approved by the host country. In terms of investment time, it can be either a new project, additional investment, or re-investment. In terms of investment forms, flexibility and diversification should be encouraged and allowed, and it is not appropriate to impose too many restrictions in the form of investment projects. Various forms of investment such as equity, creditor's rights, and loans should be allowed to maximize the participation of Chinese enterprises in international competition. In terms of compliant host countries, corresponding to the legislative model, qualified host countries should be limited to countries that have signed a BIT with China and maintain friendly relations with China. As for the economic development level of the host country, since China's overseas investment is widely distributed in both developed and developing countries, there should be no restriction on developed countries or developing countries in order to improve the applicability of overseas investment insurance.

In terms of coverage period and coverage amount, the current practice of SINOSURE is in line with international practice, and it is recommended to confirm it in the form of legislation. As far as the insurance rate is concerned, it is recommended to reset the insurance rate and ensure that the single type of insurance rate does not exceed 1% and the comprehensive insurance rate does not exceed 3%, so as to reduce the insurance cost of investors and increase their enthusiasm for insurance.

8.5. Establishing Venture Fund or Reserve System. The existing funds of SINOSURE come from the Export Credit Insurance Risk Fund, which is allocated by the national budget. Compared with the huge risks faced by overseas investment and the required funds, the scale of funds is very limited. To ensure that overseas investment insurance can truly play a protective role, it is necessary to increase financial support to SINOSURE and expand risk funds in a timely manner. At the same time, we can learn from the practice of Japan to establish a risk reserve system. For high-risk fields such as energy and minerals, power communication, infrastructure, and so on, the insured can voluntarily choose to pay the reserve before the project is implemented as compensation for future losses or as a basis for tax relief, so as to resist the risks that may be brought about by overseas investment.

8.6. Implementing the SME Support Program. At present, the number of small and medium-sized enterprises in China has accounted for more than 99% of the total number of enterprises in the country, creating a value equivalent to 60% of GDP and making significant contributions to promoting domestic economic development, increasing employment, and expanding exports and overseas investment. However, small and medium-sized enterprises lack the experience and necessary resources for overseas investment, and their risk awareness and risk tolerance capability are weaker than those of large state-owned enterprises. They face greater risks in the process of overseas investment, and it is necessary to provide support and help. SINOSURE should implement a SME support plan, set up a department to especially provide

insurance services for SMEs, open up green channel for SMEs, and design convenient and fast insurance procedures for SMEs to apply for insurance with certain discounts. In the meantime, it should provide early-stage investment consulting, risk assessment, financing assistance, etc. to SMEs to protect their overseas investment.

8.7. Developing Multilateral Cooperation Mechanism. SINOSURE can learn from foreign experience, actively develop diversified cooperation mechanisms, and cooperate extensively with private insurance agencies, foreign investment guarantee institutions, and international investment guarantee institutions. In particular, it should strengthen exchanges and cooperation with MIGA. It should adopt diversified cooperation modes such as reinsurance, co-insurance, and reinsurance and develop overseas investment insurance business with the help of various favorable resources to meet the diversified security needs of investors.

9. Notes

(1) Currency depreciation insurance refers to the risk in which overseas investors suffer losses due to the fact that the other party stops or delays payment and cannot freely convert the currency to depreciation.

(2) Delayed performance insurance refers to the risk of investment loss due to reasons not attributable to the investor, the bankruptcy of the investment counterparty, or the delay in performance due to debts for more than 6 months.

(3) Exhaustion of local remedies, also known as exhaustion of domestic remedies, means that when a foreign investor has a dispute with the government, enterprise, or individual of the host country, the dispute should be submitted to the administrative or judicial authority of the host country for settlement in accordance with the laws of the host country. Until the law has exhausted all local remedies, international procedures may not be sought, and the foreigner's home government may not exercise the right of diplomatic protection to hold the host country accountable.

(4) Expropriation means that the host country takes approaches such as nationalization, confiscation, expropriation, and so on to deprive the ownership and management rights of investment projects or the right to use and control the funds and assets of investment projects; exchange restrictions mean that the host country impedes, restricts the freedom of exchange of investors or increases the cost of exchange, and prevents the remittance of currency from the country; wars and political riots refer to revolutions, riots, coups, civil wars, rebellions, terrorist activities, and other war-like acts in the host country, resulting in the loss of assets or permanent inability of investment companies to operate; (government) default means the host country government or other subject recognized by the insurer breaches or fails to perform the agreement related to the investment project and refuses to pay compensation.

(5) Expropriation insurance refers to the risk of total or partial loss of the investment property of the insured due to expropriation or nationalization measures implemented by the host country government.

(6) Foreign exchange insurance refers to the risk in which the host country government takes corresponding measures to restrict or prohibit foreign investors from converting their investment principal, profits, or other legal income into foreign currency and transferring them out of the host country.

(7) Government default insurance refers to the risk of loss when the host government (and in some cases, state-owned enterprises) breaches or fails to perform its contract with the investor.

(8) Non-performance sovereign financial obligation insurance refers to the risk of loss to investors when the host country's central government, local government, or state-owned enterprise has unconditional financial payment obligations for investors' legitimate investments and fails to perform them.

(9) Suspended or postponed payment insurance is to insure against the risk that proceeds from the capital investment of an overseas investor that are unavailable due to the suspension or postponement of payment by the other party.

(10) The principle of continuation of nationality means that when a country wants to exercise the right of diplomatic protection for its nationals, it must prove that (1) the protected person is a citizen of that country and has the nationality of that country; (2) the protected person has continuous nationality of that country from the time of the injury to the time of jurisdiction or the official submission of the diplomatic request.

(11) War risk insurance refers to the risk of property loss of investors caused by war, revolution, riot, or civil strife in the host country.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] F. Li, "Investment risks and corresponding approaches of the Belt and Road countries," *China Business and Market*, vol. 30, no. 02, pp. 115–121, 2016.

[2] G. Wang and D. Wang, "Research on optimizing Chinese overseas investment insurance scheme——based on viewpoint of political risks prevention," *Finance and Economics*, no. 06, pp. 77–82, 2016.

[3] D. Guo and L. Li, "The perfection of China's foreign investment insurance legal system under the Belt and Road initiative," *Academic Journal of Zhongzhou*, vol. 10, pp. 63–67, 2018.

[4] Y. Ni and Q. Zheng, "Analysis on essentials of establishing Chinese outbound investment security and protection scheme," *Henan Social Sciences*, vol. 25, no. 12, pp. 19–23, 2017.

[5] H. Hu, "International comparison and references for Chinese outbound investment protection scheme," *Henan Social Sciences*, vol. 25, no. 12, pp. 23–28, 2017.

[6] S. Huang and X. Xiong, "Research on Korean overseas investment protection scheme and the enlightenment to China [J]," *Asia-Pacific Economic Review*, vol. 04, pp. 36–39, 2004.

[7] H. Yang, "Improving comprehensive service system for overseas investments and promoting implementation of "going out" strategy ——enlightenment from Korean experience," *Journal of Central University of Finance & Economics*, no. 10, pp. 99–105, 2014.

[8] K. Bi and P. Wang, "Research on policy support for international investments by Chinese retail enterprises," *Research on Financial and Economic Issues*, no. 11, pp. 114–119, 2011.

[9] R. Li, "Construction of legal mechanism for China's overseas energy investment guarantee from the perspective of comparative method," *Law Review*, vol. 35, no. 06, pp. 119–126, 2017.

[10] R. Deng, "Discussion on several issues of Chinese overseas investment insurance legal system," *Modern Law Science*, no. 02, pp. 63–66, 1996.

[11] Y. Mu and X. Chen, "The establishment of overseas investment insurance scheme of China," *Law Science*, no. 08, pp. 96–103, 2006.

[12] K. Bin, "The establishment of Chinese overseas investment insurance legal system under the background of "one Belt one Road"," *Modern Communication*, no. 23, pp. 60–62, 2018.

[13] Y. Liu, "Reconstruction of overseas investment insurance legal system under the background of "one Belt one Road"," *The Social Science Journal*, no. 01, pp. 184–188, 2021.

[14] J. Yang and Ma Lin, "Protection by insurance under the background of "one Belt one Road"," *China Financialyst*, no. 21, pp. 34-35, 2016.

[15] Z. Cai, "Overseas investment insurance scheme of the United States and Japan and the enlightenment," *Journal of International Economic Cooperation*, no. 12, pp. 53–55, 1994.

[16] L. Zhou, Bo Xiong, and C. Liu, "Comparison on overseas investment insurance scheme——in perspective of establishing Chinese overseas investment insurance scheme," *Economic Relations and Trade*, no. 09, pp. 27–30, 1997.

[17] S. Xu and M. Sun, "Enlightenment from international experiences for Chinese enterprise's prevention of risks in overseas direct investments," *Academic Communication*, vol. 05, pp. 116–120, 2014.

[18] H. Chen, "Experiences and the enlightenment of financial support for outbound direct investments in different countries," *Shanghai Insurance Monthly*, no. 11, pp. 28–31, 2011.

[19] J. Huang, "American government's role in the outbound investments and the enlightenment," *International Economics and Trade Research*, vol. 05, pp. 50–52, 2003.

[20] M. Li, "Comparison of tax policies favoring outbound investments of the United States, France and Japan," *International Taxaion in China*, no. 05, pp. 42–45, 2006.

[21] X. Pan, "Constructing a protection system for Chinese enterprises' overseas investment——studying Japan's experience for reference," *Journal of International Economic Cooperation*, no. 09, pp. 61–66, 2017.

[22] X. Zhang, Yi Liu, and L. Xiao, "Research on financial supporting system for overseas investments of Chinese enterprises under the background of "one Belt one Road" initiative——experience of Japan and the enlightenment," *Inter*, no. 03, pp. 57–64, 2019.

[23] J. Yu, *International Investment Law*, p. 245, Law Press, Beijing, 1997.

[24] L. Guo, "Legislative conception of China's overseas investment insurance system under the Belt and Road initiative," *Southwest Finance*, no. 08, pp. 11–19, 2019.

[25] H. Qi, "Legal research on U.S. Foreign investment policy," *Journal of Beijing Technology and Business University*, vol. 27, no. 03, pp. 107–112, 2012.

[26] X. Chen and Y. Su, "Financial support for enterprises' cross-border M&A: lessons from the experience of the United States and Japan," *Journal of Shandong University of Finance and Economics*, vol. 29, no. 02, pp. 9–17, 2017.

[27] J. Chen, "A comparative study on the legal system of overseas investment insurance," *Insurance Studies*, no. 04, pp. 56–58, 2002.

[28] Z. Zhang, "apan's overseas investment insurance system and its enlightenment to China," *J Contemporary Economy of Japan*, vol. 05, pp. 31–33, 1997.

[29] J. Wang and S. Lin, "On the improvement and reconstruction of China's overseas investment insurance system under the framework of the Belt and Road initiative," *The Theory and Practice of Finance and Economics*, vol. 40, no. 01, pp. 156–160, 2019.

[30] B. Tao and L. Chen, "Risk avoidance of overseas investment: international comparison and reference," *Henan Social Sciences*, vol. 23, no. 08, pp. 16–21, 2015.

[31] G. Tian and S. Wang, "Experiences of Japanese outbound direct investments and the enlightenment to China," *Foreign Economic Relations and Trade*, no. 04, pp. 52–55, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6779558, 11 pages
https://doi.org/10.1155/2022/6779558

Research Article

Study on Steel Content Estimation of Reinforced Concrete Rectangular Pool Wall

Yanfang Li,[1,2,3] **Yonghua Wang**,[1,3] **Chao Ren**,[1,3] **Bo Zhang**,[4] **and Hongzhen Kang**[1,2]

[1]*School of Civil Engineering, Tangshan University, Tangshan 063000, China*
[2]*Hebei Key Laboratory of Building Engineering and Tailings Utilization, Tangshan 063000, China*
[3]*Tangshan Key Laboratory of Lean Construction and Informatization, Tangshan 063000, China*
[4]*Beijing General Municipal Engineering Design & Research Institute Co., Ltd., Beijing 100082, China*

Correspondence should be addressed to Yonghua Wang; tscwyh@tsc.edu.cn

Received 20 April 2022; Revised 24 May 2022; Accepted 20 June 2022; Published 7 July 2022

Academic Editor: Lele Qin

For water purification plants and sewage treatment plants, there is no reference optimal steel content for the wall of reinforced concrete water pool. Focusing on the reinforced concrete water pool, this paper explores the optimal wall thickness and optimal reinforcement area at different bending moments and identifies the optimal steel content. To solve the problem, the authors established the discrete distribution function for the engineering cost per unit length of pool wall and steel content. The theoretical model was verified by numerous data through Excel numerical simulation. The research results provide a reference optimal steel content for designers and help to save the engineering cost of pool wall.

1. Introduction

Most water plants or sewage treatment plants, either completed or under construction, adopt the rectangular reinforced concrete water pool, for the pool has various advantages. For instance, the pool adapts well to the field environment; the local materials can be directly used to build the pool; the reinforcement and supporting operations are very convenient; and the pool is durable and cheap to maintain [1, 2]. In traditional structural design, the designer usually determines the structural scheme through trial calculation, verification, and modification, according to the design requirements, his/her practical experience, and similar engineering designs. The scheme is rarely optimized through comparison due to time limit and excessive workload [3, 4].

During the expected construction boom of urban domestic wastewater treatment facilities, the key problem is the shortage of funds. In civil engineering cost, the material cost accounts for about 42%. Around 30% to 50% of the material cost is incurred by rebars [5]. How to estimate the steel content of each structure accurately and comprehensively is the focus and difficulty in cost analysis. In ACI 318-19 [6], GB 50010-2010 (2015 edition) [7], CECS138:2002 [8], and other codes, the reinforcement area and crack control of concrete are stipulated, but the structural design scheme is not optimized from the angle of cost reduction. In the past research on structural design optimization, researchers have studied the structural optimization design of residential buildings, complex buildings, commercial buildings, and single-storey industrial buildings [3, 4] and the reasonable steel content range of buildings by means of support vector machine method, genetic algorithm, statistical method, experimental and numerical study, etc. [9–20]. However, there is little report on the reasonable steel content for the minimal cost of water pools.

Based on the design specifications, and a thorough consideration of the feasibility of design and construction, this paper draws on the previous design experience and standard atlas and establishes a theoretical mathematical model that satisfies the force requirements and structural requirements. Through repeated data trials and verifications, the authors identified the optimal wall thickness and steel content that minimize the overall engineering cost of the

wall of reinforced concrete water pool, when the pool wall's bending moment changes under external load. The research results provide a direct reference for designers to reduce the engineering cost of the water pool.

The remainder of this paper mainly covers four aspects: firstly, a mathematical model was established for the total engineering cost, wall thickness, and horizontal reinforcement area; next, the optimal steel content was verified through numerical simulation [10–14]; and finally, the optimal steel content was solved to minimize the engineering cost per unit area of the pool wall.

2. Mathematical Modeling

2.1. Objective Function and Variables. This research intends to find the optimal steel content that minimizes the total cost of pool wall under the premise of fixed bending moment (that is, assuming that the internal control length, width, and height of the pool, the water level in the pool, and the layout of the pool partition wall are all determined). The steel content refers to the rebar content per unit area, i.e., the proportion of reinforcement area in unit area of pool wall [5].

The total cost of the pool wall refers to the total construction cost of the wall, consisting of construction and installation fee, equipment and instrument fee, other fees of project construction, preparation fee, and the loan interest in the construction period. Among them, equipment and instrument fee, other fees of project construction, and preparation fee are not related to wall thickness and steel content. Therefore, wall thickness and steel content mainly influence the construction and installation fee in the total cost function of the pool wall.

According to the composition of cost, the construction and installation fee can be divided into five parts: subengineering fee, measure item fee, other item fee, compliance fee, and taxes [21]. By the calculation program of engineering cost, the other item fee was set to zero. The compliance fee and taxes are charged in accordance with the provisions in laws and regulations of China and related to the first three elements of engineering cost. Therefore, the authors did not consider the other item fee, compliance fee, and taxes, when they explored the cost variation induced by the changes of wall thickness and steel content. Then, the total cost of the pool wall mainly depends on two factors: subengineering fee and measure item fee.

2.1.1. Subengineering Fee. The subengineering fee contains the fee of concrete and rebars, as well as the variation in labor cost and machinery cost induced by the changes in the use volume of concrete and rebars (without considering the impact of management fee and profit).

2.1.2. Measure Item Fee. The measure item fee mainly consists of the cost of concrete formworks. When the pool has a fixed length, width, and thickness, the formworks on the two sides are of equal volume and independent of wall thickness. Besides, the unit price of concrete and rebars has nothing to do with the wall form. Thus, the total cost (C) of the pool wall is primarily affected by the amount of concrete and steel content.

For the reinforced concrete rectangular water pool, the reinforcement configuration of the wall mainly faces two constraints: the force requirement and the structural requirement. The volume of the pool wall concrete is equal to the length × height × thickness of pool wall. This study assumes that the internal control length, width, and height of the pool are certain, that is, the length and height of the pool wall are certain, so the thicker the wall, the greater the use volume of concrete, and the fewer the rebars required to meet the force requirement. Once the wall reaches a certain thickness, however, the rebar volume may increase rather than decrease, for it depends on the structural requirement. This paper temporarily ignores the truncation of horizontal rebars, and the regional configuration of horizontal rebars on the pool wall; that is, the vertical and horizontal rebars are assumed to be deployed across the height of the wall. The impacts of other factors were investigated after solving the optimal wall thickness.

In summary, the objective function of our model is the total cost of the pool wall, and the variables include wall thickness (i.e., concrete volume) and horizontal reinforcement area (i.e., rebar volume). For simplicity, a strip of the pool wall was taken as the research object (Figure 1), with the length of Ln, the height of 1 m, and the thickness of h. Then, the cost per unit length of pool wall can be converted into a function of wall thickness and reinforcement area using the following formula:

$$\begin{aligned} C &= C_1 + C_2 \\ &= \frac{y_1 \times h \times 10^{-3} \times Ln \times 1 + y_2 \times A_s \times 10^{-6} \times Ln \times \varepsilon}{Ln} \\ &= y_1 \times h \times 10^{-3} + y_2 \times A_s \times 10^{-6} \times \varepsilon. \end{aligned} \tag{1}$$

Steel content $\rho = (A_s/h \times 1)$.
Then,

$$\begin{aligned} C &= f(\rho, A_s) \\ &= f[\rho, g(\rho)], \end{aligned} \tag{2}$$

where C is the cost per unit length of the pool wall (yuan); C_1 and C_2 are the cost per unit length of concrete and the cost per unit length of rebar (yuan), respectively; y_1 is the sum of labor, material, and machinery costs per square meter of concrete (yuan); h is the wall thickness (mm); Ln is the wall length; y_2 is the sum of labor, material, and machinery costs per kg of wall rebars (yuan); A_s is the horizontal reinforcement area on the 1 m-long strip (mm^2); ε is the appearance density of rebars (7,850 kg/m^3); and ρ is the steel content of pool wall.

2.2. Constraints. In actual engineering, the model of the pool wall is constrained by three factors: the force requirements on rebars, the structural requirements on rebars, and the crack width requirements.

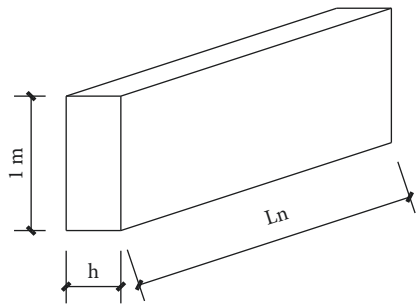


Figure 1: Research object of the model: 1 m-long strip of the pool wall.

2.2.1. Force Requirements on Rebars (Force Requirements under Strength Limit State). The wall of the reinforced concrete rectangular water pool is a bending component. Without considering prestressed rebars, this paper only takes account of the configuration of ordinary rebars. Referring to 6.2.10 of *Code for Design of Concrete Structures* (GB 50010-2010; 2015 version), the flexural capacity of the normal rectangular cross section (as show in Figure 2) must satisfy [7]:

$$M \le \alpha_1 f_c bx\left(h_0 - \frac{x}{2}\right) + f'_y A'_s (h_0 - a'_s), \tag{3}$$

$$\alpha_1 f_c bx = f_y A_s - f'_y A'_S. \tag{4}$$

Here, M is the bending moment; α_1 is the coefficient; f_c is the designed axial compressive strength of concrete; b is the width of rectangular section; x is the height of concrete compression zone; h_0 is the effective height of cross section; f'_y and f_y are the design value of tensile strength of steel bar in compression zone and the design value of tensile strength of steel bar in tensile zone; A'_s and A_s are the cross-sectional area of steel bar in compression zone and the cross-sectional area of steel bar in tensile zone; and a'_s is the unite efforts of longitudinal reinforcement in the compression zone.

That is, the load-bearing reinforcement area on the pool wall should satisfy formulas (3) and (4), when the bending moment M remains constant. Assuming that the bending component has only one rebar, it can be calculated that $A_s' = 0$. Then, formulas (3) and (4) can be simplified as formulas (5) and (6), respectively:

$$M \le \alpha_1 f_c bx\left(h_0 - \frac{x}{2}\right), \tag{5}$$

$$\alpha_1 f_c bx = f_y A_s, \tag{6}$$

$$\text{If } x < \varepsilon_b h_0, \text{ then } A_{s1} = \frac{\alpha_1 f_c bx}{f_y}. \tag{7}$$

2.2.2. Structural Requirements on Rebars (Configuration Requirements under Serviceability Limit State). According to 8.5.1 of *Code for Design of Concrete Structures* (GB 50010-2010; 2015 version), the reinforcement percentage of longitudinal load-bearing rebars in the bending components of reinforced concrete structure should not be lower than the larger value between the minimum reinforcement percentage $\rho_{\min} = 0.20$ and $45(f_t/f_y)$ [7]. Then, A_{s2} could be solved. Therefore, $A_s = \max\{A_{s1}, A_{s2}\}$.

The maximum reinforcement ratio stands for the reinforcement area when the longitudinal tensile rebars yield, and the concrete in the compressive zone fails. It can be calculated that $\varepsilon_b = 0.518$. When $x = \varepsilon_b h_0$, the maximum reinforcement ratio was 2.18%. The A_s must be controlled below the maximum reinforcement ratio.

2.2.3. Crack Width Requirements (Configuration Requirements under Serviceability Limit State). Referring to Appendix of the national standard CECS138:2002 [8], the crack width of large eccentricity tensile or compressive components must be smaller than or equal to the maximum crack width:

$$\omega_{max} = 1.8\psi \frac{\sigma_{sq}}{E_s}\left(1.5c + 0.11\frac{d}{\rho_{te}}\right)(1 + a_1)v \le [\omega_{\max}] = 0.20mm, \tag{8}$$

$$\psi = 1.1 - \frac{0.65 f_{tk}}{\rho_{te}\sigma_{sq} a_2}. \tag{9}$$

Under the permanent or standard combination of loads, the equivalent stress of the stress on the ordinary longitudinal rebars in the bending zone of reinforced concrete bending components can be calculated using the following formula:

$$\sigma_{\text{sq}} = \frac{M_q}{0.87 h_0 A_s}. \tag{10}$$

Combining formulas (8)–(10), the maximum crack width $\omega_{\max}$ of the pool wall can be solved. According to CECS138:2002 5.3.4 [8], the maximum crack width of the structural members of the reinforced concrete pool should not be greater than the following specified limit $\omega_{\max}$: for the clean water pool and the water purification treatment structure, $\omega_{\max} \le 0.25$mm; for sewage treatment structures, $\omega_{\max} \le 0.2$mm, so $\omega_{\max}$ must be smaller than $[\omega_{\max}] = 0.20$ mm.

2.3. Theoretical Modeling. When M is fixed, $M = \alpha_1 f_c bx(h_0 - (x/2))$ can be derived from the limit value of formula (5). According to formula (6), it can be solved that $x = (f_y A_s/\alpha_1 f_c b)$. Then, $M = \alpha_1 f_c bx(h_0 - (x/2)) = f_y A_s (h_0 - (f_y A_s/2\alpha_1 f_c b)) = f(h_0, A_s)$. By the definition of *Code for Design of Concrete Structures* (GB 50010-2010; 2015 version), it can be obtained that $h_0 = \text{h-}a'_s$ [7]. Since $\rho = (A_s/h \times 1)$, we have

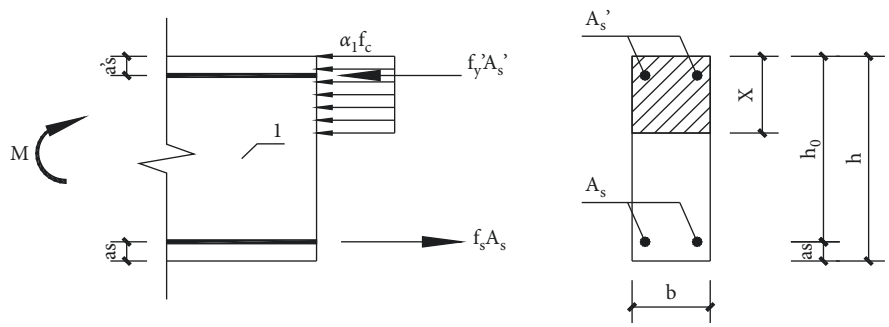


Figure 2: Calculation of flexural capacity of normal section of rectangular flexural members.

$$\begin{aligned} M &= f(h_0, A_s) \\ &= f(h, A_s) \\ &= f(\rho, A_s) \\ &= f[\rho, g(\rho)]. \end{aligned} \tag{11}$$

From formula (2), it can be learned that $C = f(\rho, A_s) = f[\rho, g(\rho)]$. Combining formulas (2) and (11), when M is constant, there exists an optimal steel content ρ that minimizes C. However, there are limited possibilities for the diameter and interval of rebars, i.e., A_s has a limited number of values. Thus, $C = f(\rho, A_s) = f[\rho, g(\rho)]$ is discrete. Next, the minimum C was searched for through numerical simulation.

3. Calculation of Optimal Steel Content through Numerical Simulation

Before formulating the verification grids for wall thickness and reinforcement area through numerical simulation (trial and error), it is necessary to preset the grid value and formula expression. Under a certain bending moment and wall thickness, the built-in formula of reinforcement area was calculated under model constraints. Next, the result of objective function (1), i.e., the total cost C, was solved, based on the combination between wall thickness and reinforcement area under a certain bending moment. Using the C value, the optimal steel content was queried, providing a reference for designers.

3.1. Calculation of Rebar Configuration

3.1.1. Calculation of Configuration and Structural Requirements on Load-Bearing Rebars. According to the normal force situation of the regular pool wall, the known conditions were set up in Excel (Table 1): the bending moment M of 250 kN·m; the wall thickness h of 400; the concrete grade of impervious C30; and the rebar grade of HRB400. The rebars were configured according to model constraints. Table 1 also lists the known data used to compute the reinforcement area of the pool wall.

According to formulas (5)–(7), and the known data in Table 1, $A_{s1} = 2047\,mm^2$ can be solved in Excel. Then, the reinforcement area table of plates was looked up in the rebar query software. The results show that, if φ20@150 rebars are used, the actual reinforcement area $A_{s1} = 2094\,mm^2$, and the reinforcement percentage ρ satisfies the requirement $\rho_{\min} = 0.2\% < \rho = 0.57\% < \rho_{\max} = 2.18\%$. Thus, the configuration of rebars φ20@150 meet the force and structural requirements on rebars.

3.1.2. Calculation of Maximum Crack Width. When rebars φ20@150 were deployed on the pool wall, the crack constraint was set up in Excel. The known conditions are presented in Table 2.

According to formulas (8)–(10), and the known data in Table 2, the maximum crack width can be solved as $\omega_{\max} = 0.332 > [\omega_{\max}] = 0.20\,mm$. The crack requirement was not satisfied, calling for expansion of rebar configuration.

The above calculations were repeated to verify whether the rebars on the wall satisfy the force and structural requirements, and whether the maximum crack width meets the crack requirement. In this way, four qualified reinforcement patterns were found for the pool wall: 20@100; φ22@125; φ25@150; and φ28@150.

The reinforcement pattern of φ22@125 was preferred because its reinforcement area was the smallest (3,040 mm^2). Then, the actual reinforcement area $A_{s1} = 3040\,mm^2$, and the reinforcement percentage ρ satisfies $\rho_{\min} = 0.2\% < \rho = 0.83\% < \rho_{\max} = 2.18\%$. The rebar configuration meets the force and structural requirements. In this case, the maximum crack width $\omega_{\max} = 0.180 < [\omega_{\max}] = 0.20$ mm meets the crack requirement. Hence, when the bending moment M is 250 kN·m, the wall thickness h is 400, the concrete grade is impervious C30, and the rebar grade is HRB400; the reinforcement pattern that meets model constraints and minimizes the actual reinforcement area is φ22@125, and $A_{s1} = 3040$ mm^2.

3.1.3. Calculation of Wall Thickness and Rebar Configuration Meeting Model Constraints. By the above computing process, the rebar configuration meeting model constraints were solved for walls of different thicknesses, when the bending moment M of the wall was 250 kN·m. The results are displayed in Table 3.

With the bending moment of 250 kN·m, the above reinforcement patterns were compared, and the optimal one was selected by the principle of minimizing reinforcement area. The optimal results are displayed in Table 4.

Table 1: Known data used to compute the reinforcement area of the pool wall.

Symbol	f_c	α_1	f_y	ε_b	$\rho_{\min}$	$\rho_{\max}$	c	M	b	h	h_0
Meaning	Designed axial compressive strength of concrete	Coefficient	Designed tensile strength of rebars	Height of relative critical compressive zone	Minimum reinforcement ratio	Maximum reinforcement ratio	Thickness of protective layer	Bending moment	1 m-long strip	Wall thickness	Effective height of cross section
Known data	14.3	1.00	360	0.550	0.20%	2.18%	35	250	1000	400	365
Unit	N/mm^2	None	N/mm^2	None	None	None	mm	kN·m	mm	mm	mm

Table 2: Known data used to compute the maximum crack width.

Symbol	f_{tk}	E_s	$[\omega_{\max}]$	a_1	a_2	v	d
Meaning	Standard axial compressive strength of concrete	Elastic modulus of rebars	Maximum crack width	Coefficient	Coefficient	Surface characteristic coefficient of longitudinal tensile rebars	Rebar diameter
Known data	2.01	200000	0.20	0.0	1.0	0.7	20
Unit	N/mm^2	N/mm^2	mm	—	—	—	mm
Symbol	c	Mq	b	h	A_s		h_0
Meaning	Thickness of protective layer	Bending moment	1 m-long strip	Wall thickness	Actual reinforcement area		Effective height of cross section
Known data	35	196.85	1000	400	2094		365
Unit	Mm	kN m	mm	mm	mm^2		mm

Table 3: Rebar configurations of different wall thicknesses.

Wall thickness	250		300			350			
Actual rebar configuration	φ25@100	φ28@125	φ22@100	φ25@125	φ28@125	φ20@100	φ22@100	φ25@125	φ28@150
Actual reinforcement area	4910	4928	3800	3928	4928	3140	3800	3928	4107
Wall thickness	400					450			
Actual rebar configuration	φ20@100	φ22@125	φ25@150	φ28@150	φ18@100	φ20@125	φ22@125	φ25@150	φ28@200
Actual reinforcement area	3140	3040	3274	4107	2540	2512	3040	3274	3080
Wall thickness	500					550			
Actual rebar configuration	φ18@100	φ20@125	φ22@150	φ25@200	φ28@200	φ16@100	φ18@100	φ20@150	φ22@150
Actual reinforcement area	2540	2512	2534	2455	3080	2010	2540	2094	2534
Wall thickness	550		600			650			
Actual rebar configuration	φ25@200	φ14@100	φ16@100	φ18@125	φ20@150	φ22@200	φ25@200	φ28@200	φ14@100
Actual reinforcement area	2455	1540	2010	2032	2094	1900	2455	3080	1540
Wall thickness	650					700			
Actual rebar configuration	φ16@125	φ18@150	φ20@150	φ22@200	φ25@200	φ28@200	φ14@100	φ16@125	φ18@150
Actual reinforcement area	1608	1694	2094	1900	2455	3080	1540	1608	1694
Wall thickness	700					750			
Actual rebar configuration	φ20@200	φ22@200	φ25@200	φ28@200	φ14@100	φ16@125	φ18@150	φ20@200	φ22@200
Actual reinforcement area	1570	1900	2455	3080	1540	1608	1694	1570	1900
Wall thickness	750					800			
Actual rebar configuration	φ25@200	φ28@200	φ16@125	φ18@150	φ20@150	φ22@200	φ25@200	φ28@200	
Actual reinforcement area	2455	3080	1608	1694	2094	1900	2455	3080	

Table 4: Rebar configuration and steel content selected by the principle of minimizing reinforcement area.

Wall thickness	250	300	350	400	450	500	550	600	750	800
Actual rebar configuration	φ25@100	φ22@100	φ20@100	φ22@125	φ20@125	φ25@200	φ16@100	φ14@100	φ14@100	φ16@125
Actual reinforcement area	4910	3800	3140	3040	2512	2455	2010	1540		1608
Steel content	1.96%	1.27%	0.90%	0.76%	0.56%	0.49%	0.37%	0.26%	0.21%	0.20%

Then, the wall of reinforced concrete water pool was simulated with a bending moment of 50–600 kN·m. Then, the reinforcement patterns of different wall thicknesses and a fixed bending moment were compared, and the one corresponding to the minimum bending moment was selected. Table 5 displays the optimal wall thickness and optimal reinforcement situation at different bending moments.

4. Calculation of Wall Cost per Unit Area

4.1. Calculation of Unit Area of Pool Wall. The above calculation of rebar configuration shows that the optimal rebar configuration is φ22@125 for the bending moment M of 250 kN·m, the wall thickness h of 400, the concrete grade of impervious C30, and the rebar grade of HRB400. Referring to the quota of engineering consumption in municipal projects [22], and the engineering information prices of Shijiazhuang, the seat of northern China's Hebei Province in August, 2020 (data source: Glodon Cloud PRICING Platform GCCP6.0), the wall cost per unit area can be solved by formula (1) as $C = C_1 + C_2 = y1 \times h \times 10^{-3} + y2 \times \mathrm{As} \times 10^{-6} \times \rho = 387.14 \times 400 \times 10^{-3} + 4.96 \times 3040 \times 10^{-6} \times 7850 = 266.77$ yuan. According to the optimal rebar configuration in Table 4, the wall costs C per unit area of pool walls of different thicknesses can be solved (Table 6).

Table 5: Optimal wall thickness and optimal reinforcement situation at different bending moments.

Bending moment	Reinforcement situation	Wall thickness											
		250	300	350	400	450	500	550	600	650	700	750	800
Bending moment 50	Reinforcement area	904	904	754	904	904	904	1130	1232	1340	1540	1540	1608
	Reinforcement pattern	φ12@125	φ12@125	φ12@150	φ12@125	φ12@125	φ12@125	φ12@100	φ14@125	φ16@150	φ14@100	φ14@100	φ16@125
	Steel content	0.36%	0.30%	0.22%	0.23%	0.20%	0.18%	0.21%	0.21%	0.21%	0.22%	0.21%	0.20%
Bending moment 100	Reinforcement area	2032	1340	1130	1027	904	1005	1130	1232	1340	1540	1540	1608
	Reinforcement pattern	φ18@125	φ16@150	φ12@100	φ18@200	φ12@125	φ16@200	φ12@100	φ14@125	φ16@150	φ14@100	φ14@100	φ16@125
	Steel content	0.81%	0.45%	0.32%	0.26%	0.20%	0.20%	0.21%	0.21%	0.21%	0.22%	0.21%	0.20%
Bending moment 150	Reinforcement area	3040	2512	2032	1540	1130	1130	1130	1232	1340	1540	1540	1608
	Reinforcement pattern	φ22@125	φ20@125	φ18@125	φ14@100	φ12@100	φ12@100	φ12@100	φ14@125	φ16@150	φ14@100	φ14@100	φ16@125
	Steel content	1.22%	0.84%	0.58%	0.39%	0.25%	0.23%	0.21%	0.21%	0.21%	0.22%	0.21%	0.20%
Bending moment 200	Reinforcement area	3800	3140	2512	2512	2032	1540	1540	1232	1340	1540	1540	1608
	Reinforcement pattern	φ22@100	φ20@100	φ20@125	φ20@125	φ18@125	φ14@100	φ14@100	φ14@125	φ16@150	φ14@100	φ14@100	φ16@125
	Steel content	1.52%	1.05%	0.72%	0.63%	0.45%	0.31%	0.28%	0.21%	0.21%	0.22%	0.21%	0.20%
Bending moment 250	Reinforcement area	4910	3800	3140	3040	2512	2455	2010	1540	1540	1540	1540	1608
	Reinforcement pattern	φ25@100	φ22@100	φ20@100	φ22@125	φ20@125	φ25@200	φ16@100	φ14@100	φ14@100	φ14@100	φ14@100	φ16@125
	Steel content	1.96%	1.27%	0.90%	0.76%	0.56%	0.49%	0.37%	0.26%	0.24%	0.22%	0.21%	0.20%
Bending moment 300	Reinforcement area		4910	3800	3800	3040	2540	2512	2010	2010	2010	1540	1608
	Reinforcement pattern		φ25@100	φ22@100	φ22@100	φ22@125	φ18@100	φ20@125	φ16@100	φ16@100	φ16@100	φ14@100	φ16@125
	Steel content		1.64%	1.09%	0.95%	0.68%	0.51%	0.46%	0.34%	0.31%	0.29%	0.21%	0.20%
Bending moment 325	Reinforcement area		4910	4910	3800	3140	3040	2540	2512	2010	2010	2010	1608
	Reinforcement pattern		φ25@100	φ25@100	φ22@100	φ20@100	φ22@125	φ18@100	φ20@125	φ16@100	φ16@100	φ16@100	φ16@125
	Steel content		1.64%	1.40%	0.95%	0.70%	0.61%	0.46%	0.42%	0.31%	0.29%	0.27%	0.20%
Bending moment 350	Reinforcement area		6160	4910	3800	3800	3140	3040	2540	2512	2010	2010	2010
	Reinforcement pattern		φ28@100	φ25@100	φ22@100	φ22@100	φ20@100	φ22@125	φ18@100	φ20@125	φ16@100	φ16@100	φ16@100
	Steel content		2.05%	1.40%	0.95%	0.84%	0.63%	0.55%	0.42%	0.39%	0.29%	0.27%	0.25%
Bending moment 375	Reinforcement area		6160	4910	3800	3800	3800	3040	2540	2512	2512	2512	2010
	Reinforcement pattern		φ28@100	φ25@100	φ22@100	φ22@100	φ22@100	φ22@125	φ18@100	φ20@125	φ20@125	φ20@125	φ16@100
	Steel content		2.05%	1.40%	0.95%	0.84%	0.76%	0.55%	0.42%	0.39%	0.36%	0.33%	0.25%
Bending moment 400	Reinforcement area		6160	4910	3800	3800	3800	3140	3040	2540	2512	2512	2010
	Reinforcement pattern		φ28@100	φ25@100	φ22@100	φ22@100	φ22@100	φ20@100	φ22@125	φ18@100	φ20@125	φ20@125	φ16@100
	Steel content		2.05%	1.40%	0.95%	0.84%	0.76%	0.57%	0.51%	0.39%	0.36%	0.33%	0.25%
Bending moment 425	Reinforcement area			6160	4910	4910	3800	3800	3040	3040	2540	2512	2512
	Reinforcement pattern			φ28@100	φ25@100	φ25@100	φ22@100	φ22@100	φ22@125	φ22@125	φ18@100	φ20@125	φ20@125
	Steel content			1.76%	1.23%	1.09%	0.76%	0.69%	0.51%	0.47%	0.36%	0.33%	0.31%

Table 5: Continued.

Bending moment	Reinforcement situation	Wall thickness											
		250	300	350	400	450	500	550	600	650	700	750	800
Bending moment 450	Reinforcement area			6160	4910	4910	3800	3800	3040	3040	3040	2540	2540
	Reinforcement pattern			φ28@100	φ25@100	φ25@100	φ22@100	φ22@100	φ22@125	φ22@125	φ22@125	φ18@100	φ18@100
	Steel content			1.76%	1.23%	1.09%	0.76%	0.69%	0.51%	0.47%	0.43%	0.34%	0.32%
Bending moment 475	Reinforcement area			6160	6160	4910	4910	3800	3800	3140	3040	3040	2540
	Reinforcement pattern			φ28@100	φ28@100	φ25@100	φ25@100	φ22@100	φ22@100	φ20@100	φ22@125	φ22@125	φ18@100
	Steel content			1.76%	1.54%	1.09%	0.98%	0.69%	0.63%	0.48%	0.43%	0.41%	0.32%
Bending moment 500	Reinforcement area			6160	6160	4910	4910	4910	3800	3800	3140	3040	2540
	Reinforcement pattern			φ28@100	φ28@100	φ25@100	φ25@100	φ25@100	φ22@100	φ22@100	φ20@100	φ22@125	φ18@100
	Steel content			1.76%	1.54%	1.09%	0.98%	0.89%	0.63%	0.58%	0.45%	0.41%	0.32%
Bending moment 550	Reinforcement area				6160	4928	4910	4910	4910	3800	3800	3140	3040
	Reinforcement pattern				φ28@100	φ28@125	φ25@100	φ25@100	φ25@100	φ22@100	φ22@100	φ20@100	φ22@125
	Steel content				1.54%	1.10%	0.98%	0.89%	0.82%	0.58%	0.54%	0.42%	0.38%
Bending moment 600	Reinforcement area					6160	6160	4910	4910	4910	3800	3800	3040
	Reinforcement pattern					φ28@100	φ28@100	φ25@100	φ25@100	φ25@100	φ22@100	φ22@100	φ22@125
	Steel content					1.37%	1.23%	0.89%	0.82%	0.76%	0.54%	0.51%	0.38%

Table 6: Wall costs per unit area of pool walls with optimal rebar configuration (yuan).

Wall thickness	250	300	350	400	450	500	550	600	650	700	750	800
Actual rebar configuration	φ25@100	φ22@100	φ20@100	φ22@125	φ20@125	φ25@200	φ16@100	φ14@100				φ16@125
Actual reinforcement area	4910	3800	3140	3040	2512	2455	2010	1540				1608
Wall cost C per unit area	287.96	264.10	256.80	266.77	268.51	281.09	285.31	284.86	303.41	321.97	340.52	361.82

As shown in Table 6, when the bending moment M of the pool wall was 250 kN·m, the wall cost C per unit area was minimized at 256.80 yuan. Similarly, the optimal rebar configuration was φ20@100 for the wall thickness of 350.

By analogy, the minimum wall costs C per unit area were obtained through repeated data calculations, with the bending moment of the wall in 50–600 kN·m and the wall thickness changing over time. The results are presented in Table 7.

According to the wall costs per unit area at different bending moments in Table 7, as well as the reinforcement patterns, reinforcement areas, and steel contents in Table 5, the minimum wall costs per unit area, and the corresponding steel contents at different bending moments were solved (Table 8).

Table 7: Wall costs per unit area at different bending moments (yuan).

Bending moment	Cost C											
	Wall thickness											
	250	300	350	400	450	500	550	600	650	700	750	800
50	133.33	152.69	160.34	184.95	203.50	222.05	249.74	272.41	295.33	321.97	340.52	361.82
100	178.93	170.31	175.54	189.92	203.5	226.13	249.74	272.41	295.33	321.97	340.52	361.82
150	215.15	217.7	212	210.66	212.64	231.19	249.74	272.41	295.33	321.97	340.52	361.82
200	244.74	238.4	231.41	249.96	249.1	247.76	266.31	272.41	295.33	321.97	340.52	361.82
250	287.96	264.1	256.8	271.3	268.51	281.09	285.31	284.86	303.41	321.97	340.52	361.82
300		307.32	277.81	296.36	285.32	288.19	305.61	303.87	322.42	340.97	340.52	361.82
325		307.32	321.03	296.36	293.90	303.87	306.74	324.16	322.42	340.97	359.52	361.82
350		355.99	321.07	296.36	314.91	312.45	322.42	325.29	342.71	340.97	350.52	378.07
375		355.99	321.03	296.36	314.91	333.46	322.42	325.29	342.71	361.26	379.81	378.07
400		355.99	321.07	296.36	314.91	333.46	331	340.97	343.84	361.26	379.81	378.07
425			369.70	339.58	358.13	333.46	352.01	340.97	359.52	362.39	379.81	398.36
450			369.7	339.58	358.13	333.46	352.01	340.97	359.52	378.07	380.94	399.49
475			369.70	388.25	358.13	376.68	352.01	370.56	368.10	378.07	396.62	399.49
500			369.7	388.25	358.13	376.68	395.23	370.56	389.11	386.65	396.62	399.49
550				388.25	358.83	376.68	395.28	413.78	389.11	407.66	405.2	419.71
600					406.8	425.35	395.23	413.78	432.33	407.66	426.21	415.17

Table 8: Minimum wall costs per unit area (yuan) and the optimal steel contents.

Bending moment	Wall cost	Wall thickness	Reinforcement area	Steel content (%)
50	133.33	250	904	0.36
100	170.31	300	1340	0.45
150	210.66	400	1540	0.39
200	231.41	350	2512	0.72
250	256.8	350	3140	0.90
300	277.81	350	3800	1.09
325	293.9	450	3140	0.70
350	296.36	400	3800	0.95
375	296.36	400	3800	0.95
400	296.36	400	3800	0.95
425	333.46	500	3800	0.76
450	333.46	500	3800	0.76
475	352.01	550	3800	0.69
500	358.13	450	4910	1.09
550	358.83	450	4928	1.10
600	395.23	550	4910	0.89

5. Conclusions

This paper establishes a mathematical model for the wall cost of reinforced concrete water pool, the thickness of concrete pool wall (concrete volume), and horizontal reinforcement area (rebar volume) and sets up a direct function between pool cost and steel content, $C = f[\rho, g(\rho)]$, under model constraints. Since the function is discrete, repeated data calculations were performed through numerical simulation, and the optimal steel contents were identified to minimize the wall cost per unit length at different bending moments. According to minimum wall costs per unit area and the optimal steel contents in Table 8, when the bending moment is between 50 and 150, the thickness of the pool wall, the optimal steel content, and the cost of the pool wall gradually increase, and the cost of the pool wall increases greatly; when the bending moment is between 200 and 300, the thickness of the pool wall remains unchanged, the optimal steel content and the cost of the pool wall gradually increase, and the cost of the pool wall increases little; and when the bending moment is between 350 and 400, 425 and 450, and 500 and550, the thickness of the pool wall, the optimum steel content, and the cost of the pool wall are unchanged. According to the bending moment of the pool wall, the structural designer can directly select the thickness and reinforcement area of the pool wall from Table 8, which minimizes the total cost of the pool wall. This study provides a good reference for designers in actual project design and solves the problem that designers have no time to optimize the design scheme and saves the cost of the pool.

Appendix

Calculation of the Maximum Crack Width of Reinforced Concrete Rectangular Section under Bending and Large Eccentric Compression (Tension)

Width of maximal crack under bending, large eccentric tension, or compression members could be calculated by using the following equation:

$$\omega_{\max} = 1.8\psi \frac{\sigma_{sq}}{E_s}\left(1.5c + 0.11\frac{d}{\rho_{te}}\right)(1 + a_1)v, \tag{A.1}$$

$$\psi = 1.1 - \frac{0.65 f_{tk}}{\rho_{te}\sigma_{sq}a_2}, \tag{A.2}$$

where $\omega_{\max}$ is the maximum crack width(mm); ψ is the nonuniformity coefficient of strain of longitudinal tensile reinforcement among cracks; σ_{sq} is the stress of longitudinal tensile rebars section calculated by quasi-permanent combination of action effect; E_s is the elastic modulus of rebars; and c is the thickness of concrete protective layer of outermost longitudinal tensile reinforcement.

d is the diameter (mm) of longitudinal tensile steel rebars, when rebars with different diameters are used, $d = (4A_s/u)$, where u is the total circumference of longitudinal tensile rebars section (mm), and A_s is the cross-sectional area of tensile rebars (mm^2).

ρ_{te} is the ratio of reinforcement of longitudinal tensile rebars calculated by effective tensile concrete cross-sectional area: $\rho_{te} = (A_s/0.5bh)$, where b is the calculated width of the cross section, and h is the calculated height of the cross section.

a_1 is the coefficient, $a_1 = 0$ for bending and large eccentric compression members, and $a_1 = 0.28[1/1 + (2e_0/h_0)]$ for the large eccentric tension members, where e_0 is the eccentricity of longitudinal force to the center of gravity of section(mm), and h_0 is the effective height of cross section (mm).

v is the surface characteristic coefficient of longitudinal tensile rebars, where $v = 1.0$ for smooth rebars; $v = 0.7$ for deformed rebars; f_{tk} is the standard axial compressive strength of concrete.

a_2 is the coefficient, $a_2 = 1.0$ for bending members, $a_2 = 1–0.2\ (h_0/e_0)$ for large eccentric compression members, and $a_2 = 1 + 0.35\ (h_0/e_0)$ for the large eccentric tension members.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This paper was funded by the General Project of Hebei Provincial Natural Science Foundation (Grant No. E2016105062).

References

[1] C. Q. Wang, *Rectangular Reinforced concrete Structure Analysis and Design of the Pool*, Xiangtan University, Xiangtan, China, 2015.

[2] Y. J. Jin, L. G. Xiao, and F. Luo, "The effects of steel content for the mechanics performance of fiber modified polymer resin concrete," *Advanced Materials Research*, vol. 690-693, pp. 760–762, 2013.

[3] H. Y. Lu, *Research on Optimal Design of High-Rise Building Structure Based on Genetic Algorithm and Criterion Metho*, Dalian University of Technology, Dalian, China, 2009.

[4] K. Daneshvar, M. J. Moradi, K. Ahmadi, and H. Hajiloo, "Strengthening of corroded reinforced concrete slabs under multi-impact loading: Experimental results and numerical analysis," *Construction and Building Materials*, vol. 284, Article ID 122650, 2021.

[5] M. M. Du and C. Y. Zhou, "Structural optimization of RC circular tanks," *Sichuan Building Science*, vol. 32, no. 1, pp. 69–71, 2006.

[6] Aci Committee, *ACI 318-19: Building Code Requirements for Structural Concrete and Commentary*, American Concrete Institute, Farmington Hills, MI, USA, 2019.

[7] Ministry of Housing and Urban-rural Development of the People's Republic of China, "Design Specification of concrete Structures," China Building Industry Press, Beijing, China, GB50010-2010, 2015.

[8] Beijing General Municipal Engineering Design and Research Institute Co, "Code for Structural Design of Reinforced concrete Pool in Water Supply and Drainage Engineering," China Building Industry Press, Beijing, China, CECS138: 2002, 2015.

[9] M. Soltanalipour, M. Ferrer, and F. Marimon, "Experimental and numerical study of the ductility of open-rib and reentrant composite slabs," *Engineering Structures*, vol. 256, Article ID 113984, 2022.

[10] G. Doudak, "Experimental and numerical study on the deflection of multi-storey light-frame timber shear walls," *Engineering Structures*, vol. 233, Article ID 111951, 2021.

[11] L. Guo, W. P. Shen, L. X. Guo, and L. Y. Wang, "Numerical simulation of concrete dam during heavy rain," *Magazine of Civil Engineering*, vol. 99, p. 9903, 2020.

[12] A. Abdellatif, M. Shedid, H. Okail, and A. Abdelrahman, "Numerical modeling of reinforced masonry walls under lateral loading at the component level response as opposed to system level response," *Ain Shams Engineering Journal*, vol. 10, no. 2, pp. 435–451, 2019.

[13] Y. Y. Zhang, Y. Q. Liu, H. H. Xin, and J. He, "Numerical parametric study on ultimate load and ductility of concrete encased equal-leg angle steel composite columns," *Engineering Structures*, vol. 200, Article ID 109679, 2019.

[14] L. M. Massone, G. Muñoz, and F. Rojas, "Experimental and numerical cyclic response of RC walls with openings," *Engineering Structures*, vol. 178, pp. 318–330, 2019.

[15] V. Plevris, "Optimum design of RC footings with genetic algorithms according to ACI 318-19," *Buildings*, vol. 10, no. 6, pp. 110–115, 2020.

[16] J. Ni, F. Tan, and F. X. He, "Research on estimation of steel content in high-rise residential buildings based on SVM," *Construction Economy*, vol. 2013, no. 6, pp. 46–50, 2013.
[17] Z. X. Tan, "General scope and control method of steel content of building structure," *Building Structure*, vol. 37, no. 7, pp. 17–19, 2007.
[18] F. Li, C. G. Zhou, and J. Hua, "Steel content analysis of a high-rise shear-wall residential building in shanghai," *Structural Engineers*, vol. 33, no. 5, pp. 8–12, 2017.
[19] F. Li, C. G. Zhou, and Z. P. Zheng, "Technical and economic analysis of monolithic precast concrete frame-cast-in-sit-ushear wall structure," *Building Structure*, vol. 46, no. 10, pp. 107–111, 2016.
[20] J. F. Guo, C. Y. Zhuang, and W. F. Zhang, "Analysis about the influential factors of steel content and design proposals," *Building Science*, vol. 26, no. 5, pp. 53–56, 2010.
[21] Q. Li, *Valuation of municipal engineering quantities bill*, Nan Jing: Southeast University publisher, Jiangsu, China, 2016.
[22] Ministry of Housing and Urban-Rural Development of the People's Republic of China, *Consumption Quota of Municipal Engineering ZYA1-31-2015 Water Treatment Engineering (Volume VI)*, China Building Industry Press, Beijing, China, 2015.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9286252, 11 pages
https://doi.org/10.1155/2022/9286252

Research Article

Accounting and Financial Management Cost Accounting Integrating Rough Set Knowledge Recognition Algorithm

Xiaoli Liu

School of Humanities and Management, Xi'an Traffic Engineering Institute, Xi'an 710300, China

Correspondence should be addressed to Xiaoli Liu; liuxiaoli@xjy.edu.cn

Received 30 March 2022; Revised 7 May 2022; Accepted 26 May 2022; Published 4 July 2022

Academic Editor: Lele Qin

The main difference between rough set theory and some methods of uncertainty theory, such as probabilistic data mining, fuzzy set theory, and evidence-based data mining, is that they do not require any prior knowledge beyond the data set being processed. This is also its advantage. At present, rough set theory has been well applied in artificial intelligence, knowledge discovery, pattern recognition, fault detection, and so on. According to the discovery model of classification knowledge, the attribute reduction of decision table, classification rule reduction, and classification algorithm under the condition of missing attribute are discussed. It tests the effectiveness of the knowledge recognition algorithm. The effectiveness of the algorithm proposed in this article reaches 87.6%, 84.4%, 94.97%, and 96.34%.

1. Introduction

With the rapid development of science and technology and the continuous progress of human civilization, individuals on the Earth have become more and more complex, so the information describing individuals has become more and more inflated and blurred. Also, the data obtained by a system are often inaccurate due to noise during acquisition. Therefore, in the face of a large amount of information, an uncertain and imprecise environment, the process of processing this information, and the process of target recognition become increasingly difficult and important. Therefore, how to extract implicit useful knowledge from this complex environment to help people make correct decisions or classify and identify has become a concern of many scholars. Financial management is a more important and indispensable part of enterprise management. It covers every department in an enterprise or an organization and has a high promotion value for improving the overall economic benefit level of the enterprise. It plays a very important role in the financial management of enterprises.

A fuzzy rough set is an extension of a rough set. By introducing fuzzy sets, it enables the attribute values of the target to be fuzzified rather than discretized using the relevant fuzzy theory. The fuzzification process preserves the differences in the original attribute values. Therefore, fuzzy rough sets can deal with uncertain and fuzzy information data more effectively. Compared with rough sets, the reduction and decision rules of the original database obtained by fuzzy rough set analysis and processing have higher accuracy.

Regarding rough sets, related scientists have made the following research. Ju describes a new cost-aware coarse-graining model that uses a multiple granularity approach. He constructed a lower- and upper-cost-aware method with multiple granularities and showed that in the multiple granularity framework, the data granularity and method are sensitive to decision and testing costs [1]. Ge uses the 13-moment eigenvalues retained by the rough set feature selection algorithm as input variables. It has the same computational error and recognition rate with reduced computational time steps [2]. She extends previous research on rough sets in two ways. He extended previous research from single particle to multi-particle, studying multi-granularity rough set theory from the perspective of three-way decision. He proposed a five-valued semantics for a multilinear rough set model generating a nondeterministic matrix [3]. Hu proposed a set method based on

rough set theory for incremental rough clustering. The quality of the final solution depends somewhat on the size of the set, and the parameter settings are reasonable to achieve the coarse approximation. The proposed method is robust to various conditions of rigid clustering [4]. Dev suggests that color channel selection is important for the accurate sky and cloud segmentation in images from ground-based cameras. He suggested using the approximate amount of visible light in the images to select the color channels. His proposed method evaluates the contribution of color channels to segmentation and determines the most efficient channel [5]. Singh introduced a technique based on rough set theory to model these symbolic representations. He provides an intuitive insight into the imprecise and imperfect knowledge of criminals. He has achieved good results in viewing sketch databases and forensic sketch databases [6]. Ji proposed a robust modified Gaussian mixture model with coarse theory for image segmentation. He compared the algorithm with synthetic and real image segmentation methods to demonstrate the superior performance of the proposed algorithm [7]. Azar proposes an improved coarse set-based predecessor for medical data classification. Coarse set priors can be used to process regular features. He proposed a method for applying dominance-based rough sets to ordered features. A dominance-corrected rough population results in higher accuracy [8]. Lee introduced the conceptual framework of the "relative value trading system." The framework focuses on the data characteristics of the currency futures market using correlation analysis and proxy analysis. The results of the experiments and analysis show that the correlation coefficient of currency pairs should be taken into account when developing a robust and profitable VR trading system in the currency futures market [9]. Kang proposes a grey stack with variable accuracy and variable precision. He further builds multiple granular structures by using grey relational relationships and then employs thresholds to control the number of satisfying conditions [10, 11]. Hao proposed an automatic detection model based on the theory of rough quantization, which takes into account the information in the field data. The simulations show that the proposed data-driven car detection model satisfactorily simulates the behavior of car detectors operating in micro-traffic [12]. Fan has introduced a new model for rough sets, which is called the maximum solution model for rough sets. Theoretical analysis and experimental results show that the algorithm can efficiently remove most redundant features without degrading the classification accuracy [13]. Diker proposed a method for fuzzy rough set models that uses a fuzzy version of the unit structure function. He defined fuzzy unit operations on fuzzy networks. It is found that the approximations of two different fuzzy rough set models together form two different Galois relations [14]. Zhu proposed a new element reduction criterion to select the lowest element. Moreover, the better performance of the corresponding algorithm in learning rough sets is maintained to some extent. Rough sets are an effective tool for estimating marginal and joint probability distributions of functions using mutual information[15]. He applied the cluster correlation analysis method to the indicators and then the rough series method to determine the weights of the extracted principal components. The results show that the weighting method based on rough series theory and principal component analysis is more reasonable and objective. Finally, some suggestions are made to promote the development of clean energy [16]. These methods provide some references for the research, but due to the short time and small sample size of the relevant research, the research has not been recognized by the public.

The innovation of this article is that the concepts related to rough sets are described using equivalence relation for classical information systems. It then proposes an attribute restoration algorithm based on an equivalence matrix to reduce the information matrix and decision matrix. In the case of fuzzy information and fuzzy decision matrices, it defines the concepts of upper approximation and lower approximation and the meaning of fuzzy functions and fuzzy matrix functions. It proposes an algorithm for function reduction and uses the UCI database to demonstrate the applicability of the algorithm [17, 18].

2. Accounting and Financial Management Costing Methods

2.1. Rough Sets. Rough set theory mainly uses the relationships derived from conditional attributes, such as similarity, correlation, proximity, and ambiguity, to complete data. It also uses the granulation results to evaluate the target concept for other purposes. It then minimizes the data model by selecting conditional attributes for different application purposes. It also captures the best or strongest representation of the data to simplify the problem and increase the efficiency [19].

Theories that can effectively deal with inaccurate, imprecise, and incomplete data analysis can be incorporated into artificial intelligence theory. It is able to discover knowledge in data with uncertainty and even in noisy data. By defining a lower approximation set with certain attribution and an upper approximation set containing uncertainty, it can better describe the boundary problem with ambiguity. In the objective world, the relationship between objects and classes is not a simple oppositional relationship of either black or white. Some objects do not necessarily belong to a certain class. It may belong to multiple classes at the same time.

Rough set theory mainly uses information systems to clearly represent the structure of data and mine the implicit knowledge.

$$E_B = \{(m,n) \in U \times U\colon\ x(m) = x(n), \forall x \in B\}, \tag{1}$$

where U is the collection of non-empty finite objects and E_B is the equivalence relation.

$$[m]_B = \{n \in U\colon\ (m,n) \in E_B\}, \tag{2}$$

where $[m]_B$ is the basic set or basic concept.

$$\begin{aligned}\overline{E}_B(M) &= \{m \in U\colon [m]_B \cap m \neq 0\} \\ &= \cup\{[m]_B\colon [m]_B \cap M \neq 0\}, \\ \underline{E_B}(M) &= \{m \in U\colon [m]_B \subseteq M\} = \cup\{[m]_B\colon [m]_B \subseteq M\},\end{aligned} \tag{3}$$

where $\overline{E}_B(M)$ is the upper approximation set and $\underline{E_B}(M)$ is the lower approximation set.

$$E_S = \{(m,n) \in U \times U\colon s(m) = s(n), \forall s \in S\}, \tag{4}$$

where E_s is the decision class and$S$ is the positive domain coordination set.

$$c(M,N) = \begin{cases} 1 - \dfrac{|M \cap N|}{|M|}, & |M| > 0, \\ 0, & |M| = 0, \end{cases} \tag{5}$$

where M, N are nonempty subsets of finite universes, $|M|$ is the cardinality of the set, and $c(M,N)$ is the relative misclassification rate.

$$\begin{aligned} BD_B^{\varepsilon}(M) &= \cup\{[m]_B\colon \varepsilon < c([m]_B, M) < 1 - \varepsilon\}, \\ NG_B^{\varepsilon}(M) &= \cup\{[m]_B\colon c([m]_B, M) \geq 1 - \varepsilon\}, \end{aligned} \tag{6}$$

where $BD_B^{\varepsilon}(M)$ is the boundary domain and $NG_B^{\varepsilon}(M)$ is the negative field.

$$C_B(m_1) = \{p_1, p_2, p_3\}, \tau_B(m_1) = \psi, \tag{7}$$

where $C_B(m_1)$ is the rough decision function and $\tau_B(m_1)$ is the fine decision function.

$$\begin{aligned} \overline{MR_B}(M) &= \bigcup_{m \in M} C_B(m) = \{p_u\colon \exists m \in M, [m]_B \cap W_u \neq 0\}, \\ \underline{MR_B}(M) &= \bigcap_{m \in M} \tau_B(m) = \{p_u\colon \exists m \in M, [m]_B \in W_u\}, \end{aligned} \tag{8}$$

where $\overline{MR_B}(M)$ is the approximate on the mark, $\underline{MR_B}(M)$ is the approximate under the mark, and E_i is the tag information collection.

$$\begin{aligned} C_B^{\varepsilon}(m) &= \left\{p_u\colon m \in \overline{E_B^{\varepsilon}}(W_u)\right\} = \{p_u\colon c([m]_B, W_u) < 1 - \varepsilon\}, \\ \tau_B^{\varepsilon} &= \{p_u\colon m \in E_B^{\varepsilon}(W_u)\} = (p_u\colon c([m]_B, W_u) \leq \varepsilon), \end{aligned} \tag{9}$$

where $c([m]_B, W_u)$ is the relative misclassification rate, $C_B^{\varepsilon}(m)$ is the generalized rough decision function, and τ_B^{ε} is the generalized fine decision function.

$$\varsigma_P(B_1) = \frac{\mu}{\sum_{m \in U}\left|C_{B_1}(m)\right|} \leq \frac{\sum_{m \in U}\left|\tau_{B_2}(m)\right| + \phi(B_2)}{\sum_{m \in U}\left|C_{B_2}(m)\right|}, \tag{10}$$

where $\varsigma_P(B_1)$ is the number of conditional attributes.

$$\tau_B^{\varepsilon}(M) = \frac{\left|MR_B^{\varepsilon}(M)\right|}{|P|}, \tag{11}$$

where ε is the misclassification rate and $\tau_B^{\varepsilon}(M)$ is the marking quality of the collection.

$$\tau_P^{\varepsilon}(B) = \frac{\sum_{u=1}^{D}\left|MR_B^{\varepsilon}(M_u)\right|}{d(P)}, \tag{12}$$

where $\tau_P^{\varepsilon}(B)$ is the mark approximate mass and B is the condition attribute set.

$$S_1\left(\frac{M}{Z}\right) = \frac{\sum_{u=1}^{b}\left|M_u \cap Z_u\right|}{\sum_{u=1}^{b}\left|Z_u\right|}, \tag{13}$$

where $S_1(M/Z)$ is the inclusiveness.

$$\varsigma_P(B) = \frac{\sum_{u=1}^{D}\left|\underline{M_u PE_B}(M_u)\right| + \varphi(B)}{\sum_{u=1}^{b}\left|M_u\right|\left|\underline{M_u PE_B}(M_u)\right|}, \tag{14}$$

where $\varsigma_P(B)$ is the mark dependency.

$$\begin{aligned} \tau_P^{\varepsilon}(B) &= \frac{\sum_{u=1}^{D}\left|\underline{MR_B^{\varepsilon}}(M_u)\right|}{d|P|}, \\ \omega_B(M) &= 1 - \delta_B(M) = 1 - S_0\left(\frac{\underline{MR_B}(M)}{\overline{MR_B}(M)}\right), \end{aligned} \tag{15}$$

where $\tau_P^{\varepsilon}(B)$ is the mark approximate mass and B is the condition attribute set.

Rough set theory is an effective tool to deal with various incomplete information such as imprecise, inconsistent, and incomplete. On the one hand, it benefits from its mature mathematical foundation and does not require prior knowledge. And on the other hand is its ease of use. Because the purpose of creating rough set theory and the starting point of research is to analyze and reason directly on the data. It discovers hidden knowledge and reveals potential laws. Therefore, it is a natural data mining or knowledge discovery method. It is compared with other methods of dealing with uncertain problems, such as data mining methods based on probability theory, data mining methods based on fuzzy theory, and data mining methods based on evidence theory.

Rough set theory is based on a classification process. It understands classification as an equivalence relation within a given space, which forms a spatial division. A rough set understands information to share data, and each shared set is called a concept. The main idea of rough set theory is to use a known database. It describes inaccurate or uncertain data with data from known databases.

The most significant differences between this theory and other theories dealing with uncertain and imprecise problems are: it does not need to provide any prior information beyond the set of data the problem needs to deal with. Therefore, the description or treatment of the uncertainty of the problem can be said to be relatively objective. This theory fails to include mechanisms for dealing with imprecise or uncertain raw data. So, this theory is highly complementary to other theories dealing with uncertainty or imprecision, such as probability theory, fuzzy mathematics, and evidence theory.

Rough sets use decision tables as the basic data representation. It is based on the classification mechanism. It understands the classification as the division of the analects

in a specific space by using the equivalence relationship, which is the ability to classify objects. In the existing decision table, different attributes play different roles in the process of knowledge acquisition. Some attributes may play a key role in the acquisition of knowledge, while others may be redundant. The existence of such redundant information not only wastes resources but also interferes with people to make correct and concise decisions. The rough set classification knowledge discovery model mainly includes the following steps:

(1) Modeling data acquisition. The so-called modeling data in the model include a training data set for model establishment and a test data set for model accuracy testing. There are two principles when selecting modeling data: comprehensiveness of data and validity of data. Comprehensiveness of data means that the data are derived from the entire scope of the model's use rather than a local scope. The validity of data means that all possibilities can be fully and effectively reflected through these data.

(2) Data preprocessing. Data preprocessing refers to the transformation of data into the form of decision expression. Its purpose is to reduce the difficulty and complexity of rough set classification knowledge acquisition and to improve the quality and effect of knowledge discovery.

(3) Attribute reduction. The attribute reduction is to destroy irrelevant information given the classification capability of the information sorting library. Since the downgrade process has a large impact on the downgraded asset valuation rules, similar valuation rules are rarely taken into account.

(4) The classification rules are reduced. It obtains useful rules in the field by analyzing a sample data set or database. The regular knowledge pattern obtains the decision rules from the decision information system. After attribute reduction of a decision table, as shown in Figure 1, it is a recognition framework based on fuzzy rough sets.

The concept of "knowledge" has many different meanings in different categories. In rough set theory, "knowledge" is considered as a classification ability. Human behavior is based on the ability to distinguish between real or abstract objects. For example, in ancient times, in order to survive, people must be able to distinguish between what is edible and what is not edible. When a doctor diagnoses a patient, he must identify which disease the patient has. These abilities to classify things according to their characteristics can be regarded as some kind of "knowledge."

During the classification process, individuals with similar differences are placed in the same category. Their relationship is an indistinguishable relationship. It assumes that only two black and white colors are used to separate objects in space into two categories: black objects and white objects. Then two objects that are both black are indistinguishable. Because the information describing their characteristic attributes is the same, they are all

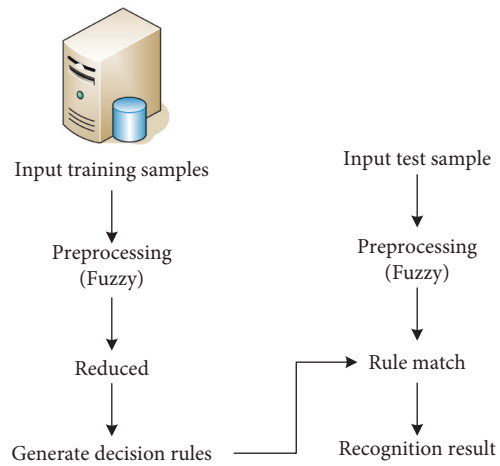


Figure 1: A recognition framework based on fuzzy rough sets.

black. If the attributes of squares and circles are introduced, the objects can be further divided into four categories: black square objects, black round objects, white square objects, and white round objects. At this time, if the two objects are both black, they are still indistinguishable. An indistinguishable relation is an equivalence relation. The indistinguishable relationship between two white round objects can be understood as their equivalent relationship under the two attributes of white and circle. The basic set is defined as a set composed of objects that are indistinguishable from each other in the universe, and it is the particles that make up the knowledge of the universe. The concept of indistinguishable relations is very important in rough set theory. It profoundly reveals the granular structure of knowledge. It is the basis for defining other concepts. Knowledge can be thought of as a family of equivalence relations. It splits the universe into a series of equivalent classes.

In a rough set, discretization is required for each continuous attribute. Discretization selects discrete breakpoints and then uses the breakpoints to divide the value range of the attribute into several subintervals. The resulting subintervals are finally mapped into several different exact variables, such as numbers 1, 2, 3, and so on. Therefore, the attribute values belonging to a subinterval are also replaced by the exact variables corresponding to the interval. It can be seen that the discretization process does not well preserve the differences and similarities between the original attribute values. Figure 2 shows the process of fuzzing a single attribute.

The simple utility of rough set methods is surprising. It can be quickly applied within a short time after its creation because of the following characteristics. It can handle all kinds of data, including incomplete data and data with many variables. It handles data imprecision and ambiguity, both deterministic and nondeterministic. It can obtain the minimum expression of knowledge and various granular levels of knowledge. It can reveal conceptually simple, easy-to-manipulate patterns from data. It can generate precise and easy to check and verify rules, especially suitable for the automatic generation of rules in intelligent control.

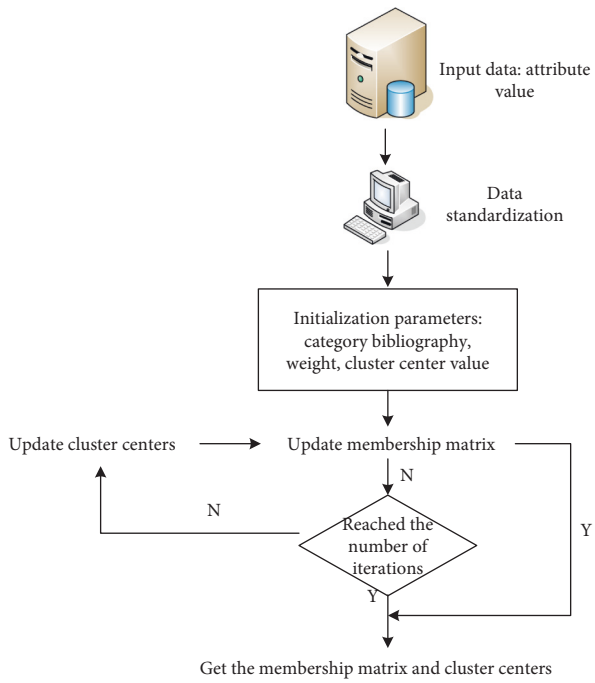


Figure 2: The process of fuzzing a single attribute.

Rough sets can effectively deal with the following problems: expression of uncertain or imprecise knowledge; empirical learning and acquisition of knowledge from experience; analysis of inconsistent information; uncertain, incomplete intellectual reasoning; data reduction while preserving information; and identifies and evaluates dependencies between data.

2.2. Accounting and Financial Management Costing. Accounting is mainly based on the accrual basis, and the unit of measurement is currency. Based on the actual transactions of enterprises and institutions, it makes accounting entries, completes accounting records, and prepares accounting statements and financial statements. Accounting is the recording, measurement, and communication of transactions and events of enterprises and institutions. The use of fictitious transactions and financial data in accounting is prohibited regardless of the institution. The main purpose of accounting is to present the financial position, performance, and cash flow of businesses and institutions. It also oversees the financial activities and income and expenditure of businesses and institutions. The basis of financial management is the objective existence of economic activities and economic relations. It is linked to the development of business and institutional activities. Financial management refers to organizing financial activities and managing financial relationships with various departments of a business or institution. Financial management is the management of value. It includes the financial activities of all enterprises and institutions and controls the entire financial work.

Accounting differs from financial management in its goals. The end result of accounting is the company's financial statements. They provide accounting information about the financial position, results, and cash flow of a business to those who use them and reflect the fiduciary responsibilities of business managers. Managerial accounting helps those who use financial statements to make informed financial decisions. Financial management is the management of finances through business activities in a specific economic environment. According to the theory and practice of institutional financial management, the typical goals of financial management are profit maximization, unit value maximization, and stakeholder benefit maximization. As shown in Figure 3, it is a classification diagram of assets used by logistic enterprises.

Accounting systems were originally set up for accounting purposes. With the development and evolution of society, the role of accounting has also undergone significant changes. Accounting reflects the economic activities that have taken place or are taking place in an entity through quantitative changes. It provides financial information to managers of entities, primarily in the form of various types of financial statements. Accounting is a very important part of any business. No business can survive without accounting. This makes it impossible to provide complete, accurate, and systematic financial information. Accounting work should continue to standardize accounting principles and should further develop general ledger, subsidiary ledger, and general ledger. It is necessary to clarify the content of the reconciliation between the accounts and truly reflect the financial status and operating results of the institution. This makes the accounting data of public institutions reliable and provides accurate and complete financial information for financial analysis and decision-making units. If the financial statements do not contain direct misstatements, accounting, and other effects, the financial management unit does not have critical business information and financial management has no room for negotiation. Therefore, accounting records are the foundation of financial management.

Financial management is based on the actual financial position of the company. It uses accounting data to forecast, plan, manage, evaluate, and control a company's financial activities. With the development of society, the market economy has been accelerating the pace of enterprise management. As an important concept, corporate financial management has become the consensus of everyone. Financial management is the life guarantee of enterprises and institutions, and financial management penetrates into all financial operations of institutions. Whether it is raising, spending, or distributing money, it is all about financial management, because all aspects of an institution's operation require financial aspects and controls. Since financial management is directly related to the survival and development of an enterprise, its core role in an enterprise is a realistic need and an objective requirement. Accounting is a form of expression. It displays an organization's business processes and results in the form of data. Financial accounting uses data from a business' financial statements and provides a specific method for systematically analyzing and

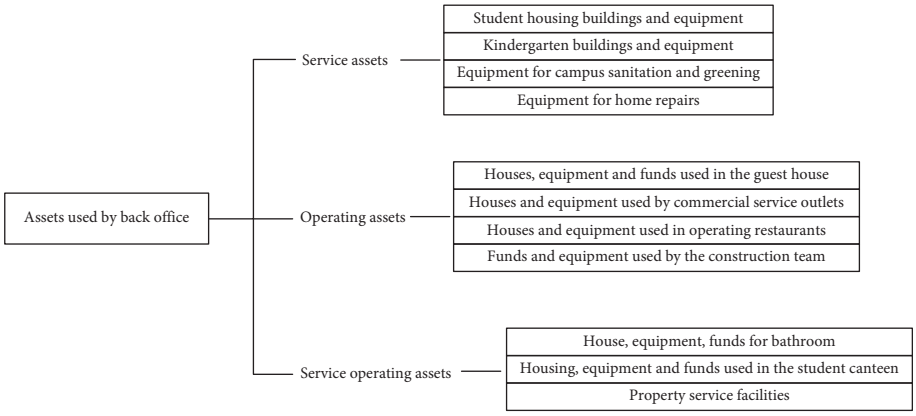


Figure 3: Classification diagram of assets used by logistic enterprises.

evaluating a business' financial management and performance. It provides insight into a company's profits and losses and future growth trends. This in turn provides important financial information for the financial management of the company and for making better financial decisions. Financial personnel should have high financial knowledge. This is the new financial management requirements for financial personnel. Enterprises should train and implement high-quality financial management personnel. Only in this way, enterprises can strictly implement the management of excess liquidity of enterprises in their daily work. This will facilitate the implementation of investment activities by enterprises. As shown in Figure 4, it is a business use case diagram of the financial management cost accounting system.

For small and medium-sized manufacturing enterprises, the simple general ledger module can no longer satisfy the detailed financial cost accounting. It can be combined with the introduction of a comprehensive budget management system or can enable the ready-to-use modules in the existing financial software. This makes the ERP system perfectly interpret and make the best use of it. In financial cost management, capital operation is the main line, and liquidity is the core assessment objective. It is related to various capability indicators of the enterprise. Accounting focuses on the accumulated profits in each period, while financial cost management looks at the value of various ratios. A comprehensive budget management system can integrate human, material, and financial information. It then forms a system for various cost accounting indicators such as procurement, production, sales, profitability, and cash flow. It realizes overall management and control, so that all departments and links within the enterprise can make overall planning and coordinate actions.

3. Accounting and Financial Management Costing Experiment

The knowledge in the database is not equally important and some information is redundant. The purpose of the so-called feature simplification is to remove irrelevant information from the database without affecting its categorizability. Since

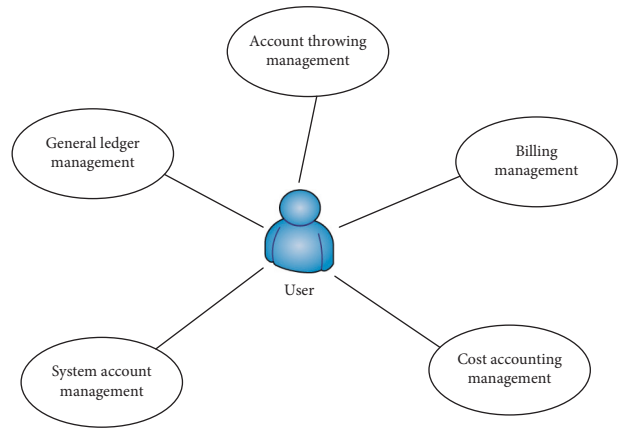


Figure 4: Business use case diagram of financial management costing system.

the process of feature simplification has a great influence on the classification rules, the number of features is reduced, and the corresponding classification rules consider less factors. If several simplifications have the same minimum number of eigenvalues, an optimal simplification is obtained. The simplification scheme with the smallest number of eigenvalues is called the best simplification scheme. Figure 5 shows the structure of the knowledge recognition system.

In order to verify the properties and some theorems of the variable multi-granularity coarse sugar set, three data sets were selected for simulation experiments, as shown in Table 1 for data description.

It is assumed that the decision attribute of the data set Dergy divides its own 376 samples into 4 decision classes and selects a subset of conditional attribute sets. It calculates the multi-granularity correlation approximation separately as shown in Table 2.

In the same way, the Tic and Zo data sets are processed in the same way, and the multi-granularity correlation approximations are obtained, as shown in Tables 3 and 4.

In order to verify the effectiveness of the method, a method to verify the effect of attribute reduction using the recognition accuracy of the classifier is given, and the recognition results of the support vector machine are shown in Figure 6.

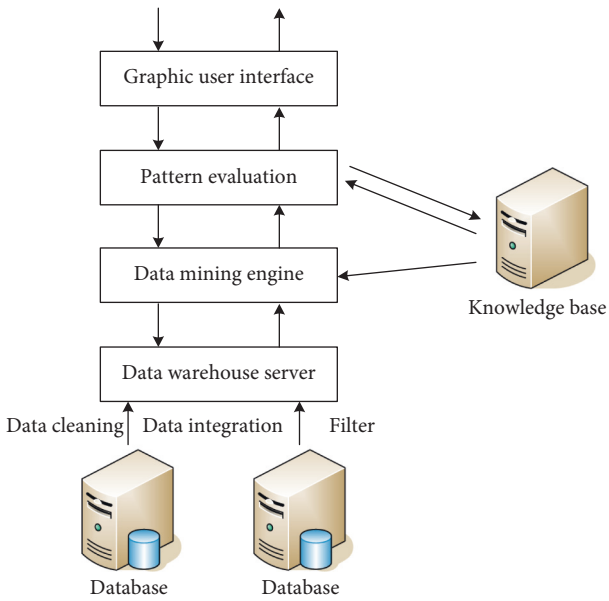


Figure 5: Knowledge recognition system structure.

It can be seen from the figure that the attribute subset selected by the method in this article obtains a classification accuracy that is almost the same as that of the unreduced data set of the full set of attributes. This shows that the redundant attributes of the data set cannot increase the classification of the data set.

It uses a completely disjoint test set and training set to test the effectiveness of the knowledge recognition algorithm. Each group of experiments was carried out 100 times, and the experimental results were taken as the average value of each experiment. The experimental results are shown in Figures 7(a) and 7(b).

It can be seen from the figure that among various training series, the classification accuracy of the method is the highest. The effectiveness of the knowledge recognition algorithm was tested, and the effectiveness of the algorithm proposed in this article reached 87.6%, 84.4%, 94.97%, and 96.34%. This shows that the method proposed in this article has the potential to transform general data into almost continuous values for decision information systems. When classical mass methods involve continuous-valued properties, an analysis must be performed first. But the separation method does not consider the influence of specific conditions on the classification ability of properties. Data collection methods are independent. This will result in data loss during the discretization process.

Each department entity is regarded as a cost center, and the financial management department is regarded as a forecast supervision center. The head office controls production and sales and is responsible for both costs and revenue. It has the responsibility center with all the business decision-making power. Internal entities are the responsibility centers that do not generate or assess revenue, but focus on assessing the costs and expenses incurred. The financial department is the responsibility center for making financial forecasts, supervising, and evaluating the cost control of internal entities. Figure 8 shows the relationship between the responsibility centers.

Table 1: Data description.

Data set	Number of samples	Condition property	Decision category
Dergy	376	35	4
Tic	960	9	2
Zo	100	17	7

Table 2: Multiple granularity correlation approximations.

Project	Decision class			
	S_1	S_2	S_3	S_4
Approximation under optimistic multi-granularity	112	52	72	41
Pessimistic multi-granularity approximation	38	2	7	5
Optimistic multi-granularity approximation	112	61	72	52
Pessimistic multi-granularity approximation	191	288	189	205

Table 3: Tic multiple granularity correlation approximations.

Project	Decision class	
	S_1	S_2
Approximation under optimistic multi-granularity	143	443
Pessimistic multi-granularity approximation	2	23
Optimistic multi-granularity approximation	515	815
Pessimistic multi-granularity approximation	935	967

Table 4: Zo multiple granularity correlation approximations.

Project	Decision class			
	S_1	S_2	S_3	S_4
Approximation under optimistic multi-granularity	41	20	3	12
Pessimistic multi-granularity approximation	13	3	2	9
Optimistic multi-granularity approximation	41	20	5	13
Pessimistic multi-granularity approximation	68	26	55	26

Experiments are carried out on two companies with the method proposed in this article. It calculated the accounting and financial management costs of the company, and the experimental results are shown in Figure 9. It can be seen from the figure that the average cost of accounting is higher than the cost of financial management, and the number of people responsible for accounting and financial management varies from company to company.

A company may have a suitable financial system. But most companies do not have an in-depth financial expense accounting system. This makes it difficult to achieve a closed loop for all system constraints. As mentioned earlier, the management of fiscal expenditure focuses on cost, time, and risk assessment. Therefore, it is necessary to improve the corresponding expenditure system, taking into account both financial investment and operation. The policies and systems that many companies adhere to date no longer support

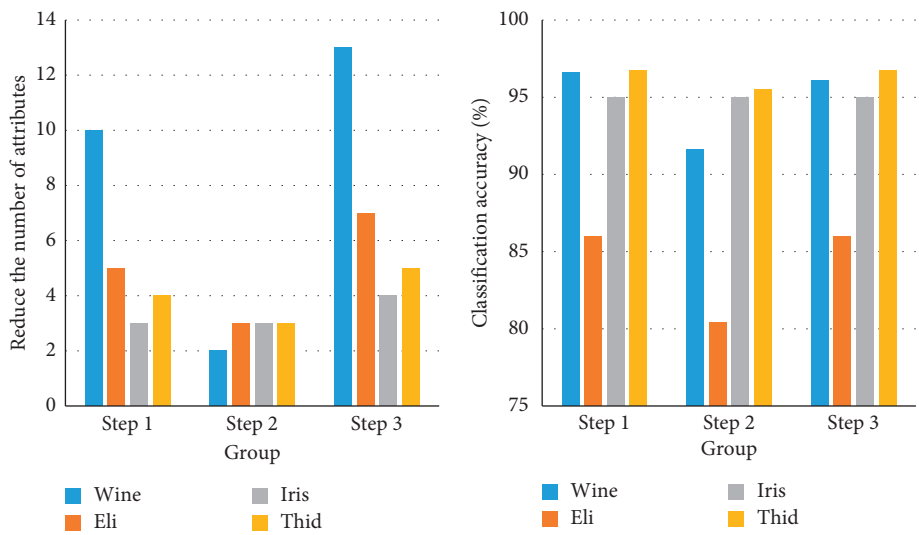


Figure 6: Support vector machine recognition results.

internal management. This seriously affects the management of corporate financing costs and continues to hinder the pace of corporate development, which must be managed by appropriate systems.

The purpose of financial management is theoretically considered to increase shareholders' assets. It is mainly aimed at listed companies. For all companies, this is generally understood as increasing the market value of the capital invested by investors. However, the income calculated in financial management is different from the income shown in the financial statement. Financial management must take into account the amount of time and the risk-benefit ratio. This is also the basic concept of financial management. Then, from the perspective of financial management, it is necessary to record the company's investment cost and capital cost in detail and always clarify the concept of "discount" and the understanding of analysis.

4. Discussion

The main focus of managing financial expenses is the potential of capital operations, and there is a lack of calculation of the company's total operating expenses. It lacks preliminary planning due to investment costs, uneven distribution of project funds, low labor costs, high capital costs, high assets and liabilities, low profit margins, and invisible profit streams. By looking at the core of each problem phenomenon, it reflects the weak link of cost accounting.

Under accounting standards, this should be sufficient for the day-to-day operations of the company. For a business to be broadly successful, it must have a well-established insurance system. Every aspect of the business needs to be linked with the proper systems, and managing financial expenses is the key to the success or failure of a business. Therefore, various cost systems need to be respected. The relevant accounting system of financial expenditure is divided into two parts: internal finance and external finance. Internal finance should strengthen the management of other commercial liabilities and stipulate the repayment period, especially the interest-bearing and transfer periods. The second is to borrow money from other parties; adjust the profits of both parties; and reduce the total tax burden, tax use, and tax risks. In the case of external financing, financing methods, capital and financing costs must be limited, and solutions and profits must be fully considered. Regarding the internal investment cost accounting system, it is necessary to improve the system, such as approval and filing of construction projects, approval and operation, adjustment and inspection, demolition and cleaning, etc. For external investments, the feasibility of conducting a proper risk assessment needs to be assessed in advance. There are similar selection criteria for computing opportunity costs, which are an indicator of institutional constraints. Critical operating cost accounting systems should be respected from the outset and appropriate systems should be supported across all product lines. In terms of materials, it optimizes the order quantity system, inventory management system, sales reduction, and other related systems, including the production process. It should also establish a common cost system, provide a standard for calculating product value by quantity, analyze cost changes, and adjust in time.

Due to individual problems in the process of enterprise establishment, departments at all levels must be established according to the needs of enterprise development. This ensures an equal distribution of rights, responsibilities, and benefits for business management during the establishment process. The three requirements identify and complement each other and promote the effective development of the company. In any institution, financial expenditure management must be manageable and reliable. The treasurer must have the authority to participate in the running of the company, not just as an informant. The division of labor among economic workers should be clear. It is necessary to set up full-time personnel and responsibilities according to the requirements of the business work, and the work cannot be confused. It incorporates the company's management

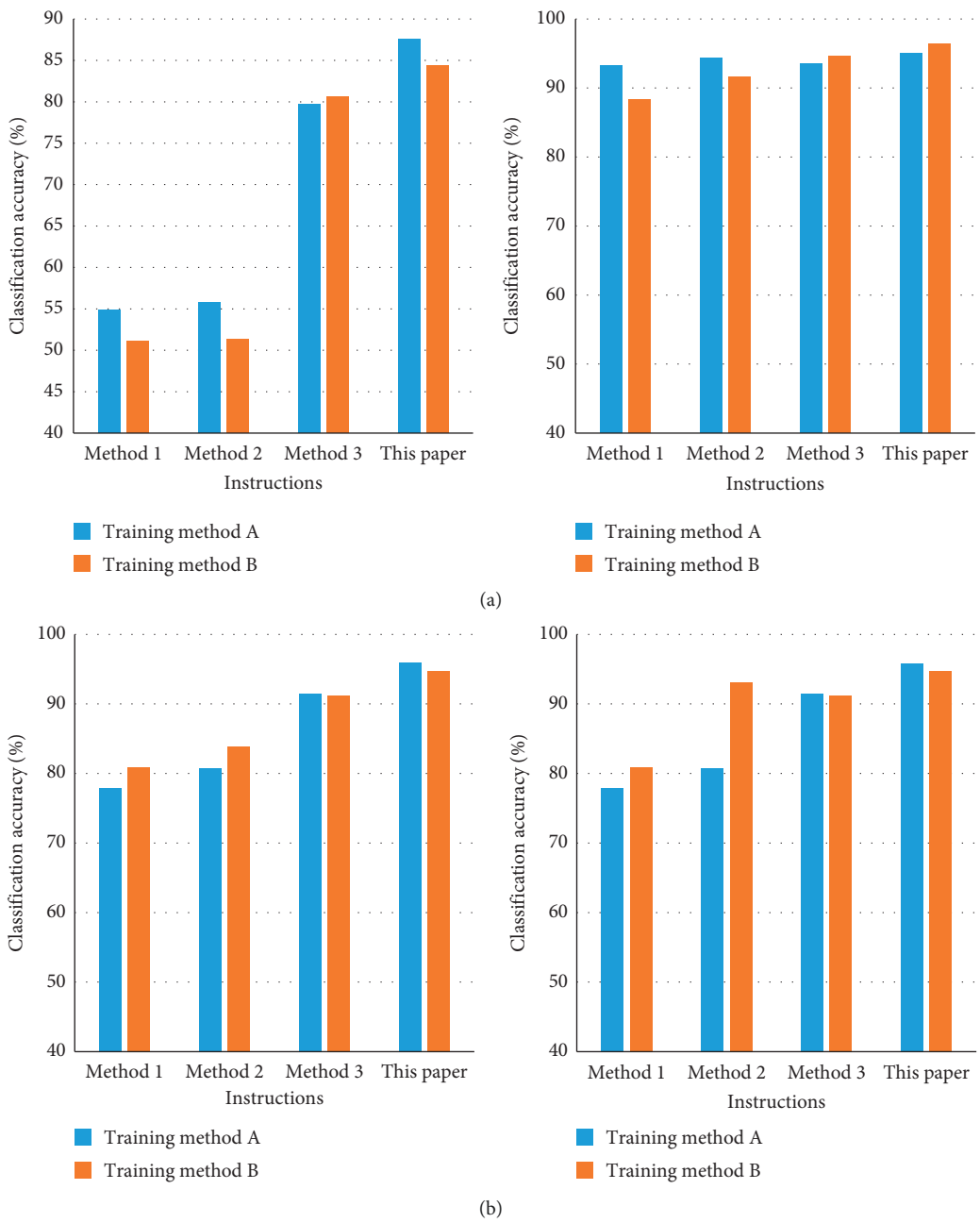


Figure 7: Experimental results on the data set.

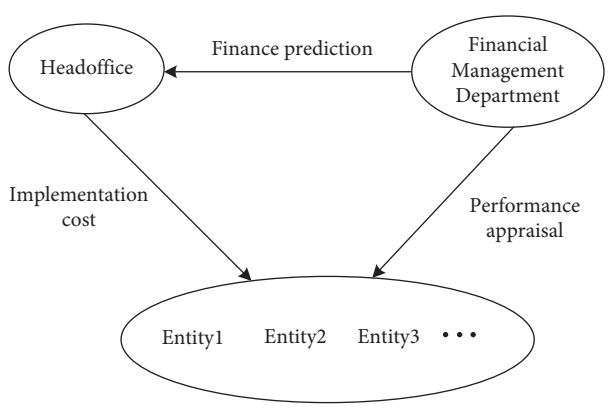


Figure 8: Diagram of the relationship between each responsibility center.

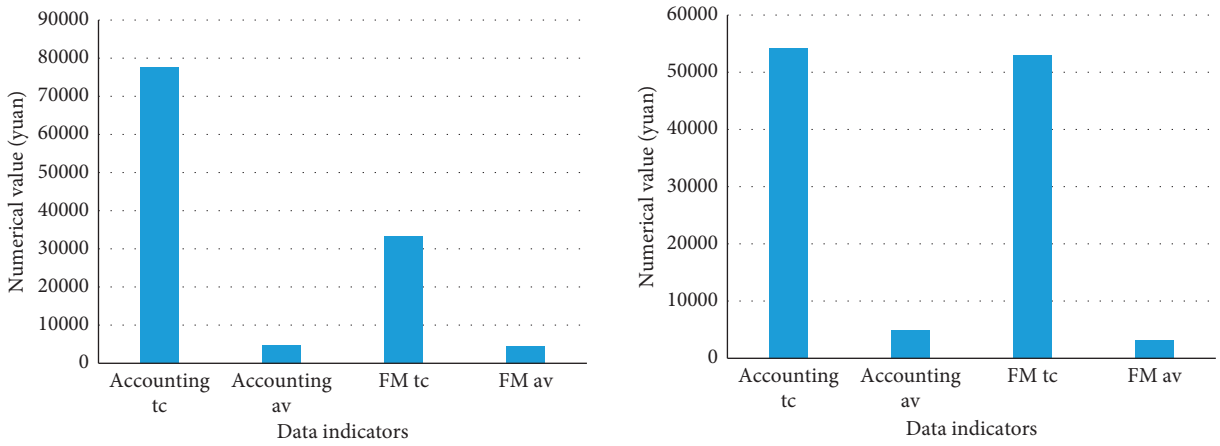


Figure 9: Experimental results.

responsibilities or departments and total operating expenses from the project plan. It is used for the implementation of specific decisions, cost analysis, and monitoring of all aspects of operation and, finally, the monitoring and evaluation of return on investment. Business leaders gain more visibility into the entire operation and can control the dynamics and control it as a whole.

5. Conclusion

Current research on rough sets usually focuses on obtaining rough set methods and their properties from different perspectives, fuzzy rough set performance, rough set attribute reduction, and rough set attribute algorithms. This article elaborates the relevant theory of rough sets and constructs a knowledge recognition system structure fuzzy rough set. Corresponding strengthening strategies are proposed for the main problems of cost accounting in the process of financial management. By improving the relevant financial cost accounting system, establishing a sound financial cost accounting system, and configuring and training comprehensive talents, the shortcomings of cost accounting can surely be solved. The new attribute importance proposed in this article is different from the conceptual thinking point of the previous definition. It is considered from the aspect of the influence of the decision attribute value on the decision table. It discriminates the importance of conditional attributes according to their defined size. However, this method is suitable for decision-making systems with multiple decision-making attribute values and will still produce relatively large errors for a single decision-making system.

The reduction result of fuzzy rough set is based on fuzzy preprocessing, so it is of great significance to study more accurate fuzzy method for the application of fuzzy rough set. Although the reduction algorithm based on conditional entropy of fuzzy rough sets proposed in this paper can find the optimal decision table, the reduction is not necessarily the smallest reduction, so it can be tried to combine with some other search methods to find the optimal solution and the smallest reduction.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] H. Ju, H. Li, X. Yang, and X. B. Zhou, "Cost-sensitive rough set: a multi-granulation approach," *Knowledge-Based Systems*, vol. 123, no. MAY1, pp. 137–153, 2017.

[2] Y. Liu, X. Yin, and B. Cao, "Variable precision rough set model and application based on grey similarity incidence relationship," *Journal of Grey System*, vol. 29, no. 3, pp. 45–57, 2017.

[3] X. Ge, J. Zhang, Y. Zhou, and J. H. H. D. M. J. Y. Cai, "Rough set neural network feature extraction and pattern recognition of shaft orbits based on the Zernike moment," *Shock and Vibration*, vol. 2021, no. 12, 11 pages, Article ID 6680640, 2021.

[4] Y. She, X. He, H. Shi, and Y. Qian, "A multiple-valued logic approach for multigranulation rough set model," *International Journal of Approximate Reasoning*, vol. 82, no. MAR, pp. 270–284, 2017.

[5] J. Hu, T. Li, C. Luo, H. Fujita, and Y. Yang, "Incremental fuzzy cluster ensemble learning based on rough set theory," *Knowledge-Based Systems*, vol. 132, no. sep.15, pp. 144–155, 2017.

[6] S. Dev, F. M. Savoy, Y. H. Lee, and S. Winkler, "Rough-set-based color channel selection," *IEEE Geoscience and Remote Sensing Letters*, vol. 14, no. 1, pp. 52–56, 2017.

[7] A. K. Singh, N. Baranwal, and G. C. Nandi, "A rough set based reasoning approach for criminal identification," *International Journal of Machine Learning and Cybernetics*, vol. 10, no. 3, pp. 413–431, 2017.

[8] Z. Ji, Y. Huang, Y. Xia, and Y. Zheng, "A robust modified Gaussian mixture model with rough set for image segmentation," *Neurocomputing*, vol. 266, no. nov.29, pp. 550–565, 2017.

[9] A. T. Azar, H. H. Inbarani, and K. Renuga Devi, "Improved dominance rough set-based classification system," *Neural Computing & Applications*, vol. 28, no. 8, pp. 2231–2246, 2017.
[10] S. Lee, D. Enke, and Y. Kim, "A relative value trading system based on a correlation and rough set analysis for the foreign exchange futures market," *Engineering Applications of Artificial Intelligence*, vol. 61, no. MAY, pp. 47–56, 2017.
[11] L. Zhang, Y. Yan, W. Xu, J. Sun, and Y. Zhang, "Carbon emission calculation and influencing factor Analysis based on industrial big data in the "double carbon" era," *Computational Intelligence and Neuroscience*, vol. 202212 pages, Article ID 2815940, 2022.
[12] Y. Kang, S. Wu, Y. Li, and J. B. Liu, "A variable precision grey-based multi-granulation rough set model and attribute reduction," *Knowledge-Based Systems*, vol. 148, no. MAY15, pp. 131–145, 2018.
[13] S. Hao, L. Yang, and Y. Shi, "Data-driven car-following model based on rough set theory," *IET Intelligent Transport Systems*, vol. 12, no. 1, pp. 49–57, 2018.
[14] X. Fan, W. Zhao, C. Wang, and Y. Huang, "Attribute reduction based on max-decision neighborhood rough set model," *Knowledge-Based Systems*, vol. 151, no. JUL.1, pp. 16–23, 2018.
[15] M. Diker, "Textures and fuzzy unit operations in rough set theory: an approach to fuzzy rough set models," *Fuzzy Sets and Systems*, vol. 336, no. APR.1, pp. 27–53, 2018.
[16] X.-Z. Zhu, W. Zhu, and X.-N. Fan, "Rough set methods in feature selection via submodular function," *Soft Computing*, vol. 21, no. 13, pp. 3699–3711, 2017.
[17] Y. He, Y. Pang, Q. Zhang, and Z. Q. Jiao, "Comprehensive evaluation of regional clean energy development levels based on principal component analysis and rough set theory," *Renewable Energy*, vol. 122, no. JUL, pp. 643–653, 2018.
[18] Z. Zhang and D. Li, "Multi-label algorithm based on rough set of fractal dimension attribute," *The Journal of Supercomputing*, vol. 76, no. 2, pp. 1105–1115, 2020.
[19] S. F. Farahbakhshian and M. T. Ahvanooey, "A new gene selection algorithm using fuzzy-rough set theory for tumor classification," *Control Engineering and Applied Informatics*, vol. 22, no. No.1, pp. 14–23, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2135836, 10 pages
https://doi.org/10.1155/2022/2135836

Research Article

Spatial Correlation Network and Driving Factors of Trade between China and RECP Countries: Empirical Investigation Based on the Social Network Analysis Method

Ding Liu

School of Economics, Zhejiang University, Hangzhou, China

Correspondence should be addressed to Ding Liu; 0621066@zju.edu.cn

Received 15 March 2022; Accepted 12 May 2022; Published 30 June 2022

Academic Editor: Lele Qin

This study adopts the revised gravity model to construct the spatial association network of trade in RECP countries and reveals its characteristics through a social network analysis method. The results are as follows: the spatial correlation of trade among RECP countries presents a complex, multithreaded network structure; the spatial correlation network of trade among RECP countries appears to fluctuate, indicating that their correlations, although influenced by the national environment, are still moving in the direction of regional integration; the degree centrality of China, Australia, and Korea is higher in terms of intermediary centrality and proximity centrality. This indicates that these countries are not only at the core of the network and have many associated relationships with other countries but also all are located at the center of the trade spatial association network; and the analysis results of the block model show that the trade spatial association network of RECP countries can be divided into four sections: net spillover, net benefit, broker, and two-way spillover. The spillover effect between the two sections has obvious gradient transmission characteristics.

1. Introduction

On April 15, 2021, China formally submitted the Regional Comprehensive Economic Partnership Agreement (RECP) to ASEAN, meaning that China has officially completed the RECP approval process. In recent years, with the increasingly severe antiglobalization situation and the resurgence of trade protectionism, especially the US–China trade war launched by the United States, the regional economy has shown further deterioration. To safeguard the multilateral trading system and construct an open world economy, China, Japan, South Korea, Australia, New Zealand, and ten ASEAN countries formally signed the RECP on November 15, 2020, marking the establishment of the world's largest free trade agreement.

RECP stands as a high-level free trade agreement initiated by 10 countries of ASEAN and later involving China, Japan, South Korea, Australia, New Zealand, and India, countries with which ASEAN has a free trade agreement. At the same time, the agreement was open to other economies in Central Asia, South Asia, and Oceania. The development of trade among RECP countries has shown two distinct features. One is that with advances in global information technology and shipping, foreign trade and economic development across countries and regions have outpaced the geographical proximity effect, and trade links between distant countries are active. The other is that the imbalance in the level of economic development, industry, and trade structure of countries provides realistic conditions for the formation of trade spatial connection networks but also poses difficulties for the disclosure of the structure of commercial spatial association networks.

RECP countries include developed countries, developing countries, coastal countries, and landlocked countries. The scientific construction of a spatial trade connection network under this condition and the exploration of its realistic impact on the construction of an open world economy and regional economic integration will have great theoretical and

practical significance. Our questions therefore include three main aspects: how to build a trade spatial association network? How to reveal the network structural characteristics of the trade spatial networks in RECP countries? How to analyze the spatial clustering characteristics of trade-related spatial networks?

Considering the signing of the Regional Comprehensive Economic Cooperation Agreement between China and the RECP countries, research on RECP has gradually entered the field of scholars. Currently, there are three main types of research based on different research perspectives.

RCEP is the largest and most important free trade agreement negotiated in the Asia Pacific region. It features the world's most populous and diverse membership and the most dynamic development of a free trade area. Since the RCEP officially took effect on January 1, 2022, the academic circles have increasingly enriched their research on RCEP. Some scholars broadened their research perspective to an international perspective and studied the economic effects between China and other member states in the context of RECP. For example, some scholars studied the changes in economic and trade cooperation between China and Japan after RCEP came into force [1] and the asymmetric characteristics of economic growth between China and RCEP member countries [2]. The perspective of some scholars has turned to domestic studies, mainly concerning the impact of China's manufacturing industry on trade [3] and the context of the China-ASEAN services trade quality development [4] of RCEP. Some scholars have explored the impact of RCEP on domestic regional development, the path of high-quality economic development in the Yangtze River Delta region from the perspective of RCEP [5], and the construction of the Guangxi Free Trade Zone (Li & Shang Mao & Zhong, 2022). However, the above studies only focus on China's economic and trade ties with a particular country or the impact of RCEP policies on domestic regional economic development. It can be seen that it does not focus on the spatial correlation of trade among RCEP countries.

Firstly, the development prospects, opportunities, and comparisons with other internationally traded organizations are examined based on the RECP. The chances, adjustments, and difficulties arising from the signature RECP have been widely studied by scholars [6, 7].

Most scholars often use the GTAP model to study RCEP, mainly focusing on the impact on industrial structure [7]. Through studying the differences, challenges, and responses of the RECP and TPP trade agreements [8] and the impact of the different trade agreements on China [9], some scholars have found that the RECP can effectively deal with the impact of the TPP construction on China's economy. Zhang and Yong [10] studied the economic impact of CPTPP and RECP on major economies in the Asia Pacific. All previous studies qualitatively analyzed the prospects, opportunities, and challenges of RECP and proposed countermeasures against TPP, but previous analysis has not paid attention to the impact of RECP nations' spatial connection partnership, to be more specific; after the signature of RECP agreement, obvious spatial association characteristics could be found in terms of regional trade and economic development.

Second, the impact of RECP on China's high-quality economic development has been widely studied. Liu et al. [11] studied the impact of RECP on China's economy from the perspective of time cost and found that if the reduction in time cost is considered, China's GDP will grow by 1.41%, 10 times more than that of tariff reduction scenario. By studying the impact of RCEP on China's textile import and export trade Zhao and Hong found that it could expand China's import and export scale in the textile industry and increase its market share. Zhao and Hong [12] studied the impact of RCEP on the creation and transfer of China's pork import trade. Wei and Zhu [13] studied the impact on China's manufacturing economy based on the GTAP model and found that the higher the degree of trade liberalization is, the greater the economic impact on China's manufacturing industry is. Li [14] found that the RECP has contributed to the formation of a "three-legged" production network model on a global scale, leading to an inward and unbalanced development trend in the market system and regional dependencies through the study of regional value chain reconstruction in China. The impact of the RECP on China's economy has been studied above, and it has been found to be an important catalyst for China's economic development, but trade relations between member countries have not been studied in terms of spatial association.

Third, the spatial connection network among countries has been noticed and its network structure has been studied. Some scholars take the Belt and Road Initiative as the research sample, from international trade [15, 19], economic development [22, 23], domestic investment [16], service trade [17], cultural trade [18], and analysis has been conducted in the spatial correlation of "Belt and Road" countries.

Third, the network of spatial connections between countries has been studied, as well as its internal structure. Some scholars have taken the Belt and Road Initiative as a sample for their research, and studies on the spatial relevance of countries under this subject include international trade [15, 19], economic development [22, 23], domestic investment [16], trade in services [17], and cultural trade [18]. It is found that there is a complex multithreaded spatial connection among countries along the Belt and Road Initiative.

Some scholars' research samples are RECP countries. From the perspective of trade networks, some studies [20, 21] have broken the limits of spatial economics with the first law of geography as a guide, built a connected network of spatial economics over long distances and in a wide range of fields, and studied the characteristics of the network structure using the method of social network analysis. However, no existing studies have employed spatial connection network analysis methods for RECP countries. Therefore, there is a gap in the social network analysis method for spatially connected relationships for business in RECP countries.

This study is based on existing research, and its main contributions are the following. First, from the perspective of theoretical analysis, this study analyzes the formation mechanism of national spatial relationship network of RECP. Second, taking 15 RECP member countries as the research sample, along with data of China, Japan, South

Korea, Australia, New Zealand, and 10 ASEAN countries from 2010 to 2019, using the modified gravity model, spatial connection network would be established and analyzed. Third, the social network analysis method is used to reveal the structural characteristics of industry spatially connected networks from the overall characteristics of the network, individual characteristics, and spatial clustering characteristics. On this basis, policy suggestions to improve the commercial space connection network will be put forward.

This study focuses on the structural characteristics of trade spatial association networks in RECP countries, and its marginal contribution is mainly manifested on two aspects. For one thing, this study adopts the social network analysis method for empirical analysis and tests the tightness and stableness of spatial networks via the measurement of network density, network relevance, network rank, and network efficiency, which fills the gap in the relevant literature. For another thing, this study is different from the traditional spatial econometric methods used to study trade issues and constructs a revised gravity model to break the restrictions of administrative regions more intuitively. It is no longer limited to the influence of geographical proximity and locality and deeply analyzes the trade spatial association network structure of RECP countries.

2. Research Method and Data Explanations

2.1. Gravity Model. The research on spatial correlation is a hot spot in regional economic research. The purpose of this study was to study the spatial correlation of trade among RECP countries. This study takes 15 countries such as China, Japan, South Korea, Australia, New Zealand, and 10 ASEAN countries as the points of trade spatial connection, and the commercial connections among countries are lines. These points and lines form a network of spatial commercial connections among the RECP countries. This study applies the gravity model (GM) to introduce trade relations between RECP countries. The gravity model in economics is inspired by the law of gravity and is also characterized by the mutual attraction between economic agents. Given that the strength diminishes as the distance between economies increases, to enhance the applicability of the gravitational model, this study proposes a modification of the traditional gravitational model in terms of trade space association, and the revised gravity model is as follows. The corrected gravity model is as follows:

$$Rij = k_{ij} \times \frac{\sqrt[3]{Pi \times Ei \times Gi}\sqrt[3]{Pj \times Ej \times Gj}}{D^2}, k_{ij} = \frac{E_i}{E_i + E_j}. \quad (1)$$

Among them, R_{ij} is the spatial correlation of trade between RECP countries and the gravity of the spatial relationship of trade between country i and country j; E_i and E_j stand for the total imports of countries i and j, respectively; P_i and P_j represent the year-end total population of countries i and j, respectively; Gi and Gj represent the total exports of countries i and j, respectively; and K_{ij} is an adjustment factor, which represents the contribution of country i to the spatial association of trade between country i and country j. In terms of distance measurement, to consider geographical and economic distance together, this study uses the distance D_{ij} between the two capitals for calculation, to figure out the gravity matrix. Each line of the gravity matrix represents the influence of special association of country i with other countries. In this study, the average gravity is taken as the critical value. If the influence of the trade spatial association of country i on country j is greater than the average gravity, then it is recorded as 1, and the pointing arrow from country i to country j should be drawn to show that there is an obvious spatial association between the two countries. According to this method, the author tested the spatial association between each set of two countries and drew the "connecting line" to construct the spatial correlation network among RECP countries.

This study examines a sample of 15 RECP countries, including China, Japan, Korea, Australia, New Zealand, Thailand, Singapore, Indonesia, Myanmar, Malaysia, Philippines, Brunei, Cambodia, Laos, and Vietnam. Total exports and imports are required to measure the gravity model, and population data are obtained from the World Bank in the process (https://www.worldbank.org/en/home).

2.2. Social Network Analysis Method. An analysis of social networks has been extensively applied to the study of the economic sector, air pollution, economic development, and international trade. In this study, the social network analysis method is used to investigate the characteristics with respect to trade spatial association networks. To be more specific, this study will analyze deeply through spatial association overall network structure characteristic, network individual centrality characteristic, and clustering model.

2.2.1. Analysis of the Overall Structure Characteristics of Spatial Association Networks. This study calculates the overall relevance of the trade spatial association network among RECP countries using the indicators such as the density, relevance, level, and efficiency of network.

Network density reflects the density of spatial relations among RECP members. The greater the network density is, the tighter relationship exists among members and the greater impact of network structure on trade among RECP member states. The network density is expressed as D_n, and the range of the index is [0, 1]. N is the number of cities in the network, L is the actual number of associations, and $N \times (n-1)$ is the number of maximum associations in the network. Therefore, network density can be expressed as follows:

$$D_n = \frac{L}{N \cdot (N-1)}. \quad (2)$$

The degree of network relevance shows the stability and vulnerability of the trade spatial association network among RECP countries. If there are direct or indirect links among each RECP members, then the conclusion can be that the spatial network has good association. If multiple lines of the spatial network are connected through a specific country, then the spatial network is highly dependent on that country;

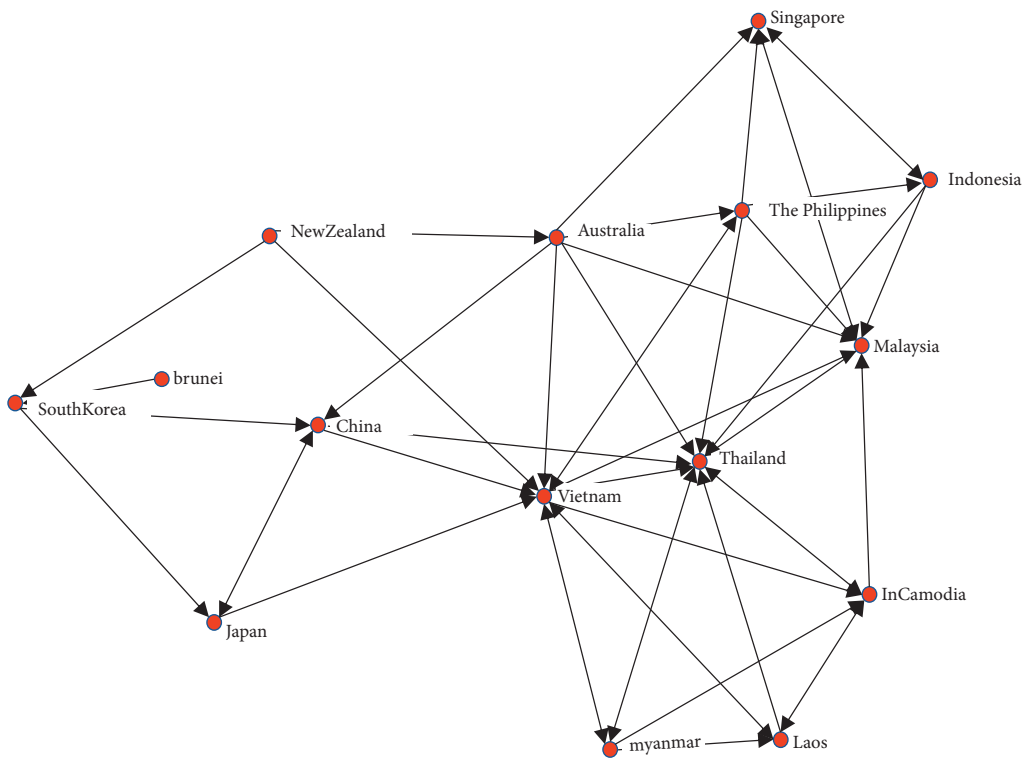


Figure 1: RECP countries' trade spatial connection network.

therefore, the network structure is unstable and the association is rather low. The index range of network relevance degree is [0, 1], V is the unreachable point in the network, N is the number of cities, and $N \times (n-1)$ is the maximum relevance number. The association degree of the network can be expressed as follows:

$$C = 1 - \frac{V}{N \cdot (N-1)/2}. \tag{3}$$

The network level shows the extent to which RECP members can achieve asymmetry, which reflects whether there is a dominant and dominated relationship in the spatial network structure. The level of the network is represented by H, the index range is [0, 1], and K is the number of symmetric points. Therefore, the network hierarchy can be expressed as follows:

$$H = 1 - \frac{K}{\max(K)}. \tag{4}$$

Network efficiency refers to the number of redundant lines in the spatial network and the number of lines required by components. In the trade spatial network of RECP countries, the higher the network efficiency is, the greater the spilled trade space exists, and the more stable the network relationship is. The network efficiency index range is [0, 1], and M is the number of redundant lines. Therefore, the network efficiency can be expressed as follows:

$$E = 1 - \frac{M}{\max(M)}. \tag{5}$$

3. Overall Network Characteristics of Spatial Association Network of RECP Countries

3.1. By Calculating Network Density, Levels, Relevance, and Efficiency. This study provides a description of the general characteristics of the spatial structure of trade relevance networks in RECP countries.

3.2. Analysis of Network Characteristics. The research in this study is focused on the 15 countries of the RECP. A revised gravity model was used to determine the spatial association of trade between RECP members, and then, the spatial trade association network between RECP countries was drawn using UCINET's visualization tool NetDraw (Figure 1). It is clear that the trade spatial connection network among RECP countries is complex and complicated. China, Vietnam, Thailand, Australia, and other countries are located at the center of the network. However, Brunei, Malaysia, and Indonesia are located at the edge. Those countries in the center have greater external radiation capacity and more complex relationship with many other countries. Due to the development of information technology and the increasing convenience of global transportation, the trade spatial connection network of the world's major economies has universal and common connection. However, due to the impact of Brexit from the EU and the Sino-US intangible trade war, trade uncertainty gradually accumulated and affected neighboring countries. Therefore, one conclusion can be taken from here: the network density is not that higher among the RECP countries. If a deep analysis has

been carried out for the deconstruction of the trade spatial network among RECP countries, three levels can be shown as follows: first, the spatial connection of trade networks between RECP countries radiates to other countries in the network; second, the trade spatial connection network among RECP countries has shifted from the bilateral trade development model to the multilateral regional trade development model; and third, there are many small groups in the RECP spatial connection network to form a final complex network. Therefore, it is necessary to let each member coordinate and cooperate.

3.3. Network Density. Network density is a measure of the proximity to the trade spatial connection network among RECP countries. The maximum possible association among the 15 countries is 210 (15 × 14). If the real number of associations in RECP is calculated to be 54 using UCINET, the spatially connected network of RECP countries is 0.2571. This indicates a high density of spatial connections among RECP countries, suggesting that further improvements are needed. When constructing the trade spatial association among countries, we should strive to improve the spatial correlation of trade among countries and create more opportunities and platforms. From 2010 to 2019, the trade spatial association network density of RECP countries showed a fluctuating trend. From 2010 to 2015, the network density increased from 0.2619 to 0.2714; however, from 2015 to 2016, it decreased to 0.2524. There is an upward trend from 2017 to 2018 and a downward trend from 2018 to 2019. This shows that the trade relations among RECP countries are affected by the international trade situation. With the Brexit and the US–China trade war, uncertainty is gaining increasing momentum. This has forced RECP countries to establish a comprehensive regional alliance, which not only can maintain the multilateral trading system effectively and create an open world economy but also has a significant practical implication for furthering regional economic integration and stabilizing the world economy. These results are shown in Figures 2 and 3.

3.4. Network Association Analysis. A method of social network analysis is used to measure network relevance through network relevance, efficiency, and level. Among them, the result of network relevance degree is 1, which shows that the spatial correlation of RECP countries is very close and easy to approach, and the spatial network structure is very sound. The measurement results of network efficiency show that the network density gradually increases from 2010 to 2019. This shows that the trade spatial connection network between RECP countries has a variety of spillover channels, and the trade spatial connection network among them is stable. The measurement results of the network level show an upward trend from 2010 to 2019, indicating that the network level of trade spatial links between RECP countries is becoming more and more strict. There are maritime and landlocked countries, so there is a hierarchical structure in the spatial network of mutually beneficial trade among countries. Combining the above indicators, this study concludes that economic and trade exchanges between the world's major economies are increasingly frequent and that they are tightly linked to the globalization process. How to reconcile economic development with trade development is a growing concern for people, governments, and the public. In terms of trade development, it is important to take into account the spillover effects of economies, develop a unified development policy, and implement differentiated development measures to jointly guarantee the construction of a coordinated development mechanism for trade among RECP countries.

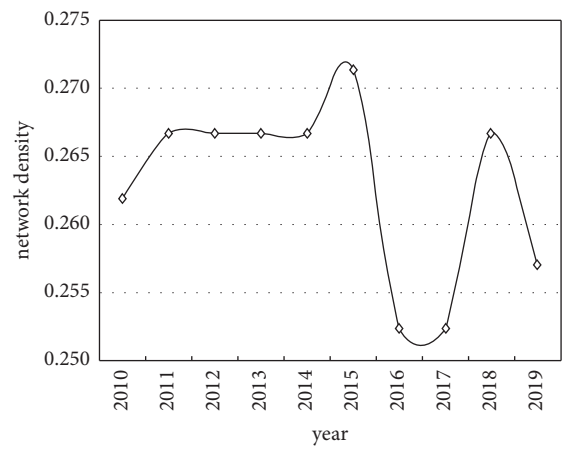


Figure 2: Evolution of network density.

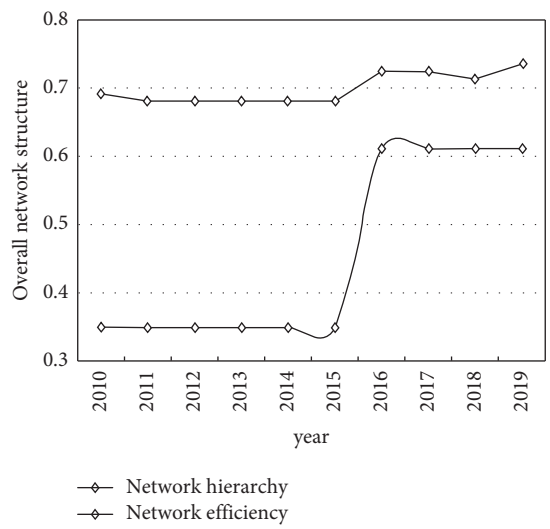


Figure 3: Evolution of network level and efficiency.

4. Individual Network Characteristics of the Trade Spatial Association Network of RECP Countries and China

The individual centrality of the RECP trade spatial relationship network is analyzed through measuring the centrality, intermediate centrality, and near centrality of the RECP countries' trade spatial relationship network.

4.1. Degree Centrality. The central point uses the number of links in the trade network to measure whether the country is at the center of the network. Based on the point centrality measurement results given in Table 1, the average point centrality of RECP countries is 36.1904, among which ten countries are higher than this figure, Vietnam, Australia, Malaysia, the Philippines, and Thailand. In the trade spatial network between RECP countries, the relationship with other countries is closer. Among them, Vietnam has the highest figure, reaching 71.429, indicating that Vietnam is in a central position in the trade space connection network between RECP countries. It is because Vietnam is the country with the largest economic aggregate in Southeast Asia, and its economic strength has gradually increased in recent years. According to the measurement results given in Table 1, Singapore ranks second among the least developed countries in terms of time concentration, which indicates that Singapore has less trade links with other countries. The reason may be that Singapore's industry is more inclined to tourism and finance, which is rather low in the trade among RECP countries, resulting in weak trade links.

4.2. Intermediary Centrality. Based on the centrality measures given in Table 1, RECP countries have an average intermediation of 6.96, above Australia, China, Korea, and Vietnam. In the spatial network of trade between RECP countries, they have strong control over trade with other countries. China's centrality is 13.90, indicating that China is at the center of the network of trade connections between RECP countries, acting as an "intermediary" and "bridge." Among the RECP countries, China has the largest economic and trade volume. Therefore, China serves as an intermediary in the RECP countries. Furthermore, China, Australia, South Korea, Vietnam, and the RECP countries have a high level of economic development and strong economic and trade ties. Brunei, Laos, and Myanmar are in third place, which indicates that these countries have a lower level of economic development and fewer economic and trade contacts with other countries. It is thus difficult to control and dominate the other countries in the network.

4.3. Near Centrality. According to the measurement results of centrality proximity given in Table 1, the average centrality of national RECP countries is 54.58, and the countries exceeding this average are Australia, China, Malaysia, and Vietnam. This suggests that in the spatial network of trade between RECP countries, these countries can establish internal links with other countries more quickly and take a central part in the network. The reason for this may be that these countries occupy a higher position in terms of their level of economic development and economic aggregates, with higher economic aggregates and foreign trade volumes. As a result, there are more spatial trade connections between these countries and other countries. Among the above countries, Vietnam has a centrality of 71.429, significantly higher than the other countries. This indicates that other countries are "closer" to Vietnam in the trade space connection network and it is the hub of the entire network of commercial space linkages among RECP countries.

Table 1: RECP countries' trade spatial connection network.

	RECP members	Outer	Inner	Degree	Near	Intermediary
1	Australia	8	1	57.143	66.667	14.542
2	Brunei	1	0	7.143	31.818	0
3	China	4	3	35.714	60.87	13.901
4	Indonesia	3	2	28.571	50	0.549
5	Japan	2	2	21.429	51.852	3.114
6	Cambodia	5	4	35.714	53.846	1.007
7	South Korea	2	3	28.571	45.161	15.201
8	Laos	4	3	28.571	50	0
9	Myanmar	4	4	28.571	50	0
10	Malaysia	2	7	50	58.333	4.982
11	New Zealand	3	1	21.429	56	6.777
12	Philadelphia	4	2	35.714	53.846	1.465
13	Singapore	2	4	28.571	46.667	0.275
14	Thailand	4	9	64.286	70	14.634
15	Vietnam	6	9	71.429	73.684	27.949
	Average	3.6	3.6	36.1904	54.58293	6.959733

5. Spatial Clustering Characteristics of the Trade Spatial Association Network of RECP Countries

To analyze the spatial clustering characteristics of trade network in RECP countries, the block model method of social network analysis is used to describe the status and role in relevant trade cyberspace. The standard with maximum segmentation depth of 2 and centrality of 0.2 was selected by the CONCOR method. If the 20 countries of RECP are divided into four blocks, the result is shown in Figure 4. The first plate has three countries, Australia, Japan, and South Korea, which are allies of the United States.

To analyze the spatial clustering characteristics of RECP countries' trade networks, an approach to the block model of social network analysis is used to describe the status and role of the relevant trade network spaces. The CONCOR method chooses a maximum segmentation depth of 2 and a centrality of 0.2 as criteria. The 20 countries of RECP are divided into four blocks, and the results are shown in Figure 4. The first block has three countries, Australia, Japan, and South Korea, which are US allies. The second section includes three developing countries: China, Brunei, and New Zealand, of which China is the most economically developed country. In Section 3, there are four members, namely Singapore, Indonesia, the Philippines, and Malaysia. They are all located in Southeast Asia and have sufficient labor force, land resources, and other factors. The fourth plate has five countries, Laos, Myanmar, Cambodia, Thailand, and Vietnam, all concentrated in Indochina Peninsula. It is not difficult to find that the economies and trade of the countries in the first and second plates are relatively developed, while the countries in the third and fourth plates are located in Southeast Asia, rich in labor and land resources.

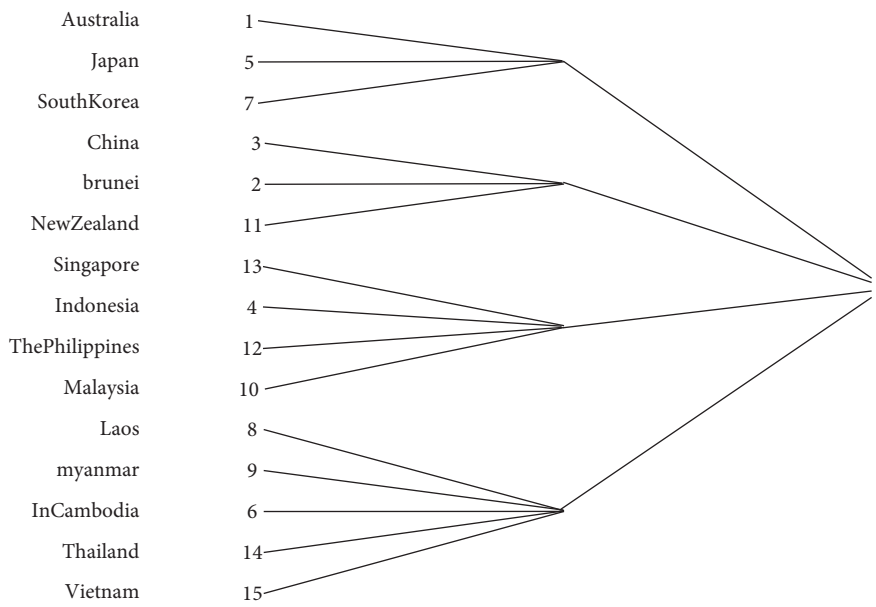


Figure 4: Clustering analysis of the trade spatial connection network.

Table 2: Block model of RECP nations' trade spatial connection network.

	Four blocks				Recipient		Sender		Interior proportion	Expected proportion
	Block I	Block II	Block III	Block IV	In the block	Out of the block	In the block	Out of the block		
Block I	1	4	4	3	1	5	1	11	8.33%	14.28%
Block II	5	0	0	3	0	4	0	8	0	14.28%
Block III	0	0	7	4	7	8	7	4	63.63%	21.43%
Block IV	0	0	4	19	19	10	19	4	82.60%	28.57%

Taking 2019 as an example, this part analyzes the role and position of each block in the RECP trading network. According to the above calculation, there are 54 links among the 15 countries, 27 of them are plate internal correlation and the others plate correlation among 15 countries, indicating that there is obvious spatial correlation and spillover effect in internal plate trade. The number of internal relations of board I is 1, and the sum of overflow rate with other boards is 11, while the overflow rate received from other boards is 5, and the actual ratio in the board is 8.33%, which is lower than the expected internal ratio of 14.28%. The internal ratio of the second board is 0, and the sum of the overflow rate and other boards is 4, while the overflow rate received from other boards is 8, and the actual ratio in the board is 0, which is far lower than the expected internal ratio of 14.28%. The gap and overflow effect between the inner and outer connecting plates are small, which can be divided into runner plates. The internal ratio of plate III is 7, and the sum of overflow ratio and other plates is 4, while the overflow ratio received from other plates is 8, and the actual ratio in the plate is 63.63%, which is much lower than the expected internal ratio of 21.43%. The internal ratio of plate IV is 19, and the total of the overflow ratios from other plates is 4. While the overflow ratio received from other plates is 10, the actual ratio in plate is 82.60%, and the expected internal ratio is 28.57%. The plate member not only emits the relationship but also receives the relationship from other plates and divides them into two-way overflow plates.

To further study the spatial correlation trading relationship between the four plates, this study calculates the network density matrix of each plate according to the distribution of correlation between plates. The density value of the whole network is 0.2571. If the density of the board is greater than the value, the value is specified as 1 and the value is specified as 0, so the density matrix of multiple values is converted into an image matrix, as given in Table 2. In addition, Figure 5 shows the relationship between the four parts of RECP national commercial space contact network. Therefore, due to the relatively high level of economic development of the first plate countries in Australia, Japan, and South Korea, the first plate plays a net spillover role in the trade and spatial connection network of Pacific island countries, and a higher industrial structure and commercial level can spill over to other sectors. However, the second sector mainly includes China. Due to the impact of regional economic integration, China plays a key role in the trade and spatial connection network of RECP countries. Its focus is to shift trade and development links from the first sector to the

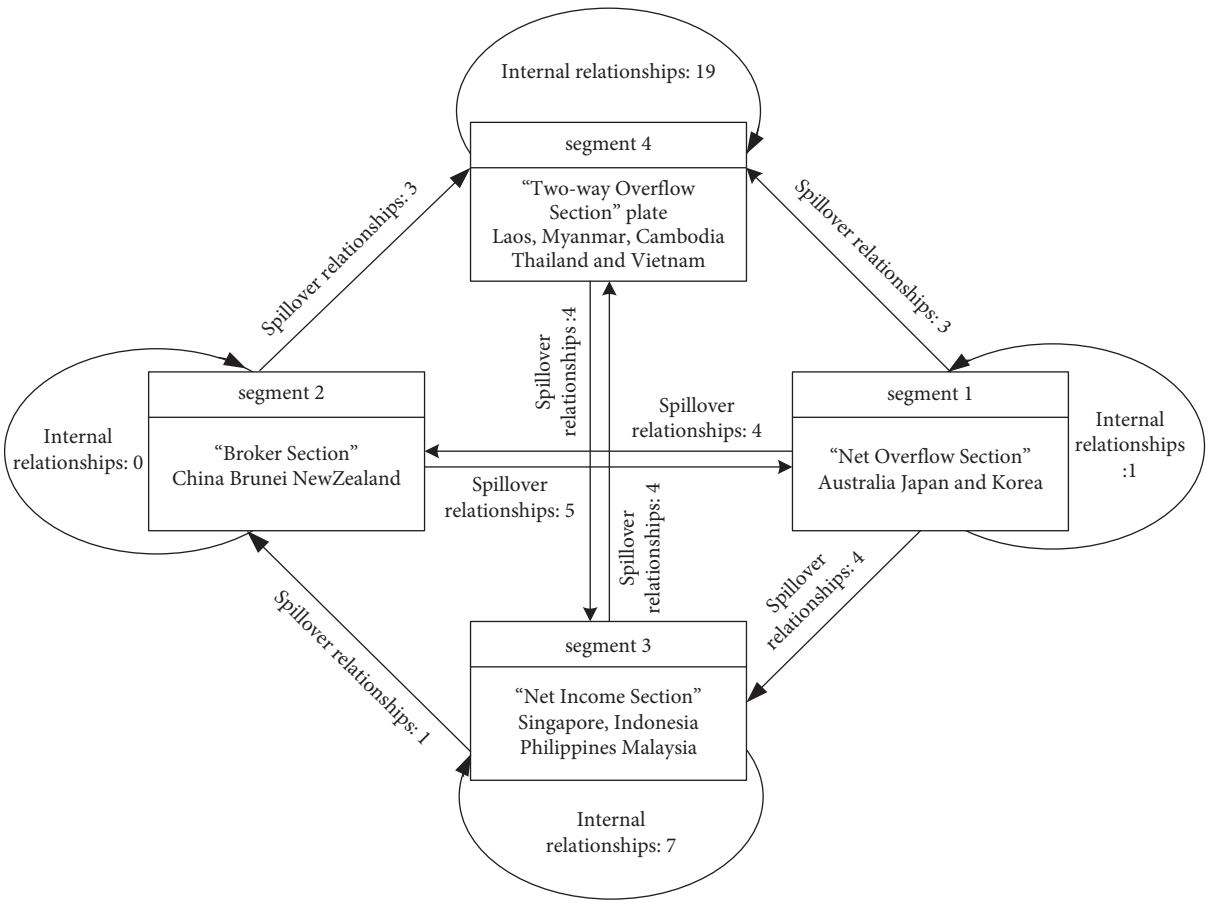


Figure 5: Correlation between the four sectors of the RECP national trade network.

Table 3: RECP trade spatial connection network density matrix and similar matrix.

	Density matrix				Similar matrix			
	Block I	Block II	Block III	Block IV	Block I	Block II	Block III	Block IV
Block I	0.167	0.444	0.333	0.2	0	1	1	0
Block II	0.556	0	0	0.2	1	0	0	0
Block III	0	0	0.583	0.2	0	0	1	0
Block IV	0	0	0.200	0.95	0	0	0	1

Note: 1 refers to connection exist and 0 refers to no connection.

fourth sector. With the abundant labor and land resources, third sector member countries are important engines in the network of trade and spatial connections of RECP countries. It transports a large number of production factors for the trade and economic development of the first and fourth plates. The fourth plate not only sends links but also receives links, playing a two-way spillover role in the trade and spatial link network of RECP countries. These results are given in Table 3.

6. Conclusion, Policy Suggestion, and Discussion

6.1. Conclusion. This study applies the correct gravity model to identify the spatial relevance of trade between China and RECP countries and explains the characteristics of the spatial relevance network of trade between PCRE countries using social network analysis methods and draws the following conclusions. Firstly, the commercial spatial connection network among RECP countries presents a complex and interrelated network structure. China, Vietnam, Thailand, Australia, and other countries are at the center of the network; however, Brunei, Malaysia, Indonesia, and other countries are at the edge of the network, while China, Vietnam, Thailand, Australia, and other countries are at the center of the network and have strong external radiation capacity and more countries are connected to it and their relations are complex. Second, from the perspective of the classification center, Vietnam, Australia, Malaysia, the Philippines, Thailand, and other countries have closer relations with RECP countries and other countries in the space trade contact network. Among them, Vietnam has the

highest concentration, reaching 71.7429, indicating that Vietnam is in the central position in the commercial space connection network between RECP countries. Third, the breakdown of brokerage centers shows that Australia, China, Korea, and Vietnam have strong control over trade between other countries in the RECP network of national trade spatial connections. The concentration of Chinese intermediaries is 13.90, indicating that China is in a central position in the trade connection network between RECP countries, acting as an "intermediary" and "bridge." Fourth, from the perspective of near central classification, Australia, China, Malaysia, and Vietnam have faster internal links with other countries in the commercial space network between RECP countries and play a central role.

6.2. Advice. Enhance coherence in trade development through the establishment of regional cooperation funds. There are great differences in the development level and industrial structure characteristics of members, as well as the cost and ability of air pollution control. As a target community in the context of air pollution, the national trade development fund can learn from the financing experience of the Green Climate Fund. Developed countries inject some funds into the mutual fund every year to promote the trade development of developing countries. At the same time, developing countries should also actively introduce foreign direct investment models, and members should pay fixed funds on a regular basis. Of course, we must also mobilize enterprises, social organizations, and other forces that may come together to actively develop and establish a "capital reserve" for multilateral cooperation to improve the spillover effect of trade among the least developed countries.

A national information, data, and technology exchange mechanism are established. The exchange of information and data between countries is not only conducive to better joint scientific research among countries, but this will also help strengthen bilateral cooperation and mutual trust and establish a better mechanism for coordinated trade development. Also, it has gained abundant investment experience in the construction of transport infrastructure. China can use its advantages to help build trade infrastructure in countries with weak infrastructure for trade development and promote information connectivity between RECP countries. At the same time, to achieve efficient and scientific trade among countries, it is necessary to establish a trade data exchange mechanism and a trade information database among RECP countries and carry out trade information exchange to promote high-quality economic development of developing countries.

6.3. Discussion. In recent years, the shadow of anti-globalization sentiment seems to have been significantly strengthened by the impact of COVID-19. Countries have established and participated in regional international trade organizations to enhance regional coordination of international economy and to govern the economic problems caused by antiglobalization; However, these measures are more based on geographical adjacent, and it aims not to break the limitation of geographical distance. If the economic governance measures were independent, there is no doubt that all countries will complete the task of international governance according to the goals, respectively. It is a spatial correlation.

Compared with previous studies, this study focuses on the spatial correlation of trade among RECP countries and improves on two aspects. For one thing, this study adopts a social network analysis for empirical research, testing the closeness and stability of spatial networks by the measurement of network density, network relevance, network rank, and network efficiency, bridging a gap in the relevant literature. Another aspect of this study is that it differs from the traditional approach of spatial econometrics in studying trade issues by constructing a revised gravity model that more intuitively breaks the restrictions of administrative regions. It is not restricted to the influence of geographical proximity and territoriality anymore and provides an in-depth analysis of the structure of the spatially connected network of trade in RECP countries.

The biggest characteristic of this study is to use the gravity model to identify the RECP space of the national trade associations, using the social network analysis method to reveal the spatial correlation structure characteristic of the network. However, as an empirical study, this study has its limitation; there is a lack of data to provide a in-depth analysis on the RECP influencing factors for the national trade association network. With the enrichment of data and the improvement of methods and technologies, this will become the direction of future academic research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] H. Chen, "A trend of bilateral economic and trade cooperation between China and Japan the RCEP effect change research," *Journal of the Asia Pacific Economy*, no. 02, pp. 19–28, 2022.

[2] N. Huang and N. S. Li, "China's economic growth with RCEP member states asymmetric impact study," *Journal of the Asia Pacific Economy*, vol. 02, pp. 8–18, 2022.

[3] J. F. Wei and Y. X. Yin, "Research on the trade impact of TARIFF reduction in RCEP on China's manufacturing industry -- GTAP simulation based on commitment table," *Journal of Harbin University of Commerce (Social Science Edition)*, no. 02, pp. 114–128, 2022.

[4] Q. L. Li, "New opportunities and challenges for high-quality development of China-Asean service trade in the context of RCEP," *International trade*, no. 02, pp. 89–96, 2022.

[5] X. Gu, L. X. Wei, Research on the path and countermeasures of promoting the high-quality development of open economy in Yangtze River Delta region from the perspective of RCEP," *Modern Economy*, vol. 3, pp. 60–69, 2022.

[6] M. L. Yuan and X. L. Zhang, "Opportunity, challenge, and Chinese strategy option after the signature of RECP agreement," *price theory and practice*, no. 1, p. 5, 2021.
[7] J. Tang and C. J. Xia, "Chinese service trade status quo, problem and suggestion," *International Trade*, no. 10, p. 6, 2016.
[8] M. J. Yu and H. W. Jiang, "Chinese double circular development status of RECP agreement(J)," *Jianghai Journal*, no. 3, p. 9, 2021.
[9] B. Y. Shi and Y. Y. Wang, "Comparative analysis of RECP and TPP's economic effect, based on GTAP model analysis," *Economic View*, no. 6, p. 8, 2016t.
[10] Z. Zhang and J. Yong, *Comparative Analysis of Economic Effect for Asian Pacific Countries of CPTPP and RCEP, Based on GTAP Model Analysis*, Asian-Pacific Economy, Singapore, 2018.
[11] Y. L. Liu and Y. K&L, "RECP influence to Chinese economy in the view of time cost, based on GTAP model analysis," *Systematic Engineering Theory And Practice*, vol. 54, no. 46, pp. 223–256, 2017.
[12] L. T. Zhao and J. Hong, "RECP's trans effect to Chinese import and trade of pork," *World Agriculture*, vol. 7, p. 10, 2017.
[13] F. Wei and W. J. Zhu, "RECP's influence to Chinese manufacturing industry, based on GTAP model analysis," *Northeast Finance University Journal*, vol. 1, p. 10, 2018.
[14] X. Li, "RECP's influence and effect to Chinese value chain structure," *Business And Economy Research*, vol. 7, p. 4, 2021.
[15] J. R. Zhao and H. Sun, "Evolution analysis of China and Belt and Road initiative countries," *International Business And Finance Exploration*, vol. 35, no. 11, p. 13, 2019.
[16] Y. Li, S. Q. Wei, S. B. Wei, Q. Zhou, and X. You, *Current Opinion in Genetics & Development*, vol. 64, no. 6, pp. 6–12, 2020.
[17] H. Niu, S. Lan, and Y. Ma, "Dynamic evolution and influence system of trade network of Belt and Road initiative countries, international commerce," *Journal Of University Of International Business And Economics*, vol. 5, p. 16, 2020.
[18] Q. Chen and C. Cheng, "Commercial influence to tourism in different countries, based on the 24 Chinese counterpar," *Tourismus Journal*, vol. 33, no. 11, p. 11, 2018.
[19] J. Gong and Y. Z. Li, *National Trade Network Analysis of China and Belt and Road Initiative Countries*, Economy And Management Comment, Germany, 2019.
[20] A. J. Sun, "G20 countries' spatial network characteristic analysis," *Hehai University Journal*, vol. 021, no. 001, pp. 42–50, 2019.
[21] J. Bai, D. Y. Liang, and R. Zhou, "Adjustment and improvement of China and G20 countries trade relationship," *Quantities Economy And Technology Analysis*, vol. 35, no. 10, p. 15, 2018.
[22] X. Yin and C. M. Liu, "Spatial network connection and its influence of Belt and Road initiative countries economic development," *Shandong Finance University Journal*, vol. 32, no. 4, p. 12, 2020.
[23] B. Xiong and Z. Hu, "Evolution and influence analysis of resource city'S transformation efficiency, based on shandong resource cities," *East China Economy And Management*, vol. 33, no. 7, p. 9, 2019.
[24] Q. Li, *RECP Potential Influence to Chinese Textile Import and Export Industry*, Northeast Finance University, China, 2016.
[25] S. Li, M. M. Shang, and L. Zhong, "The influence of RCEP on the construction of China (Guangxi) pilot Free Trade Zone and its countermeasures," *Guangxi Social Sciences*, no. 02, pp. 85–93, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6842974, 12 pages
https://doi.org/10.1155/2022/6842974

Research Article

The Impacts of Internet + Rural Financial Industry on County Economy and Industrial Growth Algorithm

Yuanhui Huang and Yimao Ye

Guangxi Technological College of Machinery and Electricity, Nanning, Guangxi 530007, China

Correspondence should be addressed to Yimao Ye; hyh@gxcme.edu.cn

Received 16 March 2022; Revised 18 May 2022; Accepted 24 May 2022; Published 29 June 2022

Academic Editor: Lele Qin

In recent years, commercial banks and rural financial institutions in and below the county area have developed rapidly, and the number of outlets has increased rapidly. But for the vast rural areas of the country, the number of outlets is still limited. At present, there are still a large number of areas with zero financial coverage in rural the country. The development of the financial industry in a region not only affects the level of local economic growth but also has a good effect on improving the income level of local residents and changing the way of local economic development. To better develop rural finance and county economy, this paper constructs an artificial neural network model and FA model to predict the rural finance industry, and four indicators are selected to test the performance measurement of the model. The hit rates of the five models are 54.65%, 53.75%, 59.78%, 65.1%, and 73.08%, respectively. The model proposed in this paper has the highest hit rate and can predict rural finance more accurately as well, allowing for clearer changes in county economic and industrial growth.

1. Introduction

To meet the new requirements of agricultural development and new rural construction, a perfect rural financial system is indispensable. As the blood of economic development, finance affects all aspects of an economic subject all the time. Over the past three decades, the development of the financial industry has made great contributions to the country's industrial construction. However, in rural areas, many financial instruments that are mature in cities and towns cannot be used in agricultural production due to various restrictions.

The main reasons for the relative lag of rural financial development are as follows: first, the rural financial development started late and lacks experience; second, the rural economic development in the country has the problem of financial exclusion. It is precise because of the problem of rural financial exclusion that economic entities in rural areas cannot enjoy financial services and obtain financial products. This has led to the unsustainable development of rural finance and a lack of endogenous motivation. Deep learning analysis has penetrated the daily work of all walks of life due to its high efficiency, high plasticity, and high universality. High efficiency means using a trained neural network to evaluate a project that takes little time.

Regarding artificial intelligence algorithms, relevant scientists have done the following research. Axel G proposes using artificial intelligence algorithms to improve the sensitivity of mammography. In this case, interval cancer rates are likely to drop and the quality of the screening system to improve. Using artificial intelligence algorithms as an additional reading tool has the potential to reduce interval cancers [1, 2]. Deng G proposed an improved artificial neural network algorithm based on incremental speed optimization, which improves the integration rate and effectively avoids local congestion. The experimental results confirm that the proposed method has high information accuracy and is suitable for the stability of the classification of rocks near the carbon path. Based on an innovative human recognition algorithm, Liang H uses a vector support engine to model the effects of learning taekwondo based on an artificial intelligence algorithm. The results show that the

presented model has a clear effect and can be used in education. Vivekanadam B uses artificial intelligence algorithms to compare dermoscopy images obtained from DSLRs, smartphones, and light USB cameras to determine the accuracy of melanoma identification. He applies several algorithms for artificial intelligence based on malignant pathology, composition, and physician contributions made in detail [3, 4]. Huo uses an optimized adaptive intermediate filter algorithm and correction method to modify the KR code based on neural network regression. The AI algorithm that he works with has a definite effect to improve the validation level of KR code images [5]. The accuracy and sensitivity of Kani H T will be improved by including more images and improving the algorithm. The use of artificial intelligence in daily IBD practice could remove the subjectivity of endoscopists in diagnosing and assessing disease severity to make treatment decisions [6]. Chen measures the sensitivity, precision, and accuracy of newly developed smart bracelets. Equipped with optometry and monoclonal ECG and artificial intelligence algorithms, the device is used in the short term [7]. Saikumar K analyzes the operation and rapid diagnosis of open-heart surgery. Implementation and progress have been made using specialized image processing techniques to achieve fast and reliable detection with the help of artificial intelligence algorithms [8]. Based on machine learning algorithms, Y Wang has developed an English distance learning management system based on artificial intelligence algorithms optimized for machine learning to meet the needs of English distance learning management: evaluating student status through careful database management and assessing student learning status in a timely and efficient manner [9]. Huang et al. apply project study methods to artificial intelligence courses on robotics career planning issues in artificial intelligence. He sees career planning as a task, evaluates and examines it, and uses ant-based algorithms to find the best design path. They give students full initiative and interest and promote creativity and student collaboration [10]. To train neural networks, Ciulla developed an accurate energy database as a basis for training specific artificial neural networks. He identified the optimal ANN topology and developed a tool for quickly and easily determining the heating energy demand of non-residential buildings [11]. Aiming at the problem of the location of distribution objects in the process of logistics distribution, Cao G established an optimal path model based on the artificial intelligence algorithm-ant colony algorithm in logistics distribution. He analyzed the pheromone concentrations along the paths between various locations and found the optimal path [12, 13]. To improve the accuracy of glioma distribution, Zhang proposed an MRI technique based on a complex three-dimensional rotation of neural tissue. Experiments show that this method can be adapted to different and different procedures in different patients and improve the accuracy of brain tumor diagnosis [14]. Zhao uses bitter data processing and separation techniques to analyze the visual characteristics of a martial arts match. He evaluated abstract models and confirmed proposed methods for improving decision-making skills and effective education in classical martial arts [15]. Smart radio networks can use artificial intelligence technology for efficient sensing and decision-making. Mourad M proposed an algorithm for a blind spectrum recognition adapter based on a centralized recognition platform. He then applies neuronal phase adapter interference technology in decision-making to make the best and most accurate decisions [16]. This method provides some reference for the study, but due to the short duration and small size of the study model, this study has not yet received any public recognition.

The innovation of this paper is the introduction of the concept of artificial intelligence algorithms. It described artificial intelligence in detail in the Method section and made statistics on the related concepts of rural finance and financial data in recent years. It builds the FA prediction model and compares it with the artificial neural network prediction model. It tests the predictive ability of the model chosen in this paper and finally predicts the rural financial industry [17].

This paper introduces the research background and significance of the article in the introduction section and refers to the relevant research results of other scientists in recent years, the methodology section explains the concepts related to artificial intelligence algorithms and rural finance, and the experimental section analyzes the results of economic growth analysis to predict the rural finance industry using artificial neural network model and FA model.

Translated with https://www.DeepL.com/Translator (free version).

2. Research Methods

2.1. Artificial Intelligence Algorithms. Artificial intelligence, also known as mechanical intelligence or simply AI, refers to the intelligence displayed by man-made machines. Artificial intelligence is generally understood as a technology that uses popular computer programs to provide human intelligence. The term also describes how and whether such intelligent systems can be studied. A special section on artificial intelligence in the general text is "Research and design of intelligent agents." Artificial intelligence is a field of computer science that seeks to understand the nature of intelligence and create new types of brains such as the human mind. Areas of study in this area include language analysis, image analysis, and life sciences, professional processes and systems, and more. Since the emergence of artificial intelligence, theory and technology have become lost and the field of programming continues to expand. Artificial intelligence can mimic the information processes of the human mind and spirit [18]. AI is not human intelligence but can think as human or exceed human intelligence. Figure 1 shows the structure of a single hidden layer neural network.

Heavy scientific and engineering calculations are meant to be undertaken by the human brain. Today's computers can not only do this kind of calculation but can do it faster and more accurately than the human brain. Therefore, contemporary people no longer regard this kind of computing as a "complex task that requires human intelligence to complete." It can be seen that the definition of complex work changes with the development of the times and the

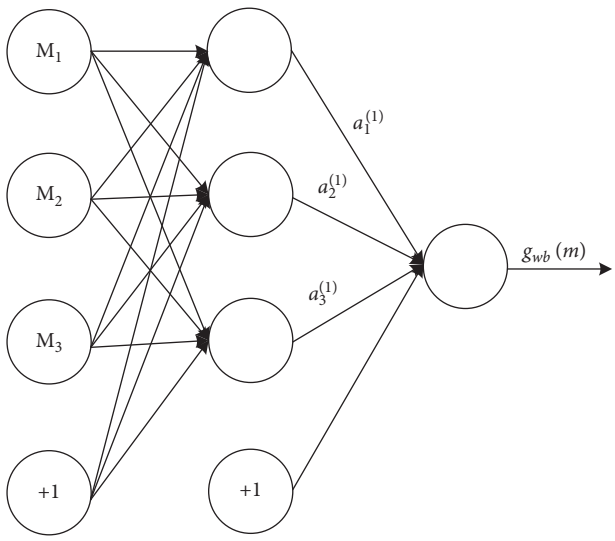


Figure 1: Single hidden layer neural network structure diagram.

advancement of technology. The specific goals of the science of artificial intelligence also naturally evolve with the times. It keeps making new progress on the one hand and turns into more meaningful and difficult goals on the other.

Artificial intelligence is the study of certain processes that build computers to simulate human thought and mental behavior such as learning, thinking, thinking, and programming. And computer engineering can reach a high level of application. The relationship between artificial intelligence and ideological science is the relationship between practice and theory, and artificial intelligence applying technology. When it comes to thinking, AI is more than logical thinking. To promote the successful development of artificial intelligence, it is necessary to learn imaginative and practical thinking. Mathematics is considered the basic science of many subjects. Mathematics also goes into language and thinking. Information services also need to borrow mathematical tools. Not only does mathematics play a role in formal logic, black mathematics, etc., but when mathematics enters the various fields of artificial intelligence, it offers advantages and rapid evolution. As shown in Table 1, there are three information processing paradigms.

Artificial intelligence is still being researched, but some scholars believe that it is dangerous to let a computer have an IQ, and it may turn against humans. This hidden danger has also occurred in many movies. Its main key is to allow machines to have the generation and continuation of autonomous consciousness. If a machine is made to have autonomous consciousness, it means that the machine has the same or similar creative, self-protective consciousness, emotion, and spontaneous behavior as a human.

There are two different ways in which artificial intelligence is implemented on a computer. One is to use traditional programming techniques to make the system appear intelligent, regardless of whether the method used is the same as that used by the human or animal body. This method is called the engineering method, and it has made achievements in some fields, such as character recognition, computer chess, and so on. The other is the simulation method, which not only depends on the effect but also requires that the realization method is the same or similar to the method used by human or biological organisms.

Nerve cells are the most important building blocks of the brain. There are differences in the structure of different neurons, which somehow combine with other neurons to form complex neural networks. But from the perspective of transmitting and remembering information, biological neurons have the same structure regardless of their type. Biological neurons must first adopt appropriate mathematical models. Data transfer between biological neurons involves many factors, which have many consequences. Not all relevant factors can be considered when creating a model, and some irrelevant implications should be ignored.

The output of the neuron can be expressed as

$$n_v = \operatorname{sgn}\left(\sum_{u=1}^{b} q_{uv} m_u - \theta_v\right). \tag{1}$$

θ_v-The action threshold of the neuron.

The expression sgn is as follows:

$$\begin{aligned} n_v &= \operatorname{sgn} \\ &= \left\{ +1,\ \sum_{u=1}^{b} q_{uv} m_u > \theta_v - 1, \sum_{u=1}^{b} q_{uv} m_u \le \theta_v \right\}. \end{aligned} \tag{2}$$

m_u-Input vector. q_{uv}-The weight value of the neuron. θ_v-Neuron threshold. n_v-The output value of the neuron.

It selects the commonly used unipolar function as the activation function of the neuron:

$$f(i) = \begin{matrix} 1, \\ 1 + e^{-i}, \end{matrix} \tag{3}$$

$$x_v^l = f\left(\sum_{u=0}^{B_{l-1}} q_{v,u}^l x_u^{l-1}\right). \tag{4}$$

x_v^l-The activation value of the node through the action of the transfer function. $q_{v,u}^l$-Weight coefficient between units.

It measures the network objective function as the sum of squared total errors:

$$H_p(t) = \frac{1}{2}\left(\sum_R s_{Rp} - n_{Rp}\right)^2. \tag{5}$$

$H_{Rp}(t)$-Objective function at the input.

The weight adjustment formula is as follows:

$$\begin{aligned} q_{v,u}^l(t+1) &= q_{v,u}^l(t) - \varepsilon \frac{\partial H(t)}{\partial q_{v,u}^l} \\ &= q_{v,u}^l(t) - \varepsilon \sum \frac{\partial H_p(t)}{\partial q_{v,u}^l}. \end{aligned} \tag{6}$$

ε-Step size, and learning rate.

Table 1: Three information processing generic types.

Project	Regular computer	Neural computing	Human brain
Information presentation	Instruction + data	Network connection processing unit function + weight	Internal neural connections
Programming	Instruction + initial data	Network topology + pattern training	Pattern training
Deal with	Digital	Digital or analog	Analog
Architecture	$1–10^4$ processor	$1–10^6$ processor	10^{11} neurons
Hardware	Integrated circuits	Electrical, optical, biological devices	Neurons
Switching speed	1 ms	$1\ \mathrm{ns}^{-1}\cdot\mathrm{ms}$	1 ms
Craft	Silicon devices	Silicon devices, optical, molecular	Biological

$$\begin{aligned}\frac{\partial i_v^l}{\partial q_v^l} &= \frac{\partial}{\partial q_{v,u}^l} \bullet f\left(\sum q_{v,b}^l i_b^{l-1}\right)\\ &= i_v^l\left(1 - i_v^l\right) i_u^{l-1}.\end{aligned} \tag{7}$$

i_v^l-The activation output value of the node.

In turn, the partial derivatives of the output layer of the network can be calculated as

$$\frac{\partial H_p(t)}{\partial i_v^l} = i_v^l\left(m_p\right) \bullet s_v\left(m_p\right), \tag{8}$$

$$\phi_v^l = \lambda_v^{l+1}\left(f'\left(i_v^l\right) \circ up\left(\phi_v^{l+1}\right)\right). \tag{9}$$

$\circ$-Dot multiplication. up$(\bullet)$-Upsampling operation.

$$\frac{\partial E}{\partial k_{uv}^l} = \sum_{i,j} \left(\phi_v^l\right)_{ij} \left(p_u^{l-1}\right)_{ij}. \tag{10}$$

$(p_u^{l-1})_{ij}$-An area that is multiplied element-wise. i, j-Image coordinates in the feature map. H-The cost function of the network.

$$\phi_v^l = f'\left(i_v^l\right) \circ \frac{\partial H}{\partial k_{uv}^l}, \tag{11}$$

$$H = -\frac{1}{n} \sum_m \sum_v \left[n_v \ln x_v^l + \left(1 - n_v\right) \ln\left(1 - x_v^l\right)\right] + \frac{\eta}{2b} \sum_\omega \omega^2. \tag{12}$$

ω-Training weights. b-Number of training instances.

$$\xi^{l+1} = \xi^l - (\varepsilon\varphi)\left[\frac{\lambda}{b}\xi^l - \frac{1}{m}\sum_m \frac{\partial H_m}{\partial q}\right]. \tag{13}$$

φ-Learning rate during network training. ε-Learning rate control coefficient. λ-Weight decay control coefficient.

$$Q^l \sim U\left[-\frac{8}{p^l + p^{l-1}}, \frac{8}{p^l + p^{l-1}}\right], \tag{14}$$

$$\xi^{l+1} = \xi^l - \frac{\varphi\phi}{b}\xi^l - \frac{\varphi}{a}\sum_m \frac{\partial H_m}{\partial q}. \tag{15}$$

U-Evenly distributed. p^l- Number of feature maps.

Neural network theory is based on the anatomy of neurons in the brain, which are interconnected, but unlike neurons in the brain that can connect to any neuron in the distance. An artificial neural network consists of different layers, connections, and directions of data transfer. Figure 2 shows a schematic diagram of the visual layer module.

The deep learning machine is a big data all-in-one product that realizes deep learning calculation, acceleration, data storage, and specific application integration through the integration of software and hardware. The software module deep learning analysis platform in the deep learning machine can provide a variety of current mainstream machine learning frameworks. This enables users to choose different computing frameworks to accelerate computing according to their needs. As shown in Figure 3, the deep learning analysis platform structure diagram.

The forward propagation process defines receiving data from the previous layer and passing it to the latter layer after calculation. The back-propagation process calculates the gradient relative to the input according to the gradient of the output of the latter layer and transmits it to the former layer. The purpose is to modify the parameters of each layer according to the loss to achieve a more accurate calculation effect. A network is a directed acyclic computational graph consisting of a series of layers. It consists of a series of layers and the interconnections between them. After the data are read from the training dataset, it is divided into a dataset for training and data for calculating loss. It then passes the data into the loss layer for training and then compares it with the data set to obtain the loss. The logistic regression network structure is shown in Figure 4.

2.2. Agricultural Finance. Rural finance is monetary financing and capital financing in rural areas. These are all companies related to rural currency circulation and loans. It is a mix of credit, finance, and rural economy. Fundraising, distribution, and management of funds in rural areas refer to the financing of rural monetary funds. Figure 5 shows the comparison of the debt ratio of small and medium-sized banks and the assets and liabilities of banking financial institutions in 2020.

The form and organization of village-level financial transactions are only external aspects of village-level finance. Rural financial institutions are the creators of special rural capital. Its emergence and development is the inevitable result of community division of labor, and it is the development of social labor distribution based on market development. When the demand for financial products and services in rural economic development and market

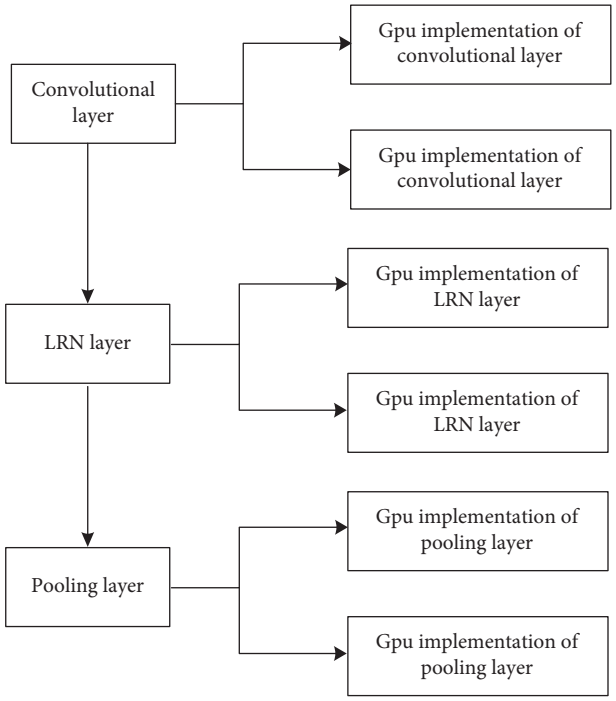


Figure 2: Schematic diagram of the visual layer module.

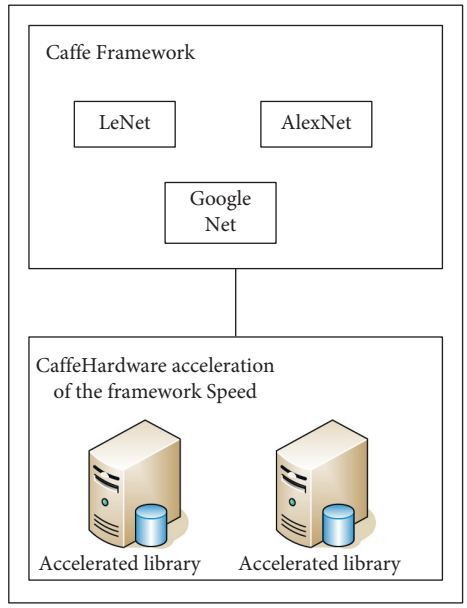


Figure 3: Deep learning analytics platform architecture diagram.

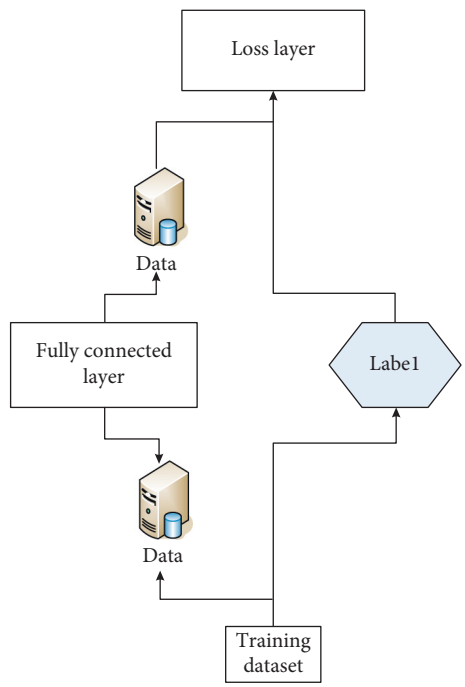


Figure 4: Logistic regression network structure.

expansion reaches a certain level, it provides intermediary services for "professional institutions." On the other hand, as long as the conditions for rural financial transactions are met, these conditions can ensure that rural financial transactions reach a certain level. Markets have created similar incentives for rural financial institutions.

On the other hand, if the current state of village financial transactions is ignored and the integration of new village financial institutions into the village economy does not increase the number of transactions in the village, it can put financial institutions in the village. It can be observed that the number of financial institutions in the village is a function of the economic function of the village.

Economic exclusion can also be defined at six levels: geographical exclusion, price exclusion, conditional exclusion, price foreclosure, market foreclosure, and foreclosure. The so-called geographic exclusion refers to the financial exclusion of economic subjects due to the long distance from the place where they obtain financial services. The further the distance between the two, the greater the degree of repulsion. The so-called evaluation exclusion refers to the financial exclusion due to the access evaluation of economic entities by financial institutions. The more stringent the evaluation conditions, the greater the degree of exclusion. The so-called conditional exclusion refers to the financial exclusion of economic entities due to unfair transactions. The more conditions attached, the greater the degree of exclusion. The so-called price exclusion refers to the financial exclusion of economic entities due to the high transaction cost of obtaining financial resources. The higher the transaction cost, the greater the degree of exclusion. The so-called marketing exclusion refers to the financial exclusion of economic entities due to the sales positioning of financial institutions. The more precise the sales target, the greater the exclusion. The so-called self-exclusion refers to the financial exclusion of economic subjects due to a lack of endogenous motivation. The smaller the self-motivation, the greater the degree of repulsion.

Financial exclusion, understood from a sociological perspective, is interrelated with social exclusion and is a subset of social exclusion. Social exclusion includes financial exclusion. Residents who are financially excluded are also socially excluded, and other aspects of residents are usually excluded to varying degrees accordingly. On the other hand,

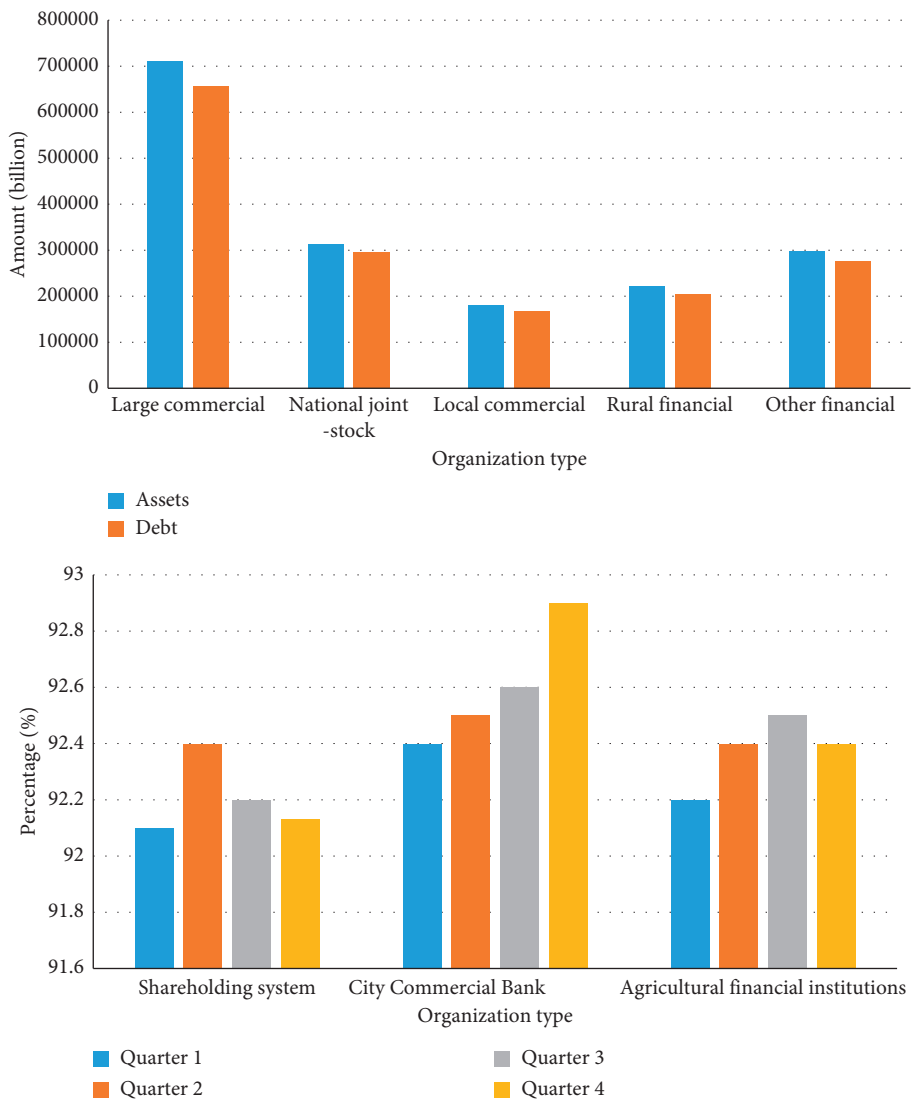


Figure 5: Comparison of debt ratio of small and medium banks.

social exclusion and financial exclusion are mutually causal. Residents are socially excluded due to financial exclusion, which in turn deepens financial exclusion due to social exclusion. Conversely, residents will also experience financial exclusion due to social exclusion, and financial exclusion will deepen social exclusion.

Financial exclusion is most evident in the vast rural areas. The long-term uneven allocation of resources has led to a widening gap between urban and rural areas. The consequence of the gap between urban and rural areas is the overall low production capacity and output level of the rural economy, and financial development is naturally limited. The fragmented development of urban and rural finance has further deteriorated the rural economic development environment. The rural financial ecological environment is a vicious circle and shows a significant Matthew effect. This is not conducive to the coordinated and mutual development of regions in China's urban and rural areas, nor is it conducive to the poverty alleviation and prosperity of the vast rural areas and rural population in the country.

The main causes of rural financial exclusion are geographical exclusion, active exclusion of financial institutions, and autonomous exclusion of excluded groups. Among them, the supply-oriented factor that causes rural financial exclusion is the active exclusion of financial institutions. This is the direct cause and is a superficial analysis of the causes of rural financial exclusion. However, no further research has been done on the root causes of the active exclusion of financial institutions. Although the problem of rural financial exclusion is only one of the many financial problems in the process of economic development, it still has the essential attribute of finance, that is, the profit-seeking nature of the financial industry. Therefore, it is not enough to just stop at the research results of the cause of the active exclusion of financial institutions. We must fundamentally study the profit-seeking nature of the financial industry to solve both the symptoms and the root causes and solve the problem of rural financial exclusion.

A common phenomenon in the country's rural areas is that even rural residents with financing needs and solvency

are still excluded from financial services. Rural finance is an important part of the rural economy. To a certain extent, the development of the rural economy depends on and attaches to rural finance. On the other hand, the "three rural problems" that have long plagued the country and the industrialization and modernization of agriculture and villages in the country to new standards, all depend on the development and rural economy. Only focusing on improving rural economic development and reducing economic exclusion in rural areas can effectively overcome the above problems. In the current Chinese institutional framework, the mismatch between supply and demand in rural finance is mainly reflected in the following three factors: First, the profit-seeking behavior of capital will make capital actively choose trading partners with low risk and high profit. Second, the transaction subject is always in an unequal transaction position in the process of information game and transaction, which increases the transaction cost paid by both parties to complete the contract. Third, the ability of agriculture to resist risks is weak. Farmers have almost no material properties with stable value, and even if they own a small amount of assets, they generally lack market recognition. Under the combined effect of the above three problems, the level of rural economic development, the level of agricultural industrialization, and the large-scale development of modern agriculture will all be affected to a greater extent.

Commercial banks and rural financial institutions in and below the county area developed rapidly, and the number of outlets increased rapidly. But for the vast rural areas of the country, the number of outlets is still limited. At present, there are still a large number of areas with zero financial coverage in rural the country. The type and number of financial institutions can neither meet the financial needs of rural areas in the country at this stage, nor can they meet the construction requirements of new rural areas under the new normal in the future. From the point of view of operating conditions, in the market share of the entire banking financial institutions, rural financial institutions account for a relatively small proportion.

The main reasons for the relatively lagging development are as follows: first, the rural financial development started late and lacked experience. Second, the economic development of the country's rural areas has the problem of financial exclusion. It is precise because of the problem of rural financial exclusion that economic entities in rural areas cannot enjoy financial services and obtain financial products. This has led to the unsustainable development of rural finance and a lack of endogenous motivation.

3. Research Results

The artificial neural network model chosen as the reference model in this paper is a three-layer BP neural network, which can approximate any function. This is a single forecasting model that directly uses neural network technology to forecast rural financial sequences. BP neural network includes an input layer, hidden layer, and output layer, and adopts a parallel network structure. Hidden layer neurons take values ranging from 2 to 10. It can directly use the rural financial industry as a training set, input it into the neural network, and the output variable is the predicted value. As shown in Figure 6, it is a rural financial prediction model based on an artificial neural network.

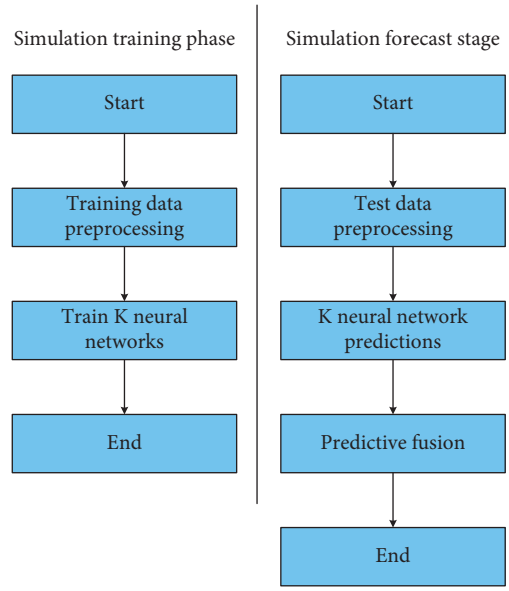


Figure 6: A predictive model of rural finance based on artificial neural network.

The FA models proposed in this work include, in particular, algorithms for degeneration, development, baseline analysis, and regression of neural networks. A general sample flow chart is shown in Figure 7. The FA portfolio forecasting model is based on the idea of decomposition reconstruction integration, which improves the learning ability of the model for financial time series as well as multiple objective functions and effectively improves the forecasting accuracy.

Exercises are trained, a loss percentage is reserved for 100 exercises, and test machine data are used to test each of the 500 exercises. The results of the experiment are shown in Figure 8.

Figures indicate that a fair share of the FA model proposed in this article is always higher than the artificial neuron model, and the method in this paper fluctuates from the 2000th to the 5000th time. However, the accuracy rate is generally higher than that of the artificial neural network model.

The loss scale measures the likelihood that data will fall into a particular category. The smaller the function loss, the faster the tissue falls. If the number of repetitions is 500, the loss pattern of the FA model is higher than that of the artificial nervous system model. Thus, the integration of the FA model is faster in the early stages. The loss function data comparison is shown in Figure 9.

Taking the rural financial industry in a certain area as the target, and collecting and collecting from the financial database, all experimental data can be divided into two subsets: a set of exercises and a set of tests. The first 1000 data are a

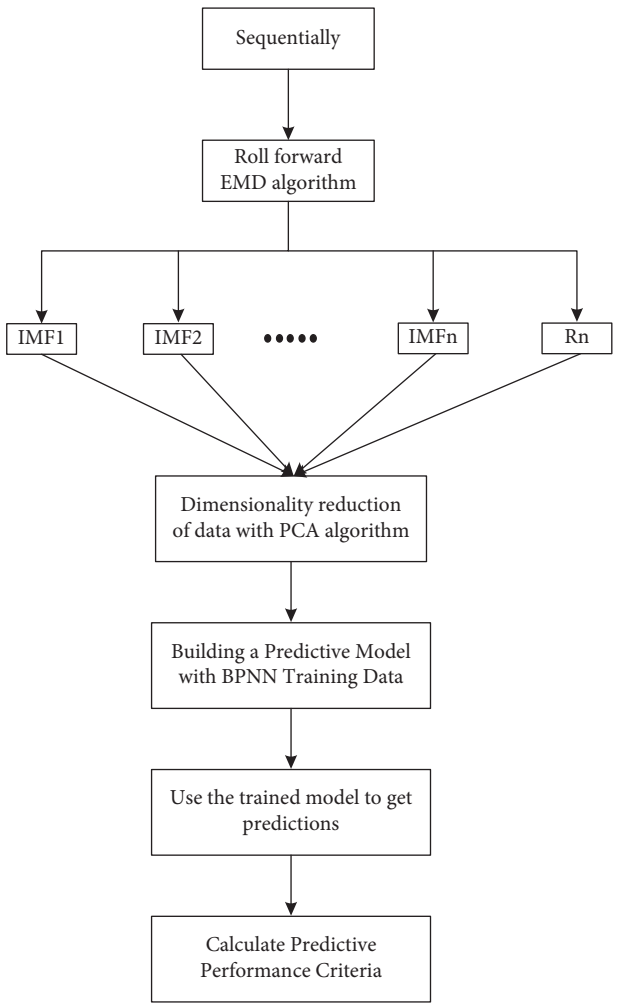


Figure 7: Overall flow chart of the model.

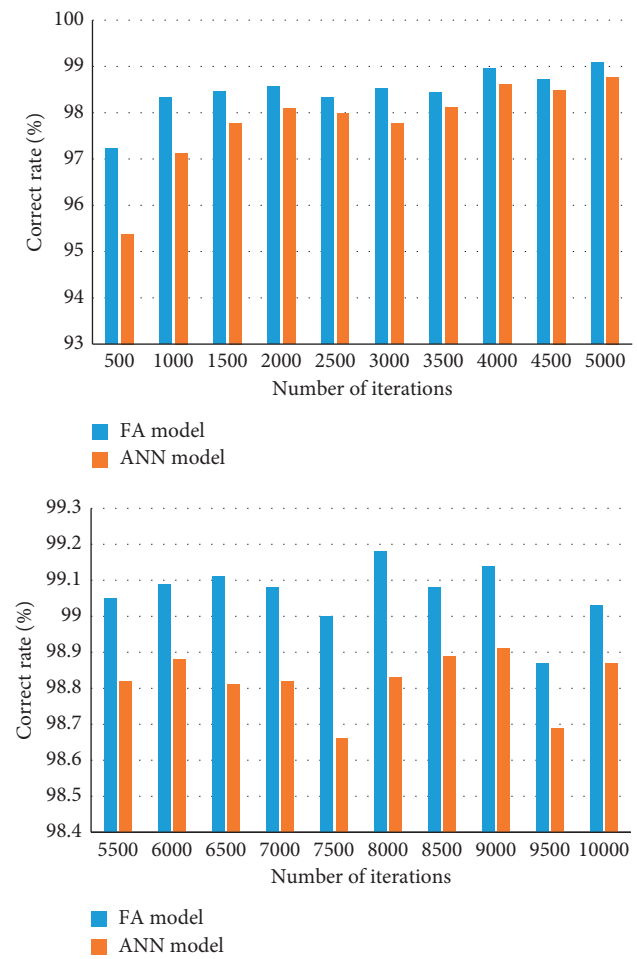


Figure 8: Training set test results.

training set, and the last 250 data are a test set, as shown in Table 2 for the data results.

Although an accurate forecast of the rural financial industry will be difficult to obtain, a rough forecast of the upward and downward direction of change is still helpful in the analysis of county-level economic and industrial growth. The performance measurement results of each prediction model are shown in Table 3.

To test the predictive strength of the sample selected in this article, a variety of rural financial sectors and four indicators were used as performance indicators in an experimental database. As shown in Table 4, the performance improvement percentage of the model used in this paper is compared with other models.

The FA model proposed in this paper is used to predict the sequence of the rural financial industry, as shown in Figure 10 for the relevant data of the prediction results.

A limited level of rural financial services will make it difficult to meet the multilevel needs of the county's economic development, and forecasting rural finance can make predictions about the county's economy.

The comprehensive and efficient use of relevant information helps to improve prediction accuracy. In actual forecasting, information will be comprehensively used when predicting the future trend of the rural financial industry, not just superficial information. Empirical findings show that almost all data sequences are close to random walks if only superficial information is used. However, the comprehensive use of transaction information can effectively improve the forecasting ability of the index fluctuation trend.

At present, the development of the rural financial industry in the province plays an important role in the agricultural economy: First of all, the sound financial laws and regulations make the rights and interests of both lenders and borrowers legal protection. Various financial institutions in rural areas have laws to abide by in the process of granting loans, which reduces the unsystematic risks of financial institutions. At the same time, for farmers, loans and insurance in the process of agricultural production will be guaranteed by law. Second, the reform of the financial system gradually removes financial regulation and develops towards financial liberalization, forming a sound market-oriented financial system. The interest rate level in the rural financial system has gradually reached a market-clearing state. Savings and investments continue to increase so as to promote the level of investment in agriculture by institutions

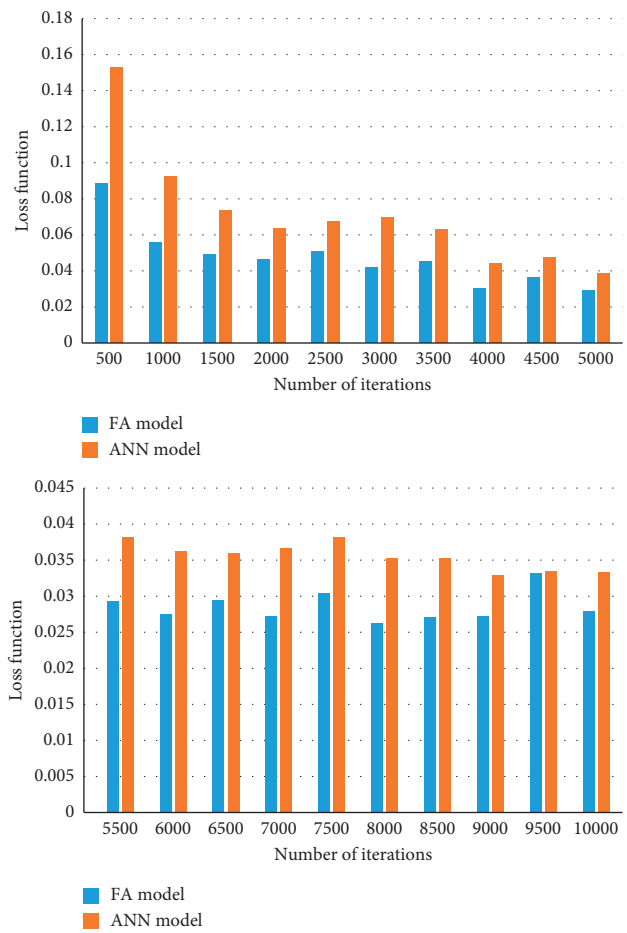


Figure 9: Loss function data comparison.

Table 2: Data results.

Index	Mean	Standard deviation	Maximum value	Minimum	Skewness
All samples	2830.256	668.987	5353.9	2085.97	1.4249
Training set	2588.954	399.821	4123.75	2853.97	1.2762
Test set	3797.528	652.457	5353.78	2086.76	0.6753

Table 3: Performance measurement results for each prediction model.

Model	Performance standard			
	MD	ME	RE	DS (%)
AA	91.3678	1.8257	109.6856	54.65
GH	108.8479	2.928	138.3183	53.75
BN	186.5833	3.4082	252.7856	59.78
ED	66.2832	1.9836	88.8658	65.1
FA	57.8421	1.3988	75.4756	73.08

Table 4: Percentage improvement in performance compared to other models.

Model	Performance standard			
	MD (%)	ME (%)	RE (%)	DS (%)
AA	37.4	33.22	31.61	35.59
GH	47.49	42.38	45.11	36.64
BN	69.39	66.21	70.05	22.4
ED	14.56	6.42	15.35	11.45

and individuals and increase the agricultural output value of Shanxi Province to drive the growth of Shanxi Province's agricultural economy. Third, the development of the financial industry itself helps to increase capital accumulation and improve the efficiency of resource use. It helps to improve the level of advanced agricultural production intensification through the development of rural financial industry, eliminate backward production models, and increase scientific and technological investment in agricultural production. This realizes the efficiency, scale, and mechanization of agricultural production and thus increases the output value per unit area. Fourth, the rural financial industry can play a role in preventing and controlling agricultural production risks. Village and township financial institutions that issue agricultural loans will spontaneously supervise agricultural production risks, which reduces the supervision cost of agricultural production risks. At the same

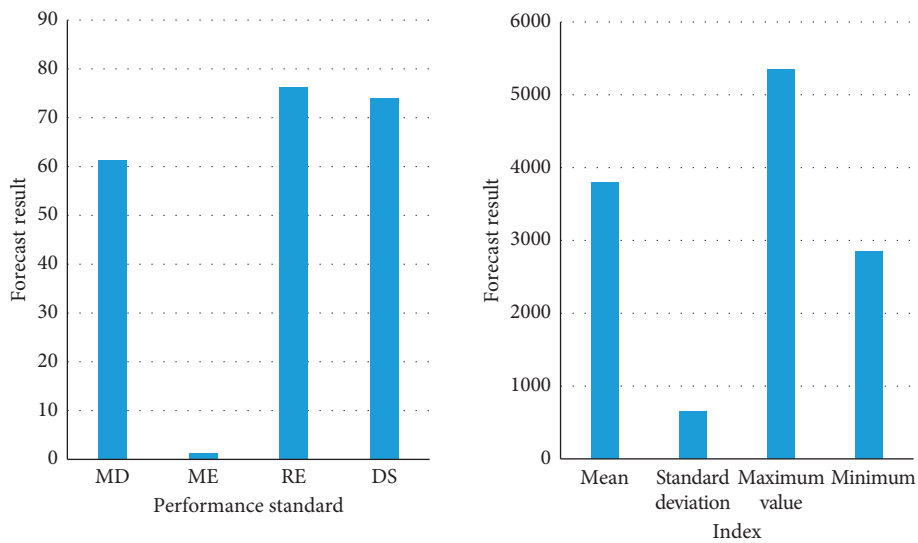


Figure 10: Data related to prediction results.

time, the continuous enrichment of rural financial instruments can also play a role in controlling risks. It greatly reduces the risk of farmers' agricultural production through the rational use of agricultural insurance, futures, and other tools. This has improved farmers' enthusiasm for production and greatly promoted the modernization of agriculture.

The role of the financial industry in promoting agriculture is currently mainly reflected in agricultural credit. The ratio of the amount of funds obtained by agricultural credit to the added value of the agricultural industry represents the degree of financial asset correlation in agricultural production. The increase in the financial correlation rate of agricultural production has a certain positive impact on the growth rate of the agricultural economy, but the current degree of impact is not high. At the same time, due to the current implementation of the agricultural credit subsidy policy, the approval and issuance of agricultural credits are mainly based on the amount and effectiveness, resulting in a low recovery rate of agricultural loans. In the long run, the continuous investment of such a large amount of funds in agriculture will lead to the shrinking of the development of other industries, which is ultimately detrimental to the development of the agricultural economy.

4. Discussion

With the deepening of the new rural construction, the reform of the agricultural economic system has made great progress, but the current rural financial system is seriously lagging behind the development of the agricultural economy. Establishing a sound rural financial system is an urgent need to further promote the development of "agriculture, rural areas, and farmers." Due to the late start of the rural financial industry, there are a lot of problems in financial laws and regulations, financial institution setup, financial supervision, financial institution asset quality, and financial practitioners' quality. As for improving the rural financial system: first, we should establish and improve local financial laws and regulations according to the current situation of the rural financial industry. This provides guidelines and legal safeguards for the financial activities of rural formal financial institutions and informal financial institutions. Second, the establishment of rural financial institutions should meet the needs of agricultural production, improve the risk assessment and risk supervision of agricultural credit, and improve the quality of agricultural credit assets. Third, the professional quality of current rural financial practitioners is generally lower than that in urban areas. It is necessary to improve the work efficiency of rural financial institutions by strengthening the training of employees.

At present, formal and informal financial institutions coexist in rural areas, and formal-informal financial institutions will continue to coexist in the process of interest rate liberalization. The government should combine long-term and short-term effects in the process of formulating financial policies. While grasping the level of agricultural borrowing, it is necessary to pay attention to the flow of loans and the management and control of loan risks, and actively guide the market interest rate of rural financial institutions to move closer to a stable market equilibrium interest rate. The long-term use of preferential agricultural financial policies to increase the agricultural investment will lead to the dependence of agricultural production on the government and the loss of self-development ability. It will also cause the outflow of rural funds and affect the long-term sustainable development of rural financial intermediaries. This adversely affects the formation of a sound ecosystem of rural finance and ultimately affects the effectiveness of financial policy implementation. The government should provide reasonable guidance to informal banks, lending organizations, and other institutions to make them effective tools to make up for the lack of formal financial market functions. At the same time, this will not cause damage to the rural financial market, so as to better formulate reasonable financial policies in response to the agricultural economic growth in Province and the improvement of farmers' living standards, and

improve the role of rural financial institutions in agricultural economic development.

Under a perfect rural financial system, the deposits of rural residents and township enterprises are an important source of funds for agricultural production. At present, due to the low level of agricultural economic development, the development of the rural financial industry has just started. Rural financial institutions have few outlets and small total deposits, which cannot provide sufficient credit funds for agricultural production. There is a big gap between the net income and savings of rural residents and urban areas and cannot play a role in promoting agricultural economic growth. While improving agricultural productivity, we should pay attention to improving farmers' living standards, expanding social security, and improving rural residents' medical care and education. This enables the development of the financial industry in rural areas to achieve self-promotion and improvement.

The innovation of the rural financial industry has the characteristics of few innovative asset products and insufficient competitive power of innovative subjects. Innovation is mainly driven by policy rather than the result of market competition. The innovation of rural financial products cannot meet the needs of the current agricultural economic reform and farmers' investment and does not meet the inherent requirements of the market economy, resulting in high costs and low efficiency. The innovation of rural financial products should take the development of the agricultural economy as the starting point, and the financial products launched conform to the characteristics of high investment and high risk of the agricultural economy. In the process of continuing marketization of interest rates, agricultural financial products should not only cover the risks of agricultural production but also consider the needs of supporting agriculture. It is necessary to fully meet the requirements of capital owners, financial intermediaries, and capital users for risk transfer and investment profit, and to promote the reform and development of the agricultural economy and industry.

5. Conclusion

Only under a sound financial system can institutions and individuals use funds rationally. It takes advantage of the local advantages to improve the local agricultural production infrastructure, so as to carry out large-scale, mechanized, and efficient agricultural production in the local area. This paper forecasts the rural financial industry and puts forward some suggestions for the development of rural finance. In this paper, preliminary prediction research is carried out, and there are inevitably some omissions in the research. The analysis of the state evaluation level is not detailed enough, only showing changes in the relevant indicators and no internal evaluation analysis. At the theoretical research stage, the concept of the theory is not deep enough. Some technical analysis indicators, such as relative strength indicators and moving averages, can be used as input variables for PCA algorithm dimensionality reduction to improve forecast accuracy and shorten training time.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This research study was sponsored by 2020 Basic Scientific Research Ability Improvement Project for Young and Middle-Aged Teachers in Colleges and Universities in Guangxi, the name of the project is Research on Industrial Sustainable Development in Poor Areas of Western China Facing Rural Revitalization, the project number is 2020KY32001. The author would like to thank the project for supporting this article.

References

[1] X. Zhang, Y. Wang, C. Liu, and Z. Chen, "A novel approach of battery pack state of health estimation using artificial intelligence optimization algorithm," *Journal of Power Sources*, vol. 376, pp. 191–199, 2018.

[2] A. Graewingholt and P. G. Rossi, "Retrospective analysis of the effect on interval cancer rate of adding an artificial intelligence algorithm to the reading process for two-dimensional full-field digital mammography," *Journal of Medical Screening*, vol. 28, no. 3, pp. 369–371, 2021.

[3] G. Deng and Y. Fu, "Fuzzy rule based classification method of surrounding rock stability of coal roadway using artificial intelligence algorithm," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 4, pp. 8163–8171, 2021.

[4] L. Hailong, "Role of artificial intelligence algorithm for taekwondo teaching effect evaluation model," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 2, pp. 3239–3250, 2021.

[5] B. Vivekanadam, "Artificial intelligence algorithm with SVM classification using dermascopic images for melanoma diagnosis," *Journal of Artificial Intelligence and Capsule Networks*, vol. 3, no. 1, pp. 34–42, 2021.

[6] L. Huo, J. Zhu, P. K. Singh, and P. A. Pavlovich, "Research on QR image code recognition system based on artificial intelligence algorithm," *Journal of Intelligent Systems*, vol. 30, no. 1, pp. 855–867, 2021.

[7] H. T. Kani, I. Ergenc, G. Polat, and Y. A. O. Ozen Alahdab, "P099 Evaluation of endoscopic mayo score with an artificial intelligence algorithm," *Journal of Crohn's and Colitis*, vol. 15, pp. S195–S196, 2021.

[8] E. Chen, J. Jiang, R. Su, and M. S. J. Y. Gao, "A new smart wristband equipped with an artificial intelligence algorithm to detect atrial fibrillation," *Heart Rhythm*, vol. 17, no. 5, pp. 847–853, 2020.

[9] K. Saikumar K and V. Rajesh V, "Coronary blockage of artery for heart diagnosis with DT artificial intelligence algorithm," *International Journal of Research in Pharmacy and Science*, vol. 11, no. 1, pp. 471–479, 2020.

[10] Y. Wang, "An improved machine learning and artificial intelligence algorithm for classroom management of English distance education," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 2, pp. 3477–3488, 2021.

[11] L. Huang, K. Zhang, W. Hu, and C. Li, "Trajectory optimisation design of robot based on artificial intelligence algorithm," *International Journal of Wireless and Mobile Computing*, vol. 16, no. 1, p. 35, 2019.

[12] G. Ciulla, A. D'Amico, V. Lo Brano, and M. Traverso, "Application of optimized artificial intelligence algorithm to evaluate the heating energy demand of non-residential buildings at European level," *Energy*, vol. 176, pp. 380–391, 2019.

[13] G. Cao, "Research on the application of artificial intelligence algorithm in logistics distribution route optimization," *Paper Asia*, vol. 34, no. 5, pp. 35–38, 2018.

[14] H. Sun, Z. Lei, Y. Huang, and J. Yu, "Multi-objective robust design of new rotate barrel based on satisfaction function," *Tehnicki vjesnik-Technical Gazette*, vol. 27, no. 2, pp. 558–566, 2020.

[15] Y. Zhang, Y.-m. Zhou, Z.-h. Liao, and G.-y.K.-c. Liu, "Artificial intelligence-guided subspace clustering algorithm for glioma images," *Journal of Healthcare Engineering*, vol. 2021, no. 2, Article ID 5573010, 9 pages, 2021.

[16] C. Zhao and B. Li, "Artificial intelligence auxiliary algorithm for wushu routine competition decision based on feature fusion," *Journal of Healthcare Engineering*, vol. 2021, no. 1, Article ID 1632393, 7 pages, 2021.

[17] T. Nguyen, Q. Pham, X. Dang, T. Doan, and X. Le, "Optimization parameters of milling process of mould material for decreasing machining power and surface roughness criteria," *Tehnicki vjesnik-Technical Gazette*, vol. 26, no. 5, pp. 1297–1304, 2019.

[18] M. M. Mabrook, H. A. Khalil, and A. I. Hussein, "Artificial intelligence based cooperative spectrum sensing algorithm for cognitive radio networks," *Procedia Computer Science*, vol. 163, pp. 19–29, C, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5082178, 17 pages
https://doi.org/10.1155/2022/5082178

Research Article

A Study on the Correlations among Organizational Learning, Dynamic Capabilities, and Innovation Performance of Innovative Firms

Yanli Li and Xiaohan Wang

School of Economics and Management, Beijing Jiaotong University, Beijing, China

Correspondence should be addressed to Xiaohan Wang; 16120713@bjtu.edu.cn

Received 20 April 2022; Revised 12 May 2022; Accepted 17 May 2022; Published 26 June 2022

Academic Editor: Lele Qin

Innovation is the core of China's national policy and the lifeline of enterprises at the local and global market. There has been a huge amount of research on innovation and elements contributing to innovation performance; however, few of them built a theoretical model to study the correlations among organizational learning, dynamic capabilities, and innovation performance. Based on the existing studies and literature at home and abroad and considering the development status of innovative enterprises in China, this paper decomposes organizational learning into three dimensions of learning commitment, shared vision, and open-mindedness and divides dynamic capabilities into three dimensions of environmental insight capability, resource integration capability, and organizational flexibility capability. To verify the model of LDP (learning-capability-performance) and hypotheses, the authors conducted a survey in Beijing, Tianjin, Hebei, Shanghai, and Qingdao, which have ranked top in the number of innovative enterprises in China in recent years. A sample of 232 valid questionnaires were collected and validated with SPSS23.0 software. The result shows that organizational learning and its three dimensions have significant positive effects on innovation performance, while only two dimensions of dynamic capabilities, resource integration capability and organizational flexibility capability, have significant positive effects on innovation performance. The third dimension of environmental insight capability has no significant positive effects on innovation performance. The dynamic capabilities and its three dimensions play a partial intermediary role between organizational learning and innovation performance.

1. Introduction

1.1. Research Background. Innovative companies are companies that rely on innovation-driven development, whose core value and philosophy is to implement a continuous innovation strategy and to obtain continuous growth and development of benefits [1].

In the analysis of the innovative enterprise concept, there are two questions worth exploring: how to achieve a continuous innovation drive and how to achieve continuous growth in business efficiency. To achieve these two things, continuous learning and progress are essential. On the one hand, in the knowledge economy, knowledge is the basis of innovation, and the acquisition and application of knowledge is an important source of the innovation drive. Wu and Wang [2] stated that resource-based view theory, organizational learning theory, and dynamic capability theory agree that organizational learning is an effective way to maintain lasting competitiveness in a dynamic internal and external organizational environment. On the other hand, in the context of China's economic transformation, the external competitive environment of enterprises presents a highly variable and dynamic nature, but new enterprises have an inherent lack of resource endowment due to difficulties in accessing resources.

While resource-based theory can only explain the heterogeneous resources that firms rely on to gain competitive advantage in a static environment, at present firms are in an unpredictable and dynamic environment. This predicament requires firms to constantly break their existing competitive

advantages and dynamically update their core competencies; otherwise, they will fall into core rigidity.

In this context, Teece et al. [3] have proposed the concept of dynamic capabilities, arguing that companies must have "the ability to dynamically integrate and reconfigure their internal and external resources, technologies, and competencies to meet the changing requirements of the environment" to gain superior profits and establish a competitive advantage in a hypercompetitive environment. Organizational learning is considered an important factor in the evolution of dynamic capabilities, and through organizational learning, it is possible to improve the dynamic capabilities of an organization to respond to changes in the environment.

From this, it is reasonable to envisage whether and how organizational learning affects a firm's innovation performance based on dynamic capabilities and whether dynamic capabilities can play a mediating role in the process of organizational learning affecting firm performance.

This paper attempts to empirically investigate the above issues through a quantitative approach, using Chinese innovative firms as the object of study. The purpose of this study is trying to contribute to the practice of strategic management theory and theoretical research and provide useful lessons for Chinese innovative firms to ultimately improve their corporate performance.

1.2. Research Objectives. Innovative enterprises are market players with significant economic and social impact, and the steady and rapid growth of their innovation performance has a direct impact on the development of the enterprise and, consequently, on the country's economic development. The aim of this paper is to investigate the relationship among organizational learning and dynamic capabilities and innovation performance so that innovative firms can convert acquired knowledge into innovation capabilities to sustain their life cycle.

This paper investigates the mechanism of the relationship between organizational learning and innovation performance by systematically reviewing and integrating previous research, taking dynamic capabilities as the starting point and innovative enterprises as the research object, and constructing a theoretical model with organizational learning as the independent variable, dynamic capabilities as the mediating variable, and enterprise innovation performance as the dependent variable [4]. Based on the scales already developed by previous authors, the existing scales are modified and improved, and new scales and research models with reference are proposed, considering the current level of innovation development in China. And through the questionnaire survey and enterprise innovation report summary, SPSS data analysis was conducted to verify the hypothesis to draw conclusions.

1.3. Research Gaps. After years of research, most scholars affirm the existence of the relationship between organizational learning and corporate innovation performance but always feel the lack of strong supporting elements between the two. To solve this confusion, researchers refine and split the organization into competency dimensions, such as decomposition into technical competencies, dynamic competencies, core competencies, and so on. And these explorations have played a crucial role in promoting the study of the relationship between organizational learning and innovation performance.

Dai [5] targeted the study on Chinese industrial firms and investigated the mechanism of the role of organizational learning, dynamic capabilities, and performance in international business performance as the dependent variable. In addition, the moderating variable of environmental factors was introduced, and the results obtained indicated that for Chinese industrial firms, the three variables were significantly positively related, organizational learning was also positively related to dynamic capabilities, and environment also played a moderating role. Lin [6] investigated 317 firms in the Guangdong Pearl River Delta and obtained a slightly different conclusion; she concluded that firms' organizational learning did not have a significant effect on innovation performance, but dynamic capabilities could make organizational learning have a significant effect on performance through its fully mediating role. Yang et al. [7] selected manufacturing firms for their study and similarly obtained a significant correlation among organizational learning, dynamic capabilities, and innovation performance.

1.4. Research Methodology

1.4.1. Literature Research Method. Online authoritative databases such as "China Knowledge Network," "Baidu Academic Discovery System," and the library of Beijing Jiaotong University for relevant literature, materials, and master's and doctoral theses at home and abroad were sorted through. Offline, the National Library of China has a collection of books and journals from home and abroad, which can be read in physical form. Two-way aggregation was conducted to understand the status of contemporary research on innovation performance in innovative enterprises, to identify research questions, to define the concepts and dimensions of core variables, and to lay the theoretical foundation.

1.4.2. Qualitative Research Method. Interviews were conducted to collect the views and suggestions of experts in the field of management and middle and senior leaders of innovative enterprises on innovation performance and to build an evaluation system for innovation performance by drawing on existing indicator systems and scales. Theoretical knowledge is also summarized and analyzed in depth.

1.4.3. Quantitative Research Methods

(i) *Questionnaire Analysis Method*

Firstly, the preliminary design of the questionnaire was carried out according to the research content and hypothesis of the article, taking innovative enterprises as the main body. Secondly, the

questionnaire was distributed in a small scale and handed over to three to five experts in the field for initial review, and the dynamic capabilities and organizational learning scales were revised according to the feedback, while the questionnaire was improved to ensure its scientific rigor. Finally, the improved questionnaires were distributed and collected on a large scale to provide real and reliable data for the study. The questionnaire is attached as appendix in the paper.

(ii) *Multivariate Data Analysis Method*

The data collected from the questionnaires were analyzed statistically. SPSS statistical software was used to carry out multivariate analysis, including descriptive statistical analysis, reliability and validity analysis, and multiple regression analysis and mediation effect test. The results obtained were used to test the hypotheses of this paper one by one and explore the profound relationship between organizational learning, dynamic capabilities, and innovation performance.

1.5. Research Novelty. Based on extensive reading of relevant literature and systematic combing of previous theoretical studies, this paper has the following innovative points.

(1) The grounding of the study is novel. According to the existing literature, most of the studies on enterprise performance are from the perspective of technological innovation or financial performance. There is no research on the relationship between organizational learning and innovation performance from the perspective of dynamic capabilities. Based on the logical paradigm of "learning-competence-performance," this paper constructs a theoretical model of "organizational learning-dynamic capability-innovation performance" for innovative enterprises. This paper provides a new way of thinking in performance research.

(2) Previous scholars have more often studied the impact of a single variable on performance, with the entry point being traditional performance rather than innovation performance, and mostly based on resource-based theory, without taking the dynamics of environmental change into consideration as a moderating factor. This paper combines the dynamic capability theory of Teece and other scholars while considering the dynamics of the environment to improve the innovation and completeness of the theoretical model.

(3) This paper extends theoretical and empirical research on innovation performance in innovative firms. Research on organizational learning, dynamic capabilities, and innovation performance has previously focused on the manufacturing sector or has not clearly identified the target firms. This paper, however, is a targeted analysis of innovative firms, rigorously selected and investigated in accordance with the article's definition of innovative firms, and has important real-life guidance on the current state of China's strong support for the development of innovative firms.

2. Literature Review

2.1. Study between Organizational Learning and Innovation Performance. The organizational learning is the process of acquiring knowledge. Garvin et al. [8] defined organizational learning as a range of activities, such as systematic problem solving, trial and error, learning from mistakes, learning from others, and accelerating the diffusion of knowledge within the organization. The essence of innovation is to acquire new knowledge or recombine existing knowledge for the enterprise's R&D activities. Therefore, many scholars have conducted relevant studies around enterprise performance starting from organizational learning and focused on innovation performance, which takes innovation as an important breakthrough. Some scholars studied the direct relationship between the two, while some introduced intermediate variables.

Fiol and Lyles [9] argued that there is a hypothesis in the study of organizational learning that it improves the future performance of organizations. Sinkula et al. [10] argued through extensive empirical research that organizational learning is more effective in interpreting and remembering market information over longer time, thus improving firm performance. Some scholars introduced intermediate or adjustment variables. Baker and Sinklua [11] combined the market orientation factor to study the effect of bivariate with organizational learning on firm performance and concluded that a good learning environment in a firm can effectively optimize market orientation and capture more market share than competitors, thus providing a sustainable competitive advantage to the firm. Daniel and Marie-Claude [12] also introduced market orientation factors, and the study obtained that both organizational learning and market orientation can contribute to performance.

In China, Liu and Jin [13] investigated firms in North, Central, and South China and found that organizational learning can indirectly improve performance by enhancing firms' capabilities in strategy, technology, and marketing. Yang et al. [14] conducted an empirical study on 267 firms and obtained that intellectual capital plays a fully mediating role as a mediating variable by distributing questionnaires and other quantitative analysis methods. Xia [15] made a specific survey of top IT companies in China in 2021. She concluded that organizational learning provides the firms with opportunities in investing new business and introducing new technologies. As a result, those firms that are good at organizational learning are more competitive than competition.

At the strategic management level, the existing knowledge resources become one of the most important strategic resources for enterprises, and the more comprehensive the acquired resources are, the more valuable the strategic planning of enterprises is. At the same time, facing the dynamically changing economic and technological

environment, the updating speed of existing knowledge resources often fails to keep up with the speed of development, and innovative enterprises are facing severe challenges. Therefore, the article includes dynamic capabilities as an intermediate variable and forms an LDP model with organizational learning and innovation performance to explore the interrelationship amid the three.

2.2. Study between Organizational Learning and Dynamic Capabilities. The inseparable link between organizational learning and dynamic capabilities has been confirmed from existing studies. Nonaka pointed out that a firm's learning capabilities can contribute to the formation of dynamic capabilities and that continuous development of new knowledge and continuous learning can achieve better results than mere knowledge accumulation. Meng [16] stated that through this innovative and dynamic learning process, companies can better and faster accept changes in the environment and integrate into the new environment. Eisenhardt and Martin [17] held that a good learning environment and learning context in an organization can be invariably upgraded to an organization-specific competitiveness, which is one of the dynamic capabilities of an enterprise:

(1) From the perspective of organizational learning segmentation, some scholars divided the promotion mechanism of organizational learning on dynamic capabilities into two levels. On the one hand, total commitment to learning will help enterprises improve their sensitivity to the environment and can quickly capture the changes in the environment; on the other hand, some talents with excellent learning ability are usually more willing to enter enterprises that attach importance to learning and work in enterprises that focus on continuous learning. In return, they will have an important impact on the company, helping the company to integrate and reorganize its resources as soon as possible in a changing environment and stabilize the state of the company.

Miner divided organizational learning into three categories: real-time improvised learning, design-based experimental learning, and action-based trial-and-error learning. He concluded that all three types of learning styles have an impact on dynamic capabilities. Based on Miner's research, Zahra et al. [18] further proposed that the above three different types of organizational learning have different effects on dynamic capabilities. With the increasing size of the enterprise and the improvement of the enterprise hierarchy and system, the benefit brought by improvised learning will become weaker, while the impact of experimental learning will become stronger, and trial-and-error learning will show an inverted U-shaped state of increasing and then decreasing.

(2) From the perspective of evolution, some scholars have combined dynamic capabilities and practices. Zollo and Winter [19] classified three different organizational learning mechanisms, namely, natural accumulation of experience, knowledge representation process, and knowledge storage process. They believed that it was the interaction of these three mechanisms that triggered dynamic capabilities and enhanced them. Based on this theory, in 2002, the two scholars concluded a new formulation that dynamic capability is a collective learning model. Through continuous evolution, organizational learning can facilitate the transformation of knowledge and the construction of new knowledge, which is important for dynamic capabilities. In particular, "intentional learning" in organizational learning can effectively avoid the trap of corporate growth caused by rigidity and enable companies to develop dynamic capabilities in a targeted manner. Chinese scholars also agreed with the evolutionary view and have conducted further research based on it. They believe that efforts are needed from both internal knowledge development and external knowledge absorption in order to effectively improve dynamic capabilities. Their integration will lead to a transformation mechanism that converts new knowledge into profits and helps enterprises gain sustainable competitive advantages.

(3) Synergistic evolution of dynamic capability and organizational learning: organizational knowledge is the synthesis of individual knowledge, but it is far above individual knowledge. Organizational knowledge represents a collection of information, values, processes, and beliefs about the organization, and it is the basis of dynamic capabilities. But without a continuous learning process, organizational knowledge is only a paper product and is less likely to become a dynamic capability that can help companies renew their existing capabilities.

According to Nelson and Winter, organizations are made up of a series of interdependent management practices and operations that change and evolve based on feedbacks from organizational performance. The refinement of organizational processes in an enterprise must be achieved through long-term uninterrupted learning, which also represents organizational learning as a necessary path for the formation of dynamic capabilities in an enterprise.

The relationship between dynamic capability and knowledge learning is shown in Figure 1.

As can be seen from the figure, knowledge and information are the two basic elements for organizations to carry out learning. In the stage of knowledge acquisition and integration, enterprises store the existing knowledge in the management process of the organization through dynamic ability, thus forming the existing new ability of the enterprise. In the process of knowledge dissemination and use, it will gradually integrate to form new practices, that is, to form new organizational capabilities. Together with the already possessed capabilities, they constitute dynamic capabilities. Dynamic capabilities enable an enterprise to take the

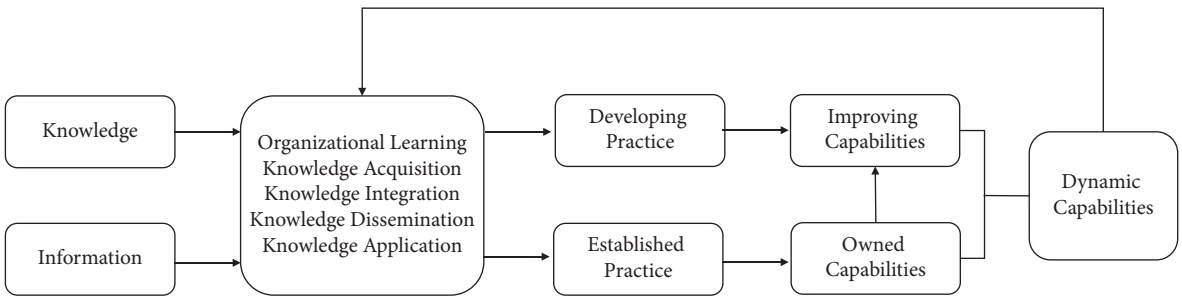


Figure 1: The relationship between dynamic capabilities and organizational knowledge learning.

initiative in the fierce market competition, to adapt to environmental changes one step ahead of competitors, and to achieve temporary victories. This victory will motivate the organization to carry out further and deeper learning to continue to gain competitive advantage, and the organization will receive positive incentives and feedbacks for learning and reach a state of virtuous circle between the two and dynamic capabilities. The realization of this virtuous circle is also an important reason to determine whether the enterprise can always maintain a competitive advantage.

2.3. Study of Dynamic Capabilities and Innovation Performance. Liu [20] defined innovation performance as a significant increase in the effectiveness and productivity of a firm's innovation process by investing a certain amount of factor resources in it, but Drucker [21] proposed that innovation performance is not just a process, but secondly a combination of all the elements of innovation.

Dynamic capabilities of firms have occupied a place in the field of strategic management, and research must necessarily bring tangible benefits to firms as one of the important purposes, so the study of the relationship between dynamic capabilities and performance production is gaining increasing attention. Zott [22], by using computer simulation, explored which specific element of dynamic capabilities affects performance, and the results showed that three attributes of the dynamic capabilities, namely, timing of resource allocation, learning, and cost, bring differences in the performance of firms under the same industry.

Referring to the research of domestic scholars, entrepreneurial resources [23] obtained a positive correlation between dynamic capabilities and performance by collecting a large sample of high-tech firms in Taiwan. Su and Liu [24] constructed a theoretical model among dynamic capabilities of complex product system innovation, innovation strategy, and innovation performance and collected data by questionnaire research for quantitative analysis. The analysis results indicated that dynamic capabilities influence product innovation performance through innovation strategy, and this influence is significantly positive. Zhang et al. [25] investigated 129 small- and medium-sized technology enterprises to explore the relationship between dynamic knowledge management capabilities and innovation performance of such enterprises, and the test results showed that dynamic knowledge management capabilities can effectively promote the improvement of innovation performance of enterprises.

In the age of digital transformation, Liu et al. [26] studied Xuzhou Construction Machinery Group (XCMG) and Shaanxi Motors Group, verifying the contribution of digital transformation on innovation performances. Zhang and Jing [27] surveyed 1198 innovative companies listed between 2007 and 2019 at Shanghai and Shenzhen Stock Markets, finding that digital transformation as innovative firms' crucial dynamic capability makes significant positive effect on innovation performance in today's technology paradigm shift.

Among many domestic and foreign scholars' studies, some study the direct relationship between dynamic capability and performance, while some introduce different intermediate variables to verify through multidimensionality. This paper takes dynamic capability as a mediating variable as an entry point to provide theoretical support for opening the "black box" of the influence of organizational learning on innovation performance.

3. Theoretical Model and Research Hypothesis

Based on the previous introduction of organizational learning, dynamic capabilities, and innovation performance, the paper firstly compares the relationship between each variable in detail and puts forward relevant hypothetical propositions. Then, a theoretical model among the three is constructed based on the proposed hypotheses.

3.1. Formulation of the Research Hypothesis

3.1.1. Research Hypothesis on Organizational Learning and Innovation Performance. The resource-based view holds that organizational learning is the process of knowledge acquisition, and the knowledge and competencies possessed by a firm become heterogeneous resources that distinguish it from its competitors. Such knowledge and skills are considered effective only if they lead to significant improvements in firm performance. According to the outcome-based view, the mission of organizational learning is to be used to improve performance, and the key factor for enterprises to gain competitive advantage originates from innovation; therefore, the improvement of innovation performance through organizational learning is one of the important purposes of conducting organizational learning.

This paper divides organizational learning into three dimensions: learning commitment, shared vision, and open-mindedness. Commitment to learning is a prerequisite to ensure smooth and stable organizational learning. A top-down commitment to active learning, positive learning, and continuous learning will greatly facilitate the acquisition of knowledge and further promote the future development of the company; shared vision is a way for the company's goals and plans to be uploaded to as many employees as possible and to reach a consensus on them, which can better fit the value of organizational learning. Open-mindedness is the prerequisite to construct innovation environment. If an enterprise cannot get rid of the old and outdated thinking and think openly according to the changing environment, it will hinder the innovation process and thus prevent the effective improvement of innovation performance. The following hypotheses are proposed:

H1: organizational learning is positively related to firm's innovation performance

H1a: learning commitment has a significant positive effect on firm innovation performance

H1b: shared vision has a significant positive effect on innovation performance

H1c: open-mindedness has a significant positive effect on innovation performance

3.1.2. Research Hypothesis on Organizational Learning and Dynamic Capabilities. Innovative enterprises are more innovative and open-minded than traditional enterprises, which means that innovative enterprises have more advantages in knowledge acquisition and utilization and should pay more attention to it. The digestion and absorption of knowledge can not only improve the overall quality of the organization, but also improve the organization's ability to respond to sudden changes in the environment and make faster changes than its competitors. This shows the importance of organizational learning in the process of organizational development.

From the literature reviewed, dynamic capabilities cannot exist in isolation, or that they cannot be effective on their own. Dynamic capability relies on the internal and external resources possessed by the organization and is built on the knowledge accumulated by the organization, which is acquired through organizational learning.

Li [28] from Tsingtao University defined that organizational learning starts from knowledge transfer, which includes knowledge acquisition, knowledge integration, and knowledge creation. The organization provides knowledge transfer with tools and system and compensate what is missing in knowledge transfer. Organizational learning is the fundamental way of sustaining and developing dynamic capabilities. In essence, it is integrating all sorts of external resources into internal and helping the firm absorb, create, and finally grow core competence to win.

Based on previous studies, the following hypotheses are proposed:

H2: organizational learning is positively related to dynamic capabilities

H2a: learning commitment has a significant positive effect on dynamic capabilities

H2b: shared vision has a significant positive effect on dynamic capabilities

H2c: open-mindedness has a significant positive effect on dynamic capabilities

3.1.3. Research Hypothesis on Dynamic Capabilities and Innovation Performance. Dynamic capability emphasizes "dynamism," which is the ability to make rapid changes to the changing environment, including the ability to see market opportunities, the ability to observe market changes, the ability to accurately identify consumer needs, and the ability to respond to competitors' competitive methods. Dynamic ability belongs to a kind of higher-order ability, which can ensure that the enterprise is not eliminated by the macro environment, always maintain stability, and has its own place in the market competition. Through dynamic capabilities, the anachronistic and old systems or conventional capabilities can be changed in a timely manner so that the company can always keep pace with the market and improve the conversion rate of business results brought by technological innovation and service innovation of the company and then effectively improve the innovation performance of the company.

Lu and Wu [29] stated that dynamic capabilities can help companies analyze themselves, calibrate their positioning, and deploy strategies with accurate positioning to promote self-innovation. Chen and Wu [30] pointed out that SMEs can flexibly adjust corporate strategies and organizational structures, absorb new resources, and adjust existing resources in a turbulent environment. So, it can be seen that dynamic capabilities are very important for SMEs in the growth period. O'Connor et al. [31], standing in the perspective of system theory and innovation theory, argued that dynamic capabilities are the triggers of innovation, which can accelerate the flow and dissemination of knowledge within the enterprise. It covers all levels of the enterprise faster and reacts in a timely manner, bringing about an effective renewal of resource allocation for the enterprise. It is easy to see that dynamic capabilities contribute to the enhancement of enterprise flexibility, remove barriers to innovation, and further bring about effective improvement in innovation performance. The hypothesis is proposed as follows:

H3: dynamic capability is positively related to firm's innovation performance

H3a: environmental insight capability has a significant positive effect on innovation performance

H3b: resource integration capability has a significant positive effect on innovation performance

H3c: organizational flexibility has a significant positive effect on innovation performance

3.1.4. Research Hypothesis on the Mediating Role of Dynamic Capabilities. Dynamic capability adapts to changes in the environment and realizes the reallocation of resources by integrating the resources possessed by the company through insight into the external environment. The resources possessed by an enterprise do not enable it to obtain performance directly, but to transform the resources into competitive advantages through dynamic capabilities, which play their mediating role. Knowledge, as the most important resource of an organization or an enterprise, plays a vital role in the improvement of enterprise performance. The lack of knowledge will lead to the backwardness of technology level and management level and the risk of being eliminated by the market. Therefore, enterprises need to continuously acquire external knowledge to enrich their resource reserves.

However, the knowledge acquired from outside cannot be directly applied to product research and development or service innovation, but has to be screened, digested and absorbed, and integrated internally and externally before it can become the resources available to enterprises. In the process of processing new knowledge, the enterprise's own digestion and absorption ability and integration ability are also continuously strengthened. Generally speaking, the acquisition of external knowledge not only expands the objective accumulation of knowledge, but also improves its own dynamic ability in the process of digestion and absorption of such new knowledge, and the effective improvement of dynamic ability can make the externally acquired knowledge transform into new products and services of enterprises, thus realizing the improvement of enterprise innovation performance.

Therefore, based on the logical sequence and mechanism of "knowledge-competence-performance" and the research of scholars, the following hypotheses are proposed:

H4: dynamic capabilities mediate the relationship between organizational learning and innovation performance

H4a: the environmental insight dimension of dynamic capabilities mediates between organizational learning and innovation performance

H4b: the resource integration dimension of dynamic capabilities mediates the relationship between organizational learning and innovation performance

H4c: the organizational flexibility dimension of dynamic capabilities mediates the relationship between organizational learning and innovation performance

3.2. Model Construction. The conceptual model as shown in Figure 2 suggests that a firm's organizational learning can have a direct impact on innovation performance and can also directly influence dynamic capabilities, while dynamic capabilities can not only have a direct impact on innovation performance but can also act as a mediator to regulate the relationship between organizational learning and dynamic capabilities so that organizational learning can have an indirect impact on innovation performance.

4. Data Analysis and Hypothesis Testing

4.1. Descriptive Statistics of the Data. In this paper, the collected questionnaires are counted, and the basic information mainly includes two parts: enterprise information and personal information. The nature of the enterprise, the industry of the main business, the location of the enterprise, the time of establishment, the number of employees, the position of the respondent, and other specific information are summarized and consolidated as shown in Table 1.

Among them, 86% of the innovative enterprises participated in the survey, especially most of them were private enterprises; nearly 90% of the respondents were middle and senior managers, and a small number of them were grassroots managers of large enterprises, so the completed questionnaires were more rigorous and reliable. The location of enterprises is mainly Beijing, Tianjin, Hebei, Shanghai, Qingdao, and a small number from Guangzhou, Shenzhen, Suzhou, Shenyang, and other places. According to the major categories of manufacturing and service industries, more enterprises belong to the service industry, accounting for 51.17%, and 48.29% belong to the manufacturing industry, which is not a big difference in general. From the perspective of the size of employees, small enterprises and large enterprises show a polarized leadership, accounting for 31.56% and 28.52%, respectively. However, in a comprehensive view, SMEs with 500 and less than 500 employees account for the majority, about 56.66%.

This study also conducted descriptive statistical analysis of the large sample, which was used to analyze the data characteristics and normal distribution. The means of all samples were distributed between 3.6 and 4.3, and the standard deviations were all below 1.2, which indicates that the sample data do not fluctuate much. Meanwhile, from the indicators of skewness and kurtosis, the absolute values of most of the data are less than 2, which can be considered that the data are close to symmetric distribution, that is, close to normal distribution, and can be analyzed later.

4.2. Reliability and Validity Tests. This study will use SPSS 23.0 software to conduct exploratory factor analysis to test the reliability and validity of the sample and to lay the foundation for the regression analysis model in the later section.

4.2.1. Confidence Level Test. The reliability test is generally expressed by Cronbach's α coefficient. It can test whether each question item of each variable can measure the same or similar characteristics and generally requires an α coefficient greater than 0.7 to meet the reliability requirements of each variable and pass the reliability test of the variable. The reliability test for each dimension of the three variables of organizational learning, dynamic ability, and innovation performance meets the requirement of $\alpha > 0.7$, and the overall α coefficient is well above 0.7, and the sample passes the reliability test.

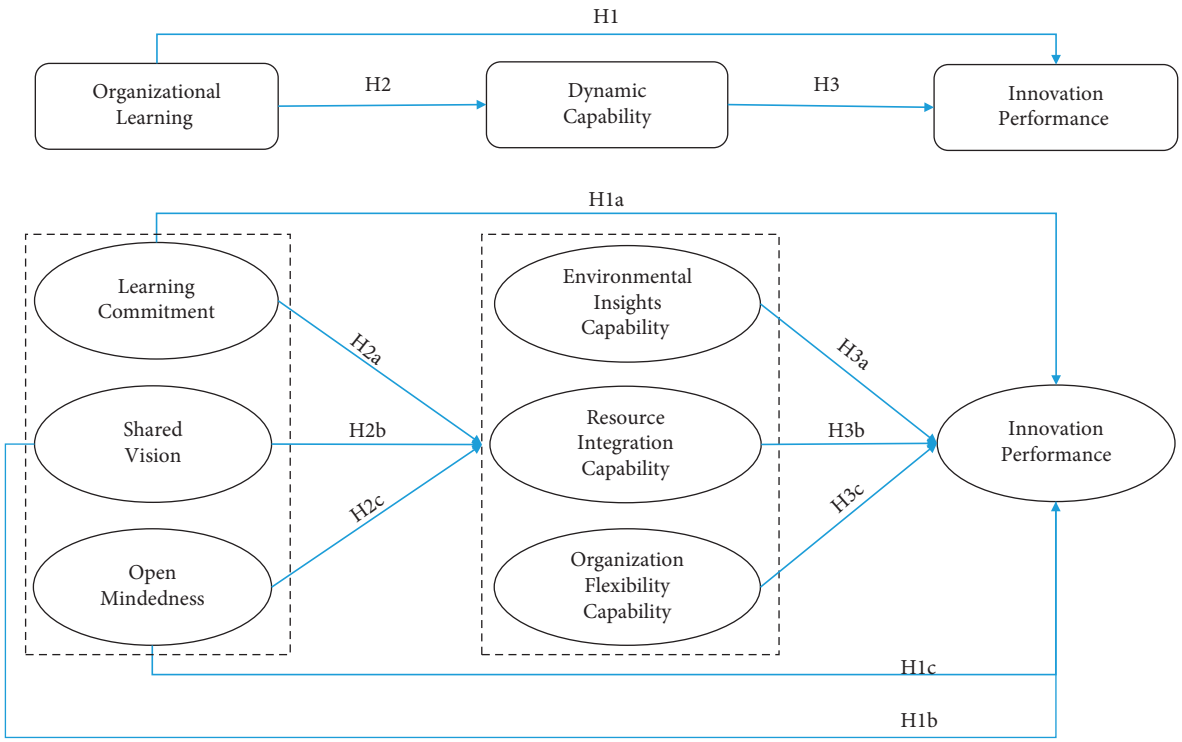


Figure 2: Conceptual model of organizational learning, dynamic capabilities and innovation performance.

4.2.2. Validity Test

(1) Validity Analysis of the Innovation Performance Scale. The KMO sample measure of innovation performance is 0.965, which is much larger than 0.7; the Bartlett sphericity test results show that the approximate chi-square value is 8457.856, with a significance of 0.000 ($p < 0.01$), and the overall structural validity of the innovation performance scale is very good.

In this paper, principal component analysis was chosen to extract factors with eigenvalues greater than 1. The total ANOVA table of innovation performance showed that a total of 1 common factor was extracted from 7 question items, which could explain 76.235% of the overall heterogeneous variables, much greater than 60%, indicating that the validity of this innovation performance scale is good.

(2) Validity Analysis of the Organizational Learning Scale. The validity test of the organizational learning scale was conducted, and the KMO sample measure was 0.936, which was greater than 0.7; the Bartlett sphericity test showed that the approximate card placement value was 2944.214, with a significance of 0.000 ($p < 0.01$), which indicated that the scale had good structural validity, and the 14 items of organizational learning were suitable for factor analysis in the next step. Factor analysis was conducted using principal component analysis, and factors with eigenvalues greater than one were extracted. A total of three male factors were extracted from the organizational learning scale, which were able to explain 77.920% of the overall heterogeneous variables, more than 60%, and the validity of organizational learning can be known to be good.

(3) Validity Analysis of Dynamic Ability Scale. The validity test of the dynamic ability scale showed that the KMO sample measure was 0.953 > 0.7; the Bartlett sphericity test showed that the approximate card placement value was 3,163.745, with a significance of 0.000 ($p < 0.01$), indicating that the scale had good structural validity and the 12 items of dynamic ability were suitable for factor analysis in the next step. Factor analysis was conducted using principal component analysis, and factors with eigenvalues greater than 1 were extracted. A total of three male factors were extracted from the dynamic ability scale, which were able to explain 84.999% of the overall heterogeneous variables, more than 60%. The validity of the dynamic ability can be known to be good.

4.3. Regression Analysis. The above tests of reliability and validity confirm that the measurement model in this study has good representational effects and can be subjected to the next step of structural analysis. In this paper, we will use stepwise regression analysis to examine the effects of organizational learning and dynamic capabilities on firms' innovation performance, the effects of organizational learning on dynamic capabilities, and the mediating role of dynamic capabilities, respectively.

Table 1: Summary of the basic situation of research enterprises.

Variables	Category	Quantity	Percentage
Ownership	State-owned enterprises	91	39.6
	Private enterprises	108	46.06
	Joint ventures	12	4.56
	Foreign wholly owned enterprises	10	3.8
	Others	42	5.97
Positions	Senior managers	94	35.59
	Middle level managers	139	53
	Grassroots managers	30	11.41
Industries	Manufacturing including mechanical, construction, electronics, chemistry, materials	127	48.29
	Services including consulting, trade, telecom, finance, tourism, medicine	136	51.71
Location	Beijing	73	27.8
	Tianjin	22	8.4
	Hebei	30	11.4
	Shanghai	55	20.1
	Qingdao	82	31.18
	Others	11	4.19
Duration of operation	Below 5 years	48	18.25
	6–10 years	52	19.77
	11–20 years	69	26.24
	Above 20 years	94	35.74
Size of employees	Below 100	83	31.56
	101–500	66	25.1
	500–2000	39	14.83
	Above 2000	75	28.52

4.3.1. Correlation Analysis. Before the subsequent testing of the hypotheses, correlation analysis is performed to determine whether there is a correlation between two variables and to indicate the degree of correlation. In this study, Pearson's correlation analysis was conducted using SPSS for each variable, and since there are multiple items for different dimensions of each variable, SPSS was used to find the correlation between "commitment to learning," "shared vision," "open-mindedness," and "environmental insight," "resource integration," "organizational flexibility," and "innovation performance," and then correlated the new variables after averaging. The three dimensions of organizational learning (i.e., commitment to learning, shared vision, and open-mindedness) were significantly and positively correlated with environmental insight, with correlation coefficients of 0.642, 0.730, and 0.751, respectively; with resource integration, with correlations of 0.627, 0.731, and 0.782, respectively; and with organizational flexibility, with correlations of 0.634, 0.707, and 0.783, respectively. From this, it can be concluded that organizational learning is significantly and positively related to dynamic capability. The three dimensions of organizational learning and innovation performance are also significantly positively correlated, with correlation coefficients of 0.626, 0.679, and 0.730, and $p < 0.01$; the three dimensions of dynamic capability and innovation performance are also significantly positively correlated, with correlation coefficients of 0.728, 0.793, and 0.843, and $p < 0.01$. Therefore, the basic research hypothesis of this paper can be initially confirmed, and subsequently, the structural equation analysis laid the foundation.

4.3.2. Three Major Problem Tests for Regression Analysis

(1) Multicollinearity Test. Before conducting regression analysis, the explanatory variables in the model should be tested for multicollinearity to prevent the existence of highly correlated relationships between variables that make the model difficult to predict accurately. Usually, VIF is used as a criterion to test whether there is multicollinearity among the variables. When $0 < \text{VIF} < 10$, it means there is no multicollinearity among the variables, and when $\text{VIF} > 10$, it means there is strong multicollinearity among the variables, and further processing of the data is needed. As shown in Table 2 below, it is the VIF test for each dimension of the variables, and the test results of VIF are all less than 10, indicating that there is no multicollinearity. As shown in Table 3, it is a factor downscaling by principal component analysis, and the three dimensions of the independent variable organizational learning and the mediating variable dynamic capability are expressed by one total variable each so as to test the multicollinearity with innovation performance, and the results show that the VIF values are all $3.172 < 10$, and there is no multicollinearity among the variables.

(2) Serial Correlation Test. Serial correlation test, also called autocorrelation test, is used to test whether there is a correlation between the overall regression model and the random error term. In this study, it is very meaningful to prove the existence of the regression equation by DW test. When the value of DW is greater than 1.5 and less than 2.5, it can be considered that there is no serial correlation in the regression model.

As shown in Table 4 below, the DW regression result of the model in this paper is 1.823, which meets the criteria, so it can be considered that there is no serial correlation between the independent variables.

(3) Heteroscedasticity Test. The heteroscedasticity test is also an a priori condition before the regression test. In this study, scatter plots are used to determine whether there is heteroscedasticity in the model. By observing the scatter plot, if the scattered points are scattered, independent, and irregular, it can be judged that there is no heteroscedasticity. By observing Figure 3, the scatter plot obtained in this study meets the requirements such as irregularity, and it can be judged that there is no heteroscedasticity problem. Combining the above multiple covariance and serial correlation tests, the basic requirements of the data structure for the subsequent study are satisfied.

Table 2: VIF test results of each dimension.

Model		Nonstandard factors		Standard factors	t	Weights	Collinearity	
		B	Errors	Beta			Tolerance	VIF
	(Constants)	0.055	0.171		0.319	0.750		
	Learning commitment	0.099	0.056	0.090	1.772	0.078	0.451	2.220
	Shared vision	0.55	0.69	0.053	0.807	0.421	0.268	3.725
1	Open mindedness	0.045	0.075	0.044	0.604	0.546	0.215	4.646
	Environment insights	0.010	0.072	0.010	0.144	0.886	0.240	4.169
	Resource integration	0.182	0.086	0.174	2.106	0.036	0.171	5.845
	Flexibility capability	0.551	0.073	0.555	7.549	0.000	0.216	4.633

Table 3: VIF test results of variables.

Model		Nonstandard factors		Standard factors	t	Weights	Collinearity	
		B	Errors	Beta			Tolerance	VIF
	(Constant)	3.781	0.033		115.544	0.000		
1	Organizational learning	0.161	0.058	0.175	2.750	0.006	0.315	3.172
	Dynamic capability	0.632	0.058	0.690	10.819	0.000	0.315	3.172

Table 4: Variable DW test results.

Model	R	$R2$	Adjusted $R2$	Errors in standard estimation	DW
1	0.841a	0.707	0.704	0.49840	1.823

4.3.3. Regression Analysis of Organizational Learning and Innovation Performance. One main hypothesis and three subhypotheses were proposed in the previous section regarding the relationship between dynamic capabilities and innovation performance. To test hypotheses H1, H1a, H1b, and H1c, regression analyses were conducted with organizational learning and its three dimensions as independent variables and innovation performance as dependent variables, respectively.

(1) Regression Analysis of Organizational Learning on Innovation Performance as a Whole. The regression analysis was conducted using the direct entry method with organizational learning as the independent variable and innovation performance as the dependent variable. The DW value was $1.825 < 2.0$, and it could be obtained that this regression model did not have the problems of multicollinearity and serial correlation. The probability of significance of the constant t-test is $0.000 < 0.05$, so the constant term can enter the regression model; the probability of significance of the organizational learning t-test is $0.000 < 0.05$, which can also enter the regression equation. The resulting regression equation between organizational learning and innovation performance was obtained as

$$\text{Innovation performance} = 0.683 * \text{organizational learning} + 3.781. \quad (1)$$

It can be seen that organizational learning has a significant positive effect on innovation performance, and the regression coefficient is not equal to zero; therefore, hypothesis H1 holds.

(2) Regression Analysis of Each Dimension of Organizational Learning on Innovation Performance. The stepwise regression method is used, and the independent variable is selected as three dimensions of organizational learning, and the dependent variable is innovation performance, and the regression analysis is conducted. The adjusted $R2$ value gradually becomes larger as the variables increase, indicating that the regression equation can express the contribution of the variables entering the equation. The DW value is $1.842 < 2.0$, indicating that the regression equation does not have the problems of multicollinearity and serial correlation. The ANOVA analysis shows that the model overall significance tests were all $0.000 < 0.05$, reaching a significant level. The explanations of innovation performance by the predictor variables entering the regression equation all reached significance and the regression coefficients were not equal to zero.

Table 5 shows that the probability of significance of the t-test for the constant term is $0.085 > 0.05$, which does not pass the significance test, indicating that the constant term cannot enter the regression equation. All three dimensions of organizational learning entered the regression equation, and the significance probabilities of the t-test were 0.000, 0.004, and 0.040, which were less than 0.05, so the regression equation of each dimension of organizational learning and innovation performance was obtained as follows:

$$\begin{aligned}\text{Innovation performance} = {} & 0.459 * \text{open mind} + 0.186 \\ & * \text{learning commitment} \\ & + 0.169 * \text{shared vision}.\end{aligned} \quad (2)$$

The regression equation shows that open-mindedness, commitment to learning, and shared vision all have a

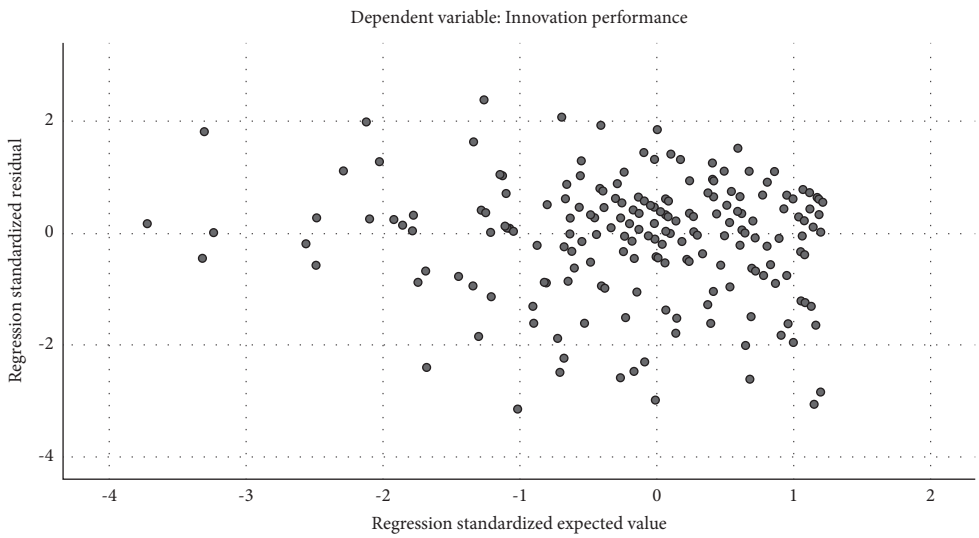


Figure 3: Residual scatter plot of the regression model.

significant positive effect on the innovation performance of the company. And the regression coefficients are 0.459, 0.186, and 0.169, respectively, with the most significant contribution of open-mindedness to corporate innovation performance. Therefore, hypotheses H1a, H1b, and H1c are valid.

4.3.4. Regression Analysis of Organizational Learning and Dynamic Capabilities

(1) Regression Analysis of Organizational Learning on Dynamic Capability as a Whole. With organizational learning as the independent variable and dynamic capability as the dependent variable, the regression analysis was conducted using the direct entry method. The DW value was $1.739 < 2.0$, which shows that this regression model does not have the problems of multicollinearity and serial correlation. The probability of significance of the constant t-test was 1.000, which was not significant, and the constant term could not enter the regression model; the probability of significance of the organizational learning t-test was $0.000 < 0.05$, which could enter the regression equation. The resulting regression equation between organizational learning and dynamic capability was obtained as follows:

$$\text{Dynamic capability} = 0.828 * \text{organizational learning}. \quad (3)$$

It can be seen that organizational learning has a significant positive effect on dynamic capability, and the regression coefficient is not equal to zero; therefore, hypothesis H2 holds.

(2) Regression Analysis of the Dimensions of Organizational Learning on Dynamic Capability. The stepwise regression method was used, the independent variable was selected as three dimensions of organizational learning, and the dependent variable was dynamic capability, and the regression analysis was conducted. The adjusted $R2$ value gradually became larger as the variables increased, indicating that the regression equation could express the contribution of the variables entering the equation. the DW value was $1.802 < 2.0$, indicating that the regression equation did not have multicollinearity and serial correlation problems. The ANOVA analysis showed that the model overall significance tests were all $0.000 < 0.05$, reaching the significant level. The explanations of dynamic capacity by the predictor variables entering the regression equation all reached significance, and the regression coefficients were not equal to 0.

Table 6 shows that the probability of significance of the t-test for the constant term is $0.000 < 0.05$, which passes the significance test and the constant term can enter the regression equation. All three dimensions of organizational learning entered the regression equation, and the significance probabilities of t-test were 0.000, 0.001, and 0.007, which were all less than 0.05, so the regression equation of each dimension of organizational learning and dynamic capability was obtained as follows:

$$\begin{aligned}\text{dynamic capability} = {} & 0.528 * \text{open} - \text{mindedness} \\ & + 0.226 * \text{shared vision} \\ & + 0.144 * \text{learning commitment}.\end{aligned} \quad (4)$$

The regression equation shows that open-mindedness, commitment to learning, and shared vision all have a significant positive effect on the dynamic capability of the company. And the regression coefficients are 0.459, 0.186, and 0.169, respectively, where open-mindedness has the most significant contribution to dynamic capabilities, followed by shared vision, and learning commitment has the least correlation. Therefore, hypotheses H2a, H2b, and H2c all hold.

4.3.5. Regression Analysis of Dynamic Capability and Innovation Performance. With dynamic capability as the independent variable and innovation performance as the dependent variable, the regression analysis was conducted using the direct entry method, and the DW value was $1.784 < 2.0$, which shows that this regression model does not

Table 5: Regression coefficient table of organizational learning on innovation performance.

Model		Nonstandard factors		Standard factors	t	Weights
		B	Errors	Beta		
1	(Constants)	0.806	0.188		4.286	0.000
	Open-mindedness	0.746	0.046	0.730	16.209	0.000
2	(Constants)	0.440	0.210		2.097	0.037
	Open-mindedness	0.587	0.063	0.574	9.293	0.000
	Learning commitment	0.242	0.068	0.222	3.586	0.000
3	(Constants)	0.366	0.211	0.459	1.731	0.085
	Open-mindedness	0.469	0.085		5.528	0.000
	Learning commitment	0.204	0.070	0.186	2.925	0.004
	Shared vision	0.176	0.085	0.169	2.067	0.040

Note. The dependent variable is innovation performance.

Table 6: Regression coefficient table of dynamic ability of organizational learning dimensions.

Model		Nonstandard factors		Standard factors	t	Weights
		B	Errors	Beta		
1	(Constants)	−3.638	0.173		−21.048	0.000
	Open-mindedness	0.912	0.042	0.818	21.572	0.000
2	(Constants)	−3.874	0.176		−21.974	0.000
	Open-mindedness	0.657	0.074	0.589	8.917	0.000
	Shared vision	0.313	0.075	0.276	4.174	0.000
3	(Constants)	−4.092	0.191		−21.401	0.000
	Open-mindedness	0.589	0.077	0.528	7.688	0.000
	Shared vision	0.257	0.077	0.226	3.344	0.001
	Learning commitment	0.172	0.063	0.144	2.737	0.007

Note. The dependent variable is dynamic capabilities.

have the problem of multicollinearity and serial correlation. The probability of significance of the constant t-test is $0.000 < 0.05$, so the constant term can be entered into the regression model; the probability of significance of the dynamic capability t-test is $0.000 < 0.05$, which can also be entered into the regression equation. The resulting regression equation between dynamic capability and innovation performance was obtained as follows:

$$\text{innovation performance} = 0.765 * \text{dynamic capability} + 3.781. \quad (5)$$

It can be seen that dynamic capability has a significant positive effect on innovation performance, and the regression coefficient is not equal to zero; therefore, hypothesis H3 holds.

(1) Regression Analysis of Dynamic Capability Dimensions on Innovation Performance. In this paper, we use stepwise regression method to analyze the three dimensions of dynamic capability as independent variables and innovation performance as dependent variables. Two factors in dynamic capability enter into the regression equation, and the adjusted $R2$ value gradually becomes larger as the variables increase, indicating that the regression equation can express the contribution of the variables entering into the equation. The DW value is $1.906 < 2.0$, indicating that the regression equation does not have the problems of multicollinearity and serial correlation. The ANOVA analysis table shows that the overall significance tests of the model are all $0.000 < 0.05$, reaching a significant level. The explanations of dynamic capacity by the predictor variables entering the regression equation all reached significance, and the regression coefficients were not equal to 0.

Table 7 shows that the probability of significance of the t-test for the constant term is $0.041 < 0.05$, which passes the significance test and the constant term can enter the regression equation. The two factors of dynamic capability entered the regression equation and the significance probabilities of t-test were 0.000 and 0.000 were less than 0.05, so the regression equation of the two dimensions of dynamic capability and innovation performance was obtained as follows:

$$\text{innovation performance} = 0.625 * \text{organizational fleaxibility capacity} + 0.252 * \text{resource integration capacity} + 0.308. \quad (6)$$

The regression equation shows that environmental insight capability does not enter into the equation, while organizational flexibility capability and resource integration capability have a significant positive effect on the innovation performance of enterprises. And the regression coefficients are 0.625 and 0.252, respectively, and the organizational flexibility capability has the most significant contribution to the firm's innovation performance. Therefore, hypotheses H3b and H3c are valid and hypothesis H3a is not valid.

4.3.6. Analysis of the Mediating Effect of Dynamic Capability. The regression coefficients between organizational learning and dynamic capability and its three dimensions (environmental insight capability, resource integration capability, and organizational flexibility capability) are significant. In order to test hypotheses H4, H4a, H4b, and H4c, this study constructs four regression models with organizational learning and dynamic capability and its three dimensions as independent variables and innovation performance as dependent variables, respectively, to compare and analyze the mediating effect of dynamic capability.

Model 1 in Table 8 shows that when dynamic capabilities are added, the standardized coefficient of organizational learning is 0.175 and the regression coefficient is $0.006 > 0.005$, which can be considered insignificant; the standardized coefficient of dynamic capabilities is 0.690 and the regression coefficient is significant at the level of 0.000. According to the test of mediating effect, it can be concluded that there is a mediating effect of dynamic capability between organizational learning and innovation performance, which verifies hypothesis H4.

Model 2 shows that the standardized coefficient of environmental insight capability is 0.375 and the regression coefficient is significant at the level of 0.001. When controlling for environmental insight capability, the standardized coefficient of organizational learning is $0.454 < 0.746$ and the regression coefficient is significant at the 0.001 level. According to the test procedure, it can be concluded that environmental insight capability partially mediates the relationship between organizational learning and innovation performance. The regression analysis of organizational learning on dynamic capabilities shows that the standardized coefficient of environmental insight capability is 0.779, because from the calculation, the mediated utility of environmental insight capability accounts for $0.779 * 0.375/0.746 = 39.159\%$ of the total utility, which verifies hypothesis H4a.

Model 3 shows that the standardized coefficient of resource integration capability is 0.540, and the regression coefficient is significant at 0.001 level is significant. When controlling for resource integration capability, the standardized coefficient of organizational learning is $0.322 < 0.746$ and the regression coefficient is significant at the 0.001 level. According to the test procedure, it can be concluded that resource integration capability partially mediates the relationship between organizational learning and innovation performance. By calculation, the mediated utility of resource integration capability accounts for $0.789 * 0.540/0.746 = 57.113\%$ of the total utility, which verifies hypothesis H4b.

Model 4 shows that the standardized coefficient of organizational flexibility capability is 0.666 and the regression coefficient is significant at the 0.001 level. When controlling for organizational flexibility capacity, the standardized coefficient of organizational learning is $0.227 < 0.746$ and the regression coefficient is significant at the 0.001 level. According to the test procedure, it can be concluded that organizational flexibility capability partially mediates between organizational learning and innovation performance. The hypothesis H4c was verified by calculating that the mediated utility of organizational flexibility capability accounts for $0.779 * 0.666/0.746 = 69.546\%$ of the total utility.

Through correlation analysis and stepwise regression analysis of 232 valid questionnaires with the help of SPSS23.0, the following findings were obtained: organizational learning and its three dimensions all have significant positive effects on firms' innovation performance, so hypotheses H1, H1a, H1b, and H1c all hold; organizational learning and its three dimensions also have significant positive effects on dynamic capabilities, so hypotheses H2, H2a, H2b, and H2c are all valid. There is no significant correlation between environmental insight capability and innovation performance, while the remaining two dimensions, resource integration capability and organizational flexibility capability, have a significant positive impact on innovation performance, so hypothesis H3a does not hold, and hypotheses H3, H3b, and H3c hold. Finally, all three dimensions of dynamic capabilities play a mediating utility between organizational learning and innovation performance; therefore, hypotheses H4, H4a, H4b, and H4c are all valid.

5. Management Suggestions

Through extensive literature reading and practical investigation, combined with the research content and direction of this study, this paper gives relevant management recommendations on how innovative enterprises can improve their innovation performance, taking Beijing-Tianjin-Hebei, Shanghai, and Qingdao as the main sample sources.

Through the empirical study, it is found that organizational learning plays an important positive influence role in promoting the growth of innovation performance; therefore, building a learning organization and fostering a good environment for organizational learning are very beneficial to the sustainable development of enterprises. During the research, it was found that innovative enterprises in Beijing, Tianjin, Hebei, and Qingdao regions did not pay enough attention to organizational learning, like to shout empty slogans and named empty policies without implementing them into actions. At the same time, by verifying the positive influence of dynamic capability on innovation performance and its intermediary role, the author believes that innovative enterprises should improve their dynamic capability on the basis of solid organizational learning. This

Table 7: Regression coefficient table of dynamic capability dimensions on innovation performance.

Model		Nonstandard factors		Standard factors	t	Weights
		B	Errors	Beta		
1	(Constants)	0.531	0.141		3.772	0.000
	Organization flexibility capability	0.837	0.035	0.843	23.751	0.000
2	(Constants)	0.308	0.150		2.050	0.041
	Organization flexibility capability	0.620	0.069	0.625	9.048	0.000
	Resource integration capability	0.264	0.072	0.252	3.655	0.000

Note. The dependent variable is innovation performance.

Table 8: Dynamic capacity mediation.

Model		Nonstandard factors		Standard factors	t	Significance
		B	Errors	Beta		
1	Organizational learning	0.161	0.058	0.175	2.750	0.006
	Dynamic capability	0.632	0.058	0.690	10.819	0.000
2	Organizational learning	0.416	0.060	0.454	6.926	0.000
	Environmental insights	0.387	0.068	0.375	5.707	0.000
3	Organizational learning	0.295	0.056	0.322	5.235	0.000
	Resource integration	0.565	0.064	0.540	8.775	0.000
4	Orga learning	0.208	0.050	0.227	4.147	0.000
	Flexibility capability	0.661	0.054	0.666	12.161	0.000

should be an important development direction for innovative enterprises in the future.

This paper will give the following management suggestions for reference from the constitutive dimensions of organizational learning and dynamic capability:

(i) Based on open-mindedness, innovative firms should foster an open-mind culture rather than a traditional way of top-down in Chinese companies.

(ii) Based on learning commitment, innovative firms should strengthen their training systems.

(iii) Based on shared vision, innovative firms should embrace all employees and promote all's involvement.

(iv) Based on organizational flexibility, innovative firms should build its responsive mechanism to environment changes and uncertainties.

(v) Based on resource integration, innovative firms should make best use of cross-function resources and strengthen coordination.

6. Research Limitations and Outlook

6.1. Limitations of the Study. This paper mainly selects Beijing-Tianjin-Hebei, Shanghai, and Qingdao as the main respondents of innovative enterprises and explores the relationship between organizational learning, dynamic capabilities, and innovation performance by means of distributing questionnaires. Due to the limited resources available and personal research level, there are many shortcomings in this study, which are mainly summarized as follows:

(1) *Limitations of the Sample Area and Number*

On the one hand, the research regions selected for this study are Beijing, Tianjin, Hebei, and Shanghai, where there are many innovative enterprises, and Qingdao, which is a region with great potential for innovation development and is better known. The regional coverage is relatively narrow, and the findings may have some regional characteristics, which do not guarantee the generalizability of the findings. On the other hand, although the sample size is sufficient for this study, it is still small in terms of rigor, which may also affect the results.

(2) *The Time Limitations of Organizational Learning Research*

Organizational learning is a long-term process, and it takes a period of time to monitor the learning process from the initial learning to the acquisition of learning outcomes. Therefore, when the same time point is selected to obtain data, the degree and stage of organizational learning varies from one innovative company to another, and the degree of impact on dynamic capabilities and innovation performance also varies. In the future, we will improve the selection of time periods and conduct longitudinal tests to obtain more accurate and rigorous research results.

(3) *Subjective Limitations of Questionnaires*

These are the most important source of data for this study. Unlike objective information and data, subjective answers are bound to be personal, and even though the questionnaire has been revised, the nonobjective nature of the questionnaire cannot be avoided.

6.2. Research Outlook. Looking at the whole study, combined with the findings and limitations of the study, there are many areas for improvement and further research in this paper, mainly the following:

(1) Expand the scope of the study. The selection of innovative enterprises should not be limited to a few famous first- and second-tier cities, but should cover all regions of the country, such as northern China, northeast China, southeast China, and southwest China, and conduct research according to different geographical classifications, or through the division of first-, second-, and third-tier cities to classify research so that the results of the study can be more comprehensive and representative.

(2) Explore the detailed influence paths between each dimension of organizational learning and each dimension of dynamic capability and innovation performance. The impact between dimensions and subdimensions is divided in more detail. At the same time, the study of the pathway relationship between variables and subdimensions can also be included in the scope of the study to make the study more rigorous and complete.

(3) Adopt a longitudinal research approach. The article is based on the acquisition of data at a specific cross section of time. The disadvantage of this approach is that it does not reflect the dynamic process of change. Therefore, the data should be collected over a longer period depending on the content of the study, measured in years, and recorded over a number of years so that the relationship between variables can be analyzed through a longitudinal comparison of the data. Alternatively, other influencing factors, such as the dynamics of the environment, could be added to minimize possible confounding factors in the study to obtain more scientific findings.

Appendix

Questionnaire

Questionnaire about correlation among organizational learning, dynamic capabilities, and innovation performance.

Dear Sir/MAdam, Dear Sir/MAdam, Hello! THank you for taking the time to participate in this questionnaire.

This questionnaire examines the relationship between organizational learning, dynamic capabilities, and innovation performance in innovative companies. The aim of the study is to capture the dynamic capabilities of companies to enhance their organizational learning capabilities and thus improve the innovation performance of innovative companies. The questionnaire is designed to obtain data for research purposes only and will not be used for any commercial purposes. This questionnaire is completely anonymous, and your personal answers will be treated in strict confidence, so please do not have any concerns. If you would like to know the results of this statistical survey, please leave your e-mail: _____

Thank you for your cooperation and support!

School of Economics Management.

Beijing Jiaotong University.

Part I: Basic Information

(i) The following is a description of the basic situation of the enterprise and your personal situation, please draw "☑" on the corresponding option.

(1) The nature of your company's business:

(a) State-owned enterprise
(b) Private enterprise
(c) Wholly foreign-owned enterprise
(d) Sino-foreign joint venture
(e) Other

(2) Your company's industry:

(a) Manufacturing (machinery, construction, electronics, chemicals, materials, outsourcing production, food processing, etc.)
(b) Service industry (consulting services, commerce, trading, telecom, finance and insurance, catering and tourism)

(3) The number of employees in your company is approximately

(a) less than 100
(b) 100–500
(c) 501–1000
(d) more than 1000

(4) The actual number of years your company has been in existence is

(a) less than 5 years
(b) 5–10 years
(c) 11–20 years
(d) more than 20 years

(5) Your current position belongs to

(a) Senior management
(b) Middle management
(c) Basic management
(d) General staff

(6) The city where your company is located: _____

Part II: Organizational Learning. Please evaluate your degree of agreement/disagreement towards the following statement and please draw "☑" based on your evaluation. The rating is as follows (Table 9): 1—strongly disagree; 2—disagree; 3—neutral; 4—agree; and 5 —strongly agree.

Part III: Dynamic Capabilities. Below is a description of your company's dynamic capabilities. Please draw "☑" based on your evaluation of your company status. The rating is as follows:1—strongly disagree; 2—disagree; 3—neutral; 4—agree; and 5 —strongly disagree. (Table 10).

Part IV: Innovation Performance. Please draw "☑" based on your assessment. The rating is as follows: 1—strongly disagree; 2—disagree; 3—neutral; 4—agree; and 5 —strongly agree; (Table 11).

Table 9: Questions for organizational learning.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Learning commitment					
(1) Organizational learning is critical for firms to gain competitive advantages	1	2	3	4	5
(2) Management regards learning a method to improve job performance	1	2	3	4	5
(3) Learning and training to employees is regarded as investment not cost	1	2	3	4	5
(4) Managers and employees believe stopping learnings will increase future risks	1	2	3	4	5
(5) Managers believe learning is the basis for sustainable development	1	2	3	4	5
Shared vision					
(6) The company from top managers to working levels have just one shared goal or vision	1	2	3	4	5
(7) Managers share future vision with employees	1	2	3	4	5
(8) All employees work hard to achieve the goal	1	2	3	4	5
(9) Employees believe they are responsible for the company future	1	2	3	4	5
(10) All have a clear understanding of the company's positioning and future business plan	1	2	3	4	5
Open-mindedness					
(11) Company values and appreciates originated opinions and advice	1	2	3	4	5
(12) Managers motivate employees to take different perspectives in thinking	1	2	3	4	5
(13) Managers welcome reasonable advice	1	2	3	4	5
(14) Managers often discuss failure and success cases	1	2	3	4	5

Table 10: Questions of dynamic capabilities.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Environment insights					
(1) Deep understanding of industry rules and trend	1	2	3	4	5
(2) High sensitivity to external changes	1	2	3	4	5
(3) Capabilities to identify opportunities and develop action plans	1	2	3	4	5
(4) Multi channels to gain customer insights	1	2	3	4	5
Resource integration					
(5) Dynamic coordination of cross function actions	1	2	3	4	5
(6) Secured allocation of resources cross functions	1	2	3	4	5
(7) Coordination meets each function's expectation	1	2	3	4	5
(8) Best use of extra resources according to market changes	1	2	3	4	5
Organizational flexibility					
(9) Allow employees to break conventional ways of working to be responsive and dynamic	1	2	3	4	5
(10) Set up adequate channels/mechanism to hear employee feedbacks	1	2	3	4	5
(11) Allow employees to decide and take actions based on market reality	1	2	3	4	5
(12) Change or adjust strategic actions ahead of competitors	1	2	3	4	5

Table 11: Questions for dynamic capabilities.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
(1) More products/service than competitors	1	2	3	4	5
(2) More IP/patents than competitors	1	2	3	4	5
(3) More revenue from new products/service	1	2	3	4	5
(4) Continuous success rate in new product development	1	2	3	4	5
(5) Faster speed than competitors to launch new products	1	2	3	4	5
(6) Continuous cost down along with technology improvements	1	2	3	4	5
(7) Active adoption of new policies to improve performance	1	2	3	4	5

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This research was supported by the key project of the National Social Science Foundation of China (21azd118).

References

[1] H. Cao and J. Zhao, "Impacts of dynamic capabilities on enterprise performance," *Strategic Management*, vol. 11, no. 6, pp. 54–65, 2008.

[2] S. Wu and J. Wang, "A study on organizational learning, innovation atmosphere & innovation performance," *Science & Technology Management*, vol. 6, no. 02, 2014.

[3] D. J. Teece, G. Pisano, and A. Shuen, "Dynamic capabilities and strategic management," *Strategic Management Journal*, vol. 18, no. 7, pp. 509–533, 1997.

[4] Y. She, *Decision Making Model in Continuous Innovation by Innovative Firms*, Yunan Finance University, Kunming, China, 2017.

[5] H. Dai, *An Empirical Study of Organizational Learning Capacity and Dynamic Capability on International Business Performance of Chinese Industrial Enterprises*, Chongqing University, Chongqing, China, 2006.

[6] P. Lin, *Research on Dynamic Capability of Organizations*, Xiamen University, Xiamen, China, 2008.

[7] S. Yang, T. Li, X. Dang, and S. Xin, "An empirical study on the relationship between dynamic organizational learning capabilities and firm performance," *Operations Research and Management*, vol. 18, no. 2, pp. 155–161, 2009.

[8] D. A. Garvin, A. C. Edmondson, and F. Gino, "Is yours a learning organization," *Harvard Business Review*, vol. 86, no. 3, pp. 109–1, 2008.

[9] C. M. Fiol and M. A. Lyles, "Organizational learning," *Academy of Management Review*, vol. 10, no. 4, pp. 803–813, 1985.

[10] J. M. Sinkula, W. E. Baker, and T. Noordewier, "A framework for market-based organizational learning: linking values, knowledge, and b," *Journal of the Academy of Marketing Science*, vol. 25, no. 4, pp. 305–318, 1997.

[11] W. E. Baker and J. M. Sinkula, "The synergistic effect of market orientation and learning orientation on organizational performance," *Journal of the Academy of Marketing Science*, vol. 27, no. 4, pp. 411–427, 1999.

[12] R. Daniel and B. Marie-Claude, "Information technology and organizational learning: a review and assessment of research," *Act. Mgmt.&Info.Tech*, vol. 10, no. 2, pp. 125–155, 2000.

[13] Y. Liu and S. Jin, "A study on the impact of entrepreneurial orientation and organizational learning on core competencies and organizational performance-empirical evidence from 210 firms in Central, South and North China," *Science and Technology Management*, no. 4, pp. 12–35, 2009.

[14] J. Yang, C. Wang, and J. Li, "Research on organizational learning and its formation mechanism of family enterprises," vol. 30, Zhejiang University, Hangzhou, China, 2012, Master's Thesis.

[15] L. Xia, "Research on the relationship between enterprise internal factors, organizational learning and innovation performance," *Technology & Management*, vol. 12, no. 2, 2021.

[16] W. Meng, "Research on the impact of cross-border search on innovation performance of technology-based SMEs-dynamic capability as a mediating variable," Doctoral Dissertation, p. 28, Liaoning University, Shenyang, China, 2016.

[17] K. M. Eisenhardt and J. A. Martin, "Dynamic capabilities: what are they?" *Strategic Management Journal*, vol. 21, no. 10-11, pp. 1105–1121, 2000.

[18] S. A. Zahra, H. J. Sapienza, and P. Davidsson, "Entrepreneurship and dynamic capabilities: a review, model and research agenda," *Journal of Management Studies*, vol. 43, no. 4, pp. 917–955, 2006.

[19] M. Zollo and S. G. Winter, "Deliberate learning and the evolution of dynamic capabilities," *Organization Science*, vol. 13, no. 3, pp. 339–351, 2002.

[20] M. Liu, "Commentary on innovation performance and research on private hi-tech companies," *Advanced Technology & Policy*, no. 1, pp. 52–54, 2005.

[21] P. Drucker, *Post-capitalist Society*, Butter-worth-Heineman, New York, 1993.

[22] C. Zott, "Dynamic Capabilities and the emergence of intra-industry differential firm performance: insights from a simulation study," *Strategic Management Journal*, vol. 24, no. 2, pp. 97–125, 2003.

[23] L. Y. W. Entrepreneurial Resources, "Dynamic capabilities and start-up performance of taiwans," *High-tech Firms*, vol. 60, no. 5, pp. 549–555, 2007.

[24] J. Su and J. Liu, "Research on the relationship between dynamic capabilities and innovation performance in complex product systems," *Scientific Research Management*, vol. 34, no. 10, pp. 75–83, 2013.

[25] W. Zhang, J. Zhao, and X. Tong, "Research on the relationship between dynamic knowledge management capabilities and innovation performance: the moderating effect of innovation openness," *Science and Technology Progress and Countermeasures*, vol. 32, no. 5, pp. 131–135, 2015.

[26] Q. Liu, Y. Zhang, and Y. Lei, "Research on the process, logic and mechanism of digital transformation to enable enterprise innovation," *Science & Technology Research*, vol. 38, no. 07, pp. 1–14, 2021.

[27] J. Zhang and L. Jing, "A study of digital transformation, dynamic capabilities and innovation performance based on data analysis of listed innovation firms in China," *Economy and Management*, vol. 36, no. 3, 2022.

[28] J. Li, "Research on relationship between knowledge transfer, organizational learning and dynamic capabilities,", Doctoral Dissertation, Tsingtao University vol. 6, p. 3, 2019 .

[29] W. Lu and Y. Wu, "Technological innovation in SMEs from a strategic perspective," *Economics and Management*, vol. 15, no. 6, pp. 36–41, 2001.

[30] Z. Chen and X. Wu, "A study of the dynamic capabilities of SMEs in emerging markets," *Scientology Research*, vol. 24, no. 2, pp. 261–267, 2006.

[31] A. B. O'Connor, S. R. Schwid, D. N. Herrmann, J. D. Markman, and R. H. Dworkin, "Pain associated with multiple sclerosis: systematic review and proposed classification," *Pain*, vol. 137, no. 1, pp. 96–111, 2008.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2333342, 6 pages
https://doi.org/10.1155/2022/2333342

Research Article

Research on the Informatization Construction and Development Mode of Internal Control in Colleges and Universities Based on Game Model

Yuzhen Cheng

Office of Financial Affairs, Beijing Jiaotong University, Beijing100044, China

Correspondence should be addressed to Yuzhen Cheng; yzcheng@bjtu.edu.cn

Received 9 April 2022; Revised 18 May 2022; Accepted 8 June 2022; Published 24 June 2022

Academic Editor: Lele Qin

With the advancement of information technology, the informatization construction of internal control has evolved into crucial fundamental support for the construction of internal control in colleges and universities. The informatization construction of internal control is a systematic project of which the selection of software development mode is the key link. In this paper, a detailed analysis is carried out on the equilibrium strategy of the two parties in the game between the informatization construction department of internal control in colleges and universities as well as software development companies by establishing a game model and a software maintenance risk management model for both sides, in order to probe into the selection of the software development mode in colleges and universities. The model test and case study prove that the fully commissioned development mode is the optimal mode for the informatization construction of internal control in colleges and universities, and relevant suggestions are made. This research has provided sufficient theoretical support for the informatization construction of internal control in colleges and universities.

1. Introduction

In 2012, the Ministry of Finance issued the "Regulations on Internal Control of Administrative Institutions (Trial)" to carry out the construction of internal control of administrative institutions nationwide. The Regulations mentioned that "Units should make full use of modern scientific and technological means to strengthen internal control. Centralized management by specialized departments should be implemented for the construction of information systems, and economic activities and their internal control processes should be embedded in the unit's information system to diminish or eliminate human manipulation factors and protect information security [1]." In 2015, the Ministry of Finance's "Guiding Opinions on Comprehensively Promoting the Construction of Internal Control in Administrative Institutions" emphasized that "the principal person in charge of a unit should make full use of information technology to organize and promote the construction of internal control of the unit, and assume leadership responsibility for the effectiveness of establishing and implementing internal control [2]". In 2016, the Ministry of Education also issued "Guidelines for Internal Control of Colleges and Universities Directly Under the Ministry of Education (Trial)" (hereinafter referred to as "Guidelines for Internal Control"), to initiate the construction of internal control in colleges and universities, requiring colleges and universities to establish a reasonable, comprehensive, and effective internal control system to regulate their daily economic activities. The Guidelines also put forward the requirements of "informatization management construction of internal control of economic activities [3]." The above documents emphasize the importance of internal control informatization.

With the all-around development of information technology, economic and business information systems have been deployed to most colleges and universities. Despite the rapid advancement of informatization in colleges and

universities, the construction and management of internal control informatization are still in their infancy. For this reason, how to implement internal control informatization is a major issue commonly faced by colleges and universities. Besides, the informatization construction of internal control, as a systematic project, needs to be implemented in accordance with standardized implementation steps under the guidance of scientific methods, in which the selection of software development mode is the key link. In this paper, based on the game theory, a detailed analysis is carried out on the equilibrium strategy of the two parties in the game between the centralized management department of internal control informatization in colleges and universities as well as software development companies by establishing a game model and a software maintenance risk management model of the selected model for both sides. Based on the research results, the fully commissioned development mode is the optimal mode for the informatization construction of internal control in colleges and universities, and relevant suggestions are made.

2. Literature Review

Research on the internal control informatization was carried out in a relatively early period of time abroad. Popescu et al. [4] believed that the internal management and control system of public entities includes three objectives: the effectiveness and efficiency of operations, the reliability of internal and external information, and the compliance with relevant laws, regulations, and internal policies. The implementation and development of the internal control system can be promoted by developing and updating the internal control system. Michelle [5] conducted a case study on the internal control informatization of a large enterprise. Based on the informatization of the management process of internal control, the enterprise transferred the original internal control process to the internal information management system through control review and risk nodes, which not only improved the operating efficiency of the internal process but also effectively elevated the level of internal control and management of the enterprise. Encouraged by the success of this research, an increasing number of companies have attempted to implement internal control informatization. Domestic research on internal control informatization started relatively late, most of which explored the framework of building internal control information systems by promoting the development of theory through practice. Tang et al. [6] contended that from the practice of unit construction, the implementation progress and prevalence of internal control informatization has become major factors of verifying the design and implementation effect of the internal control system. Peng [7] analyzed the problems in the informatization of economic activities in Chinese universities, such as financial management, asset management, procurement management, and contract management from the perspective of internal control, and explored the establishment of an information management platform for economic activities based on business process reengineering under the background of internal control construction in universities. He also proposed to set up a platform with a view to establishing a reasonable, comprehensive, and effective internal control system within colleges and universities by means of information technology to regulate the daily economic activities of colleges and universities, so as to ensure the legal compliance of economic activities, the safety and effective use of assets, and the improvement of financial assets management in colleges and universities. Zhang [8] proposed to build a new ecosystem of informatization internal control from three aspects, namely the application of informatization big data, IT governance concept, and business process reengineering, which is conducive to implementing the internal control of colleges and universities and giving full play to the monitoring role of internal control in the development and financial operation of colleges and universities.

Many domestic departments tend to select the development mode based on the experience of leaders and information technology-related personnel, which lacks objectivity and scientificity. Li [9] proposed to select the most suitable software development mode for six different types of enterprises by means of the AHP method and Expert Choice software from a quantitative perspective. Xiang (2014) et al. [10] applied the analytic hierarchy process (AHP) to deduce the optimization of the development mode of the existing information system of logistics enterprises and analyzed the development and operation mechanism of the information system of the logistics enterprises, as well as the expansion and reconstruction capability of their information system. In terms of game model, Zheng and Zhou [11] modeled the relationship between network slice tenants (NSTs) and users as a multimaster and multislave Stackelberg game, constructed the strategy space and profit function of both sides, and proved that there is a unique Nash equilibrium between users after NSTs decision-making. By analyzing the game model through backward induction, a distributed iterative algorithm was proposed to obtain the optimal throughput demand of users and the optimal slice pricing of NSTs. In the study of Zhou et al. [12], different game models were established to compare and analyze the optimal profit of the Stackelberg game of power suppliers in the traditional mode and cooperative game of power suppliers based on block chain, and finally, numerical simulation was conducted via MATLAB software. Xu et al. [13] established three pricing decision models based on game theory and gave corresponding analysis, in which the influences of three different green cost-sharing modes on product's retail price, greenness, and revenue of supply chain members were elaborated.

3. Informatization Development Model of Internal Control

It is mentioned in the "Guidelines for Internal Control" that "the development of information system for economic activities in colleges and universities can adopt such modes as self-development by departments, joint development by

multiple departments within the school, direct outsourcing of commercial software, and customized development by entrusting external units. Colleges and universities should fully assess the development and maintenance risks of the selected mode and make a plan to deal with the risks" The selection of software development mode in colleges and universities is constrained by various conditions such as cost, applicability, practicality, scalability, ease for maintenance, and security. In this paper, two modes of fully commissioned development and partial commissioned development are discussed.

Based on the game theory, the two parties involved in the game are the software development company A and the informatization management department B of internal control in colleges and universities. In the process of the game, it is assumed that both parties are fully rational economic persons, with the purpose of maximizing their respective interests.

3.1. Game of Software Development Model Selection. A's game strategy is (accept development, not accept development), and B's game strategy is (partially commissioned development, fully commissioned development). The probability of A accepting development is X, and that of not accepting development is 1-X. The relationship between A and B is based on benefit-sharing and risk-sharing. Let A bear the risks $Xf(\beta)$ $(X<1)$ arising from accepting development and B bear the corresponding losses $(1-X)f(\beta)$. So the payment matrix of both parties is: Table 1 shows the Single-game payment matrix based on risk-sharing for A and B.

The analysis is as follows.

When B chooses partially commissioned development, the revenue comparison that A chooses to accept and not to accept is

$$\begin{aligned}(E_A[1-Xf(\beta)]-C_A)-(E_A[1-f(\beta)]-C_A)\\ =(1-X)f(\beta)>0.\end{aligned} \tag{1}$$

At this time, A's choice to accept the strategy is more profitable than choosing not to accept the strategy.

When B chooses fully commissioned development, the revenue comparison that A chooses to accept and not to accept is

$$(E_A[1-f(\beta)]-C_A)-(E_A[1-f(\beta)]-C_A)=0. \tag{2}$$

At this time, A's choice to accept the strategy is equal to the benefits obtained when it does not accept the strategy.

It can be seen from the above two situations that no matter how B chooses, the revenue of A choosing not to accept the strategy is not higher than that of choosing to accept the strategy. Therefore, not accepting the strategy is the inferior strategy of A, and A chooses to accept the strategy according to the theory of eliminating inferior strategies.

When A chooses to accept, the revenue comparison of B's choice of partially commissioned development and fully commissioned development is

$$\begin{aligned}(E_B[1-(1-X)f(\beta)]-C_B)-(E_B-C_B)\\ =-(1-X)f(\beta)<0.\end{aligned} \tag{3}$$

At this time, B's choice of partially commissioned development strategy is less profitable than that of a fully commissioned development strategy.

When A chooses not to accept, the revenue comparison of B's choice of partially commissioned development and fully commissioned development is

$$(E_B-C_B)-(E_B-C_B)=0. \tag{4}$$

At this time, B gets the same revenue no matter choosing the fully commissioned development strategy or the partially commissioned development strategy.

It can be seen from the above two situations that no matter how A make the decision, the return of B choosing the partially commissioned development is not higher than that of choosing the fully commissioned development strategy. Therefore, the partially commissioned development strategy is the inferior strategy of B, and B chooses the fully commissioned development strategy according to the theory of eliminating inferior strategies.

In conclusion (accept, fully commissioned development) is the Nash equilibrium solution of the game problem.

3.2. Game of Software Maintenance Risk Management. In the event of an accident in system maintenance, first, A proposes a risk-sharing scheme S_1. If B approves it, the game ends; otherwise, B proposes a risk-sharing scheme S_2. If A approves it, the game ends; otherwise, A must accept the mandatory risk-sharing scheme S_3.

The content of the scheme S_1 is A bears the risk as X_1, B bears the risk as $f(\beta)-X_1$. If B agrees, then both parties bear the risk as $(X_1, f(\beta)-X_1)$.

The content of the scheme S_2 is A bears the risk as X_2, B bears the risk as $f(\beta)-X_2$. Due to the existence of opportunity cost, let the interest rate of opportunity cost remain unchanged as, if A accepts the scheme, the risk loss to be borne by both parties is $(\delta X_2, \delta[f(\beta)-X_2])$ (where δ is the risk negotiation loss coefficient, $\delta=1+r$).

The content of the scheme S_3 is: A bears the risk as X_3, B bears the risk as $f(\beta)-X_3$. The scheme S_3 is mandatory, and if the game round is missed, the total loss will keep rising. The longer the negotiation time, the more unfavorable it will be to both sides. If A and B fail to reach a consensus in multiple rounds of games and must accept the scheme S_3, then the risk loss to be borne by both parties is $\{\delta^2 X_3, \delta^2[f(\beta)-X_3]\}$.

If both sides of the game can reach an agreement as soon as possible, the game result will be more favorable to both sides. It is assumed that $X_2=\delta X_3$ and $X_1=\delta^2 X_3-\delta f(\beta)+f(\beta)$. Figure 1 shows the continuous dynamic game between A and B.

3.3. Marking the Dynamic Game Process Using Decision Trees. If both sides of the game can reach an agreement as soon as possible, the game result will be more favorable to both sides.

Table 1: Single-game payment matrix based on risk-sharing for A and B.

		The informatization management department of internal control in colleges and universities	
		Partially commissioned development	Fully commissioned development
Software development company	Accept (X)	$E_A[1 - Xf(\beta)] - C_A$, $E_B[1 - (1 - X)f(\beta)] - C_B$	$E_A[1 - f(\beta)] - C_A, E_B - C_B$
	Not accept ($1 - X$)	$E_A[1 - f(\beta)] - C_A, E_B - C_B$	$E_A[1 - f(\beta)] - C_A, E_B - C_B$

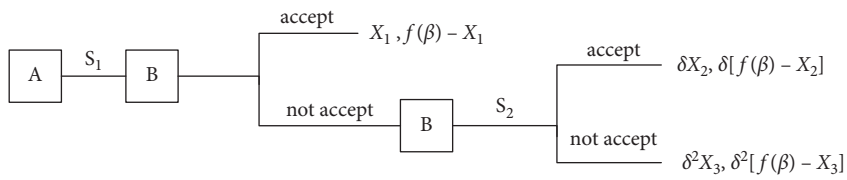


Figure 1: Continuous dynamic game between A and B.

The following is a recursive induction method to find the potential optimal solution:

If A does not approve the scheme S_2 but can only accept the scheme S_3, then A bears the risk as $\delta^2 X_3$, B bears the risk as $\delta^2[f(\beta) - X_3]$. If A approves the scheme S_2, then A bears the risk as δX_2, and B bears the risk as $\delta[f(\beta) - X_2]$. From $X_1 = \delta^2 X_3 - \delta f(\beta) + f(\beta)$, it can be concluded that $\delta X_2 = \delta^2 X_3$. It can be seen from that the risk of A approving the scheme S_2 is equal to that of accepting the scheme S_3, and then A may accept the scheme S_2 at this time.

Because $\delta^2[f(\beta) - X_3] - \delta[f(\beta) - X_2] = \delta f(\beta)\ (\delta - 1) = \delta f(\beta) r > 0$, B faces fewer risks in the second game than in the third game.

If B does not approve the scheme S_1 but A approves the scheme S_2, then A bears the risk as δX_2 and B bears the risk as $\delta[f(\beta) - X_2]$. If B approves the scheme S_1, then A bears the risk as X_1 and B bears the risk as $f(\beta) - X_1$. From $X_2 = \delta X_3$ and $X_1 = \delta^2 X_3 - \delta f(\beta) + f(\beta)$, it can be concluded that $(f(\beta) - X_1) - \delta[f(\beta) - X_2] = f(\beta) - \delta^2 X_3 - \delta f(\beta) + f(\beta) - \delta[f(\beta) - \delta X_3] = 0$. It indicates that B does not approve the scheme S_1, and the risks that A approves the scheme S_2 need to bear are equal to those that B approves the scheme S_1. In this case, B may accept the scheme S_1.

Because $\delta X_2 - X_1 = \delta\delta X_3 - (\delta^2 X_3 - \delta f(\beta) + f(\beta)) = \delta f(\beta)(\delta - 1) = \delta f(\beta) r > 0$, A is less risky in the first game than in the third game.

It can be seen from the above analysis that both A and B will gladly accept the scheme S_1 put forward by A in the first round, in which A bears the risk as $\delta^2 X_3 - \delta f(\beta) + f(\beta)$ and B bears the risk as $\delta f(\beta) - \delta^2 X_3$. So $(\delta^2 X_3 - \delta f(\beta) + f(\beta), \delta f(\beta) - \delta^2 X_3)$ is the subgame perfect Nash equilibrium solution of the game problem.

4. Case Study of Internal Control Information Construction in Colleges and Universities

Based on the above analysis, the complete delegation is a relatively optimal task allocation model, which has not only been tested theoretically but also corroborated by university cases.

For example, before the implementation of internal control information construction, the asset management system of University A was a system development task undertaken by the Information Office itself, and the financial platform was delegated to a system development company by the Finance Office. This development model uses a local delegation model. In actual use, it was found that there was a problem of information isolated island between the two systems, and data could not be interacted and shared due to the system compatibility problem between the systems. In the first phase of internal control information construction, the Internal Control Information Management Department of University A adopted a complete delegation model, that is, the contract management system and internal control data exchange platform were completely delegated to the system development company. After the two systems were put into operation, they solved the problems of development cycle and Scalability and were well received by all departments.

University A organized project review experts to evaluate the influence factors of the two different models, as shown in Table 2. In the complete delegation model, the system development cycle is fast, the system is more scalable and suitable, and the operation and maintenance risk is low, but the development cost is relatively high. But for universities, development cycle, system scalability, and suitability, operation and maintenance risks are more important than cost. In summary, the internal control information construction in University A has proved in practice that delegating the task to the system development company completely is a relatively optimal task allocation model.

5. Suggestions on the Informatization Construction of Internal Control in Colleges and Universities

With the informatization construction of internal control in colleges and universities, the management norms and processes of colleges and universities have been solidified and optimized, and changes have been made to the management model of various economic activities in colleges and

Table 2: Comparison table of influencing factors in the development model.

Delegation mode	Development cycle (10 points total)	Cost (10 points total)	System scalability (10 points total)	System suitability (10 points total)	Operation and maintenance risk (10 points total)	Total
Local delegation	5	7	4	5	5	26
Complete delegation	8	6	9	9	6	38

universities, which play a vital role in the implementation of the internal control system in colleges and universities. For this reason, how to implement internal control informatization is a major issue commonly faced by colleges and universities.

(5.1) When colleges and universities have a reserve of information technology talents, self-development and multidepartmental joint development modes on campus can save costs and facilitate the subsequent system maintenance; When colleges and universities do not have stringent requirements on the management and personnel of internal control, direct outsourcing of commercial software, and commissioning of external units to customize development modes can reduce maintenance risks. However, the disadvantage is that colleges and universities need to bear the commissioned development cost, and the technical personnel from the software company is required to participate in later maintenance. It is recommended that colleges and universities should make an assessment according to their own situations, rationally design the informatization construction plan of internal control, break down the information island or duplicate construction, and realize the effective connection between the existing information systems of various departments and the communication and sharing between existing information systems and new ones.

(5.2) With the acceleration of the informatization construction of internal control in colleges and universities, development and operation accidents frequently occur. Especially in the fully commissioned development mode, the stable operation of software and information security are particularly important. It is recommended that colleges and universities should be wary of any unexpected situations that may occur from the perspective of risk management, and timely formulate risk handling plans for the development and maintenance of internal control informatization construction to improve their ability to cope with emergencies and risks.

6. Conclusions

Based on the game theory, a game model of information development mode of internal control in colleges and universities and a game model of risk management of software maintenance are established in this paper. The two parties involved in the game are the software development company and the informatization management department of internal control in colleges and universities. It is verified by the model and case study that the fully commissioned development is an optimal development mode compared to the partially commissioned development mode. In future research, emphasis will be placed on exploring how colleges and universities can more effectively allocate the informatization construction tasks of internal control when facing more constraints in reality. What's more, from a practical perspective, future research will focus on exploring a systematic development mode that is suitable for the internal control informatization of administrative institutions. In this way, the research can provide theoretical support for the construction of internal control informatization of administrative institutions.

Data Availability

The data that support the findings of this study are available from the author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Ministry of Finance, *The Internal Control Standard for Administrative Institutions (Trial)*, pp. 11–29, 2012.

[2] "Guiding opinions of the Ministry of Finance on comprehensively promoting the internal control construction of administrative institutions," *Proclamation of the Ministry of Finance of the People's Republic of China*, no. 02, pp. 40–43, 2016.

[3] Ministry of Education, *The Guideline for Internal Control of Economic Activity of Colleges and Universities Directly of the Ministry of Education (Trial)*, pp. 4–20, 2016.

[4] M. Popescu, S.-M. Popescu, and G. Mangu, "Internal management control approach by implementation of stages of the internal control management system in public entities," *Internal Auditing and Risk Management*, vol. 42, no. 1, pp. 53–58, 2016.

[5] R. Michelle, "Extended free auditing," *A journal of Practice and Theory*, vol. 19, pp. 76–82, 2012.

[6] D. Tang, S. Teng, Y. Chang, and Wuwei, "Analysis and suggestions on informatization of internal control of administrative institutions in the new era," *Chinese CPA*, no. 01, pp. 34–38, 2019.

[7] W. Peng, "Research on the information platform of economic activities in colleges and universities from the perspective of internal control," *Friends of Accounting*, no. 24, pp. 84–86, 2018.

[8] W. Zhang, "Try to analyze the internal control construction of university informatization under the background of big data," *Accounting Monthly*, no. 22, pp. 23–27, 2017.

[9] J. Li, "Research on enterprise accounting information system software development method selection based on AHP," *China Management Informationization*, vol. 17, no. 08, pp. 38–40, 2014.

[10] C. Y. Xiang, J. Liu, and D. Wang, "Research on the development mode of logistics enterprise information system based on AHP," *Journal of Shandong Jiaotong University, Study on information system development mode of logistics enterprises based on AHP*, vol. 22, no. 01, pp. 24–27, 2014.

[11] Z. Zheng and J. Zhou, "Game optimization strategy for multi-tenant network resource allocation[J/OL]," *Computer Engineering: 1-9*, 2021.

[12] J. Zhou, J. Li, J. He, and Y. Gao, "Cooperative game between microgrid and bulk power grid on block chain based on blockchain," *System Engineering Theory and Practice*, vol. 41, no. 08, pp. 2090–2100, 2021.

[13] G. Xu, H. Chen, X. Wu, and C. Zhou, "Game analysis on green cost-sharing in competitive supply chain," *Journal of Systems Engineering*, vol. 35, no. 02, pp. 244–256, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2556365, 12 pages
https://doi.org/10.1155/2022/2556365

Research Article

Logo Design Process and Method of Intellectual Property Big Data in the Digital Media Era

Xin Jia,[1] **Yan Dong**,[2] **and Bingxue Wang**[3]

[1]*School of Design, NingboTech University, Ningbo 315000, China*
[2]*College of Mechanical and Electrical Engineering, Harbin Industrial University, Harbin 150000, China*
[3]*Research Institute of Theatre, Film & Television, Communication University of Zhejiang, Hangzhou 310018, China*

Correspondence should be addressed to Bingxue Wang; wangbingxue@zju.edu.cn

Received 9 April 2022; Revised 18 May 2022; Accepted 28 May 2022; Published 18 June 2022

Academic Editor: Lele Qin

Logo design is related to the image of a company, unit, product, etc. A good logo can leave a deep impression on people and intuitively understand the content of the product. With the increasing emphasis on intellectual property protection, the design of logos should also pay more attention to the protection of property rights. It can be said that the logo of some big brands is enough to represent the enterprise itself; for example, seeing the red cross as a hospital. This paper aims to propose a logo design process and method under the background of intellectual property big data, so as to make the logo design more procedural and efficient, and to better focus on the protection of property rights. By introducing the relevant knowledge of logo design and trademark registration, it is indicated that trademark search can be used as an auxiliary tool for logo design. Combined with digital media and big data technology, a logo image recognition and classification method is designed so that the trademark registration and screening stage can avoid the infringement design to the greatest extent, so as to put forward the design process and method to improve the innovation ability of logo design. According to the research, the classification accuracy rate of the algorithm proposed in this paper is 91.5%, and the recognition rate of various defects is also above 95%. In addition, in design practice, the stability of design proposals should be monitored through multiple search methods using trademark search tools. If a high similarity is found in the search results, the design direction should be adjusted in time until the final design scheme is determined.

1. Introduction

A trademark is an iconic symbol of a business or institution that represents the strength and uniqueness of a brand. However, due to the specificity of trademarks, many studies tend to focus on trademark-related tasks in natural settings. Especially in the fields of piracy and infringement detection, brand traceability tracking, commercial advertisement analysis, intelligent transportation, and commodity image search, it has huge application prospects. Logo classification and detection technology have huge application prospects in the fields of product advertisement analysis and product image search. Therefore, a complete electronic product catalog can be constructed to help companies quickly detect relevant brands, complete the detection of piracy and infringement, and personalized recommendation of products.

At the same time, with the rapid development of deep learning and computer vision technology, deep convolutional neural network theory has been widely used in many fields, such as image classification, object detection, behavior recognition, and image retrieval. Convolutional neural networks can train and extract expressive image features, so more and more image classification and detection techniques are applied to real life. Logo image classification and detection have become a key research topic. The research content refers to finding the location of the logo in the picture and judging the category to which the logo belongs by processing the input original image. Therefore, in the new media era, relevant research on the logo design process is of great significance.

The innovations of this paper mainly focus on the following two aspects: (1) For the Logo-2K+ classification

dataset, this paper proposes a fine-grained classification scheme that can learn useful regional features from numerous local features under the supervision of only label information. Combining local features with semantic features finally achieves effective classification. By fusing global and local features, a multifeature set is constructed to describe the target more accurately. Using two sub-components to learn more subtle, diverse, and mutually exclusive local interclass confusing information to achieve two-level effective classification from coarse-grained features to fine-grained features. (2) In this paper, YOLOv3 with three scales is used as the basic framework to solve the problems of multiscale and small targets, and the focal loss, classification loss, CIoU loss, and regression loss are improved and integrated into it. In order to solve the problems of unbalanced positive and negative samples and inaccurate regression, and finally achieve effective logo detection.

2. Related Work

Logo is a unique sign composed of patterns, words, etc., used to identify the products and services of companies, public organizations, institutions, etc. It not only conveys product information but also represents the brand value of the product, so the image of the logo in publicity is particularly important. Ensuring the quality of the logo is an effective means to maintain the image and honor of enterprises and major organizations. In order to maintain the image of the logo, different organizational units have their own specific regulations for the use of the logo. There are many research designs on it. The purpose of Zhu et al.'s study was to explore how features of logo design affect consumer responses based on visual representation. Signs from different regions may have different characteristics that affect the level of logo preference. According to his experimental results, four factors that influence logo preference include modernity, aesthetics, interest, and style [1]. Mahmood et al. proposed a disfluency-based heuristic framework to understand the impact of inefficient visual cues on equity crowdfunding platforms. He used processing fluency theory and visual heuristics to modify logo design [2]. Tessensohn did a study on Japan's revised Unfair Competition Prevention Law (UCPL), which is said to be the world's first law aimed at protecting "big data" itself [3]. Deere is very interested in the world economy and studied the world economic property rights protection laws, aiming to address the maintenance and development of laws in developing countries [4]. Peng et al. echo recent calls for organizing research to address larger, globally relevant issues and focus on history by analyzing key debates on intellectual property rights (IPR) between the United States and China [5]. Kesan J P solves the complex relationship between IPR and the agricultural biotechnology industry. He details the value chain of the agricultural biotechnology industry and its implications for IPR protection [6]. Niculescu et al. explore the strategic decision of incumbents to open up proprietary technology platforms in order to achieve peer-to-peer competition in a market characterized by network effects. He proposes a game-theoretic model that analyzes the interaction between the degree of openness of a conceptualized peer-to-peer platform, the absorptive capacity of an entrant, and the strength of network effects. His experiments show that models with exogenous network effects may significantly underestimate the range of absorptive capacity values of entrants for whom incumbents should open their platforms, leading the latter to miss out on valuable cooperation opportunities [7]. It can be found that the current research direction of logo design is mainly the depth and acceptance of the design, and there is relatively little research on big data property rights, so the following research is necessary. At the same time, the related research has not programmed the idea of logo design, nor has it really used the artificial intelligence algorithm to optimize the design process.

3. Logo Design in the Age of Digital Media

3.1. Digital Media Era. Today is the era of diversified digital media, and the diversification of design makes various cultural concepts, design concepts, design styles, and expressions collide with each other. Digital media is a variety of media forms extended based on various network technologies and digital technologies, as shown in Figure 1. Digital media has both digital content and digital technology; that is, it not only contains pure digital content but also covers the embodiment of various theoretical, technical, and hardware support for it. The main features include the following two aspects. On the one hand, digital media uses advanced digital technology to improve the quality and efficiency of the collection, production, and transmission of information content. Digital technology also promotes the generation of various digital media carriers. Different from traditional media works, the display methods of digital media works can integrate text, graphics, music, commentary, narration, and other display methods and sensory language into one with the help of computers and other technologies, and ultimately produce interaction with people's vision and even hearing. On the other hand, people's requirements for information presentation have also undergone great changes, which has also led to the emergence of digital media to provide more innovative and personalized content for the public. In the era of digital media, the Internet is ubiquitous, and people's lives and work can be separated from the constraints of real factors such as time and space. Its dissemination is highly intelligent. Work in the digital media era can realize interactive communication in the process of dissemination based on technological advantages. With the help of the Internet to obtain the required information content, different audiences can also shop online, watch live broadcasts in real time, read online, and listen to books [8, 9].

3.2. Digital Media and Art Logo Design. Modern media art is an art form that integrates sound, shape, color, and movement. It is an inevitable product of the rapid development and popularization of electronic technology. Today's young people are particularly fond of electronics, animation, and personal things, and most of them have their

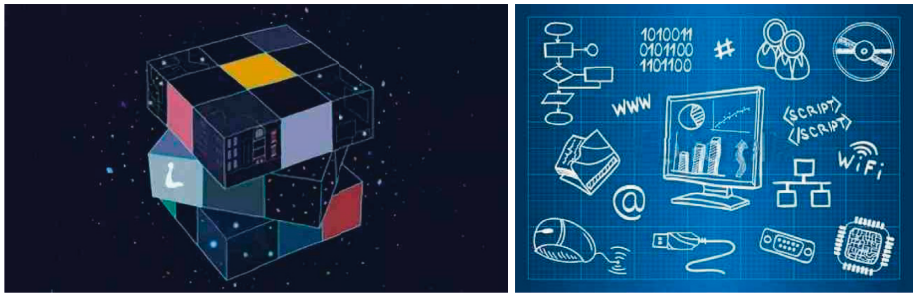


Figure 1: Digital media design.

own Weibo, space, homepage, and other things. This makes modern media art have the basis for rapid development and is also a cultural and artistic form. Modern media art is a very wide range of art forms. Therefore, to study modern media art, it must also be studied from the disciplines of art, sociology, technology, aesthetics, and popular culture. Today's modern media has formed a true art form-modern media art. Because digital technology is its main carrier, it can also be called digital media art [10, 11]. With the strong influence of digital media technology, many traditional artists have also begun to use the emerging technology of digital media. This technology allows them to find a new creative method, especially for young students and artists who are eager to raise the banner of media art. This is an excellent phenomenon because the creation of art requires innovation, and the use of new methods is itself an innovation. The use of digital media technology to create not only makes traditional hand-painted works as popular and loved by the audience but also makes hand-painted works of art have the possibility and trend of rising, which is undoubtedly one of the issues that should be paid attention to at the moment, as shown in Figure 2.

Digital art has broad market prospects. Taking the animation industry in the field of electronic art as an example, according to statistics from relevant departments, the market capacity of China is almost over 100 billion yuan. Moreover, the electronic art industry is characterized by the combination of consumption and creation, which is a brand-new industrial state. A scholar in the Netherlands found that the multilevel "long tail" theory of profits formed by the American digital industry represented by "Dream Works,"its core is "sharing" —the sharing between producers and consumers. This sharing has completely changed the previous operation mode, which also makes producers no longer just blindly "speak," and consumers can no longer only "listen," and the relationship between the two has undergone tremendous changes.

In digital media, design is a very important part, without design digital media will not be alive. Design is not only a method, but also a visible idea. It can solve the problems of strategy, planning, and design together. The design includes three aspects: First, the formation of plans and ideas. Second, people need to express ideas in a way that other can see. The third is to complete the content of the performance. In design, the core thing is thought, and thought comes from the mind, so in daily life, people

Figure 2: Digital logo design.

should see more, think more, and collect inspiration and materials [12].

The fusion of art and computer technology is a trend, and this trend may bring some problems. One of the most serious problems is that the boundaries between the two are becoming smaller and smaller. What art pursues is a personalized and original behavior, and its preciousness is its distinctiveness and its spirit of seeking differences. And computer technology pursues unity and standardization. The pursuits of the two are qualitatively different in direction, so when using the method of combining the two to create, we must distinguish what needs to be paid attention to. In terms of social production, people should pay more attention to the direction that needs to be pursued technically, and in terms of art, people should pay attention to expressing their own thoughts and spirits. Digital media art, like traditional art, comes from life. Without life, any form of art has no meaning. Now the generation of digital products is also because of people's needs in life. Since it is art, no matter what form it is, it is worth learning, because art is an expression of beauty, and art in the form of digital media should be carried forward. This is an unchangeable reality [13, 14].

Whether it is media or art, it exists to meet people's needs and is produced under certain social conditions. The impact of digital technology on art is obvious. Art works are often spread with the help of modern media technology, and modern media is supported by digital technology. Art work has an impact only when it is communicated, which makes art and digital technology closely linked. Digital media not

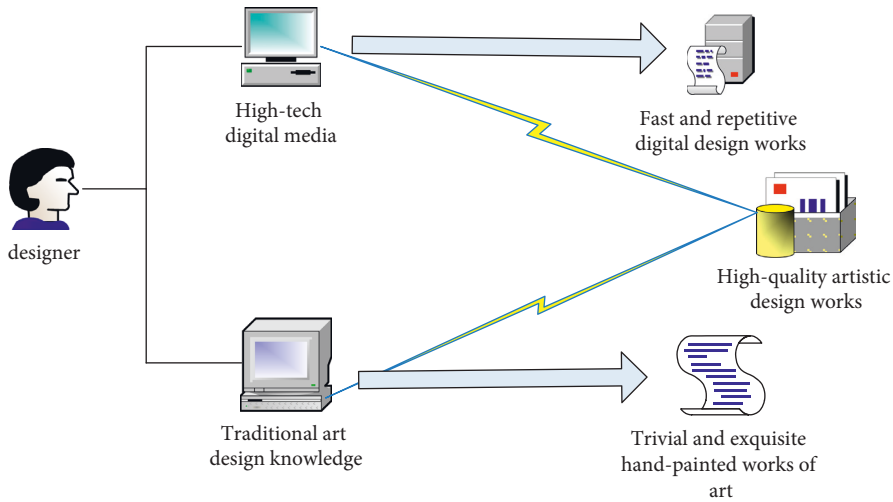


Figure 3: Combining digital technology with traditional art design.

only plays a role in the dissemination of art to a certain extent but it also determines the form of art works in the process of dissemination, as shown in Figure 3.

3.3. Big Data and Intellectual Property. The object of a patent right is a technical solution to a specific technical feature. According to the basic requirements of the patent system, this technical solution can be used to solve technical problems existing in reality, which have economic value as information. Moreover, with the improvement of the technical level, this kind of information has already been disclosed to the whole society through the Internet in digital form. Therefore, big data will contain more or less patent information. In the application process based on big data, the utilization of patent information is mainly reflected in two aspects. Provide digital information products containing patent information; methods of "mining" and "utilizing" data information may be patented methods. Returning to the status quo of the Chinese legislation, since the objects protected by the Chinese Patent Law are limited to patented products, patented methods, and designs, the products in the form of digital information are not included in the scope of patent protection and business methods are not regarded as objects that can be granted patent rights. Therefore, big data itself will not directly lead to the risk of patent infringement, or cause consequences that affect the normal exercise of patent rights. Compared with traditional patent infringement, patent infringement in the context of big data does not have obvious specificity [15].

As the right of the exclusive owner of a trademark to mark its own products and services, its object is essentially a kind of symbolic information used for identification. From the point of view of the function of trademark and the application of big data, the intersection of the two is very limited. However, after digitizing the identifying information in the trademark, it can be compared among a wide range of data information through the application of big data. To a certain extent, digital retrieval of trademark information can be realized, which is helpful to improve the efficiency of trademark application review, or to discover inconspicuous trademark infringements. As for the trademark registration of big data and related technologies and applications themselves, it is still a traditional trademark registration examination standard issue in essence. Generic names of goods or services cannot be registered as trademarks. The particularity lies only in the fact that "big data," as a representative of a series of information technologies, has strong technical attributes, which is easy to cause confusion between the censorship authorities and market players [16, 17].

4. Logo Recognition Method Based on Intellectual Property Big Data

4.1. Logo Recognition Algorithm

4.1.1. Shape Context Algorithm. In this paper, a shape context algorithm is proposed as an algorithm to measure the similarity between logos. The shape context algorithm proceeds in three steps:

Calculate the context information for each point on the two image point sets separately:

Generally, when the given image is not the contour image of the target object, some preprocessing should be done, including edge extraction, uniform sampling, etc. First, the inner and outer contours of the image must be extracted before they can be used for the calculation of the shape context algorithm. For example, when the number of contour points in the input image is insufficient, the image needs to be enlarged, and then sampling is performed when the number of contour points is sufficient. However, the image enlargement process may cause the original shape outline to become thicker, so it may be necessary to refine the image to keep the width of the outline as wide as possible by a single-pixel [18, 19]. As shown in Figure 4, we determine two different contour images of capital letter A. In this step, a point is the center to make concentric circles, and the circle is divided into 12 sectors. The concentric circles have five layers, so the entire contour map is divided into 60 grids.

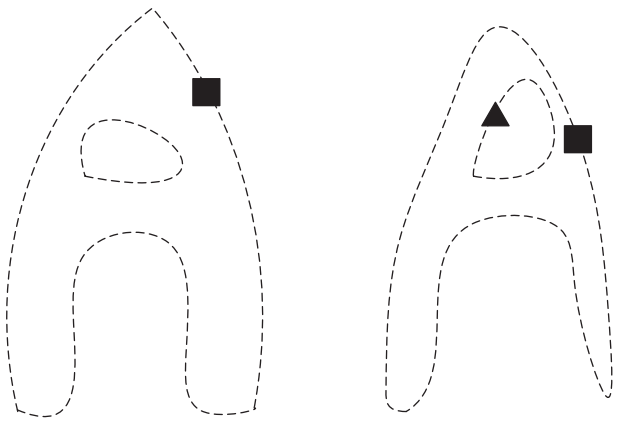


Figure 4: Sketch of handwritten letters.

The distribution of all other points on this contour in the grid should be counted. The shape information of each point is represented by the set of relative vectors that all other points form with it. To facilitate calculation of statistics and observations, a histogram is made to represent these vectors. Take the points marked by diamonds, triangles, and squares in Figure 4 as examples, make concentric circles, and calculate and draw histograms, respectively.

Calculate the difference between each two corresponding points in the two image point sets:

The shape context algorithm uses the χ^2 test statistic (the chi-square test statistic, the degree of deviation between the actual observed value of the statistical sample and the theoretically inferred value), as shown in the following formula:

$$C_s = \frac{1}{2}\sum_{k=1}^{k}\frac{[g(k)-h(k)]^2}{g(k)+h(k)}. \tag{1}$$

Among them, k refers to the kth grid, and g and h, respectively, represent a point in the two image point sets.

Use the Hungarian algorithm for matching search:

The shape penalty is shown in the following formula:

$$H(\pi) = \sum_i C\left(p_i, q_{\pi(i)}\right). \tag{2}$$

Finally, a transformation T is used to measure the transformation between shapes, that is, shape distance. Based on this shape distance, the similarity between the shapes of two objects can be basically measured. The shape distance calculation is shown in the formula:

$$\begin{aligned} D_{SC}(P,Q) = {} & \frac{1}{n}\sum_{p\in P}\arg\min_{q\in Q} C(p, T(q)) \\ & + \frac{1}{m}\sum_{q\in Q}\arg\min_{p\in P} C(p, T(q)), \end{aligned} \tag{3}$$

The shape context algorithm can capture the internal features of 2D images and obtain the point relationship between images at the same time, and maximize the use of point context information in the process of point set matching. The shape context algorithm has a very poor matching effect when the image has a background and too many noise points. However, compared with other contour-based matching methods, the shape context algorithm is simple and does not need to consider the coordinate position of the point set, and has good robustness for nonrigid matching. This property makes it a better similarity measure algorithm [20].

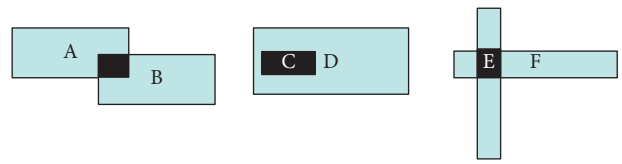


Figure 5: Schematic diagram of rectangle intersection.

4.1.2. Screening of Overlapping Regions of Identification Results. In target recognition, it is usually necessary to determine whether the output rectangle area overlaps. The calculation idea of judging whether two rectangles intersect or whether there is an overlapping area is mainly to calculate whether the coordinates of the four vertices of the first rectangle are included in the area where the second rectangle is located. However, there are logical flaws in this calculation idea. As shown in Figure 5, rectangles A and B, and rectangles C and D, all satisfy that the vertex coordinates are inside another rectangle, but although rectangles E and F have overlapping parts, they do not satisfy the judgment condition.

The specific calculation process is as follows:

Let the coordinate of the upper left corner of rectangle A be (x_{A1}, y_{A1}) and the coordinate of the lower right corner to be (x_{A2}, y_{A2}). The coordinate of the upper left corner of rectangle B is (x_{B1}, y_{B1}) and the coordinate of the lower right corner is (x_{B2}, y_{B2}). Then, the width of rectangle A is recorded as width_A and the height is recorded as height_A. Similarly, the width of rectangle B is recorded as width_B and the height is recorded as height_B. The center coordinates of rectangle A are marked as (x_{Ac}, y_{Ac}) and the center coordinates of rectangle B are marked as (x_{Bc}, y_{Bc}). To judge whether two rectangles intersect, it only needs to satisfy formulas (5) and (6):

$$\begin{aligned} \text{width}_\text{A} &= |x_{A1} - x_{A2}|, \\ \text{width}_\text{B} &= |x_{B1} - x_{B2}|, \\ \text{height}_\text{A} &= |y_{A1} - y_{A2}|, \\ \text{height}_\text{B} &= |y_{B1} - y_{B2}|, \end{aligned} \tag{4}$$

$$\begin{aligned} (x_{Ac}, y_{Ac}) &= \left(\frac{x_{A1}+x_{A2}}{2}, \frac{y_{A1}+y_{A2}}{2}\right), \\ (x_{Bc}, y_{Bc}) &= \left(\frac{x_{B1}+x_{B2}}{2}, \frac{y_{B1}+y_{B2}}{2}\right), \\ |x_{Ac} - x_{Bc}| &\le \frac{\text{width}_\text{A}}{2} + \frac{\text{width}_\text{B}}{2}, \end{aligned} \tag{5}$$

$$\left|y_{Ac} - y_{Bc}\right| \leq \frac{\text{width}_A}{2} + \frac{\text{width}_B}{2}. \tag{6}$$

Assuming that there is an intersection area between two rectangles, set the intersected rectangle to be C, the coordinates of the upper left corner of rectangle C to be (x_{C1}, y_{C1}), and the coordinates of the lower right corner to be (x_{C2}, y_{C2}), then:

$$(x_{C1}, y_{C1}) = (\max(x_{A1}, x_{B1}), \max(y_{A1}, y_{B1})), \tag{7}$$

$$(x_{C2}, y_{C2}) = (\max(x_{A2}, x_{B2}), \max(y_{A2}, y_{B2})). \tag{8}$$

Use formulas (7) and (8) to find the overlapping area of the two rectangular boxes, and calculate the overlapping area. Calculate the proportion of the overlapping area occupied by the two rectangles according to the overlapping area. If the overlap ratio threshold is exceeded, the two are determined to be the same logo area, and if the overlap ratio threshold is less than the overlap ratio threshold, the two are determined to be two independent logo areas.

4.1.3. Algorithm Evaluation Index. For the performance evaluation of the algorithm, the evaluation indicators such as the accuracy rate are used to evaluate whether the logo defect detection algorithm can accurately detect logo defects. This paper uses the confusion matrix to illustrate the evaluation indicators as shown in Table 1.

The description of each index in Table 1 is shown in Table 2.

Therefore, the definitions of Accuracy, Precision, Recall, and F1-Score are as follows:

$$\begin{aligned} \text{Accuracy} &= \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}, \\ \text{Precision} &= \frac{\text{TP}}{\text{TP} + \text{FP}}, \\ \text{Recall} &= \frac{\text{TP}}{\text{TP} + \text{FN}}, \\ F_1 \cdot \text{Score} &= \frac{2\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}. \end{aligned} \tag{9}$$

Among them, the accuracy rate reflects the rate that all positive and negative samples are correctly classified, and the accuracy rate reflects the proportion of the normal logo samples in the discrimination result that are actually normal logo. The recall rate reflects the ratio of all normal logo inspection results judged to be normal logo, and the F_1 score is a comprehensive indicator of overall precision and recall. Only when both values are larger, the F_1 score is higher.

4.2. Logo Image Recognition Classification and Defect Search Based on Large Database. Data set 1 is used for the design and analysis of the logo defect detection algorithm in this paper. The source of the data set is divided into two parts: one part is the logo image obtained from the files used by SoftBank SBC&S Company daily; the other part is the logo image artificially produced according to the relevant defect judgment criteria of SoftBank SBC&S Company. This part of the data is produced by Photoshop software. Some images of the dataset are shown in Figure 6.

Table 1: Evaluation metrics.

Fact	Prediction result	
	Example (T)	Counterexample (F)
Example (T)	TP	FN
Counter example (F)	FP	TN

Table 2: Description of evaluation indicators.

Evaluation indicators	Indicator description
TP	OK logo detection result is OK
FP	NG's logo detection result is OK
TN	NG's logo detection result is NG
FN	OK logo detection result is NG

The total number of logo images in this dataset is 2020. Among them, there are 1208 normal logo images (OK images) and 812 defective logo images (NG images). The ratio of OK Logo to NG Logo is about 1.5 : 1. Positive samples are slightly higher than negative samples. The defect logo may have one or more defects, but they are classified according to the defect detection priority introduced in the article. The detailed data distribution is shown in Table 3.

For normal logo, the maximum gray level greater than ratio can be extracted that is, the maximum gray level proportion is in 1 area. Adaptive foreground and background separation is performed for this type of logo, and foreground masks are extracted for subsequent foreground color detection. First, if the ratio of the maximum number of pixels is found to be greater than the ratio, then take the maximum gray level as the center, record the ratio as threshold, and expand to both sides to select the threshold for adaptive foreground and background separation. The algorithm flow figure for selecting the adaptive threshold is shown in Figure 7. After the expansion on both sides is completed, the pixels in the gray-level neighborhood are taken as the background, and the rest are classified as the foreground.

4.3. Logo Picture Defect Inspection

4.3.1. Color Defect. Part of the experimental results was randomly selected from the experimental data set as shown in Table 4. Referring to the logo color defect judgment criteria, the average foreground and background values of the logo can better reflect the real situation of the logo color. Referring to the logo color defect judgment criteria, the average foreground and background values of the logo can better reflect the real situation of the logo color. Color changes within this error range are invisible to the human eye. The foreground and background of the no. 2 logo are normal, but the contrast calculation result of gray is 12, which is too small to distinguish. It can be seen that the

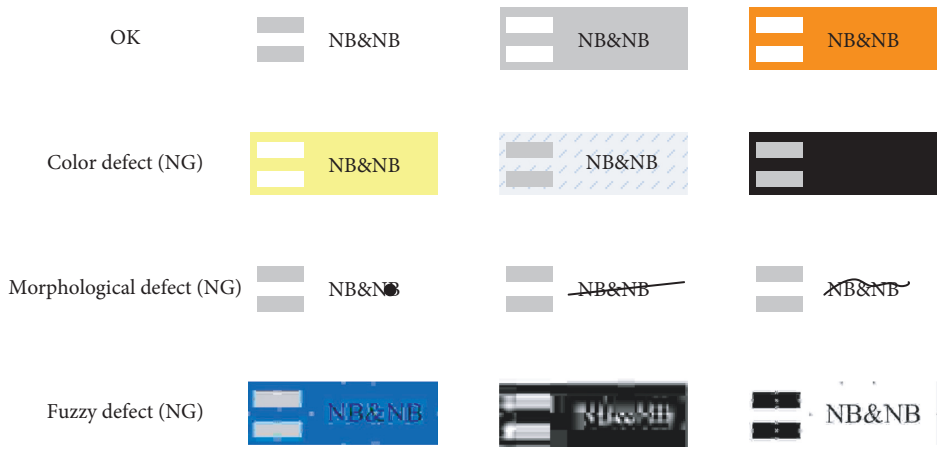


Figure 6: Data part display of dataset 1.

Table 3: Data distribution of dataset 1.

Logo defect category	Logo image quantity (piece)
Normal (OK)	1208
Color defect (NG)	269
Morphological defect (NG)	275
Fuzzy defect (NG)	268

algorithm in this paper can better detect the color of the logo foreground and background.

Then, all the logo images in the dataset are identified. The logo image color defect detection algorithm in this paper has a test accuracy of 97.0% in the 1208 normal logo images and 269 color defect logo images in dataset one.

From the above experimental results, the color detection algorithm in this paper quantitatively analyzes the foreground and background of each area. The subjective judgment of the human eye is combined with the actual numerical analysis to detect the problem of logo color defects. In general, the algorithm in this paper has played a good role in the detection of logo color defects. The reason why the algorithm does not reach 100% is mainly affected by the small size of the logo image. Because the logo image is too small in size, the boundary between the foreground and the background is often blurred, and many errors will be introduced in the process of foreground color detection and background color detection, causing misjudgment, which will affect the results of the algorithm.

4.3.2. Morphological Defects. Compared with the traditional image direct difference method and the image moving difference method based on the convolutional autoencoder-based logo morphological defect analysis algorithm proposed in this paper. If the number of white pixels (pixel value is 255) in the image difference result is less than 2% of the total number of pixels in the whole image, it is considered as a normal logo; otherwise, it is considered as a morphological defect logo. In order to ensure the uniformity of the experimental data, under the premise of the above data set division, 242 normal logo images and 275 morphological defect logo images in the test set are compared and tested, as

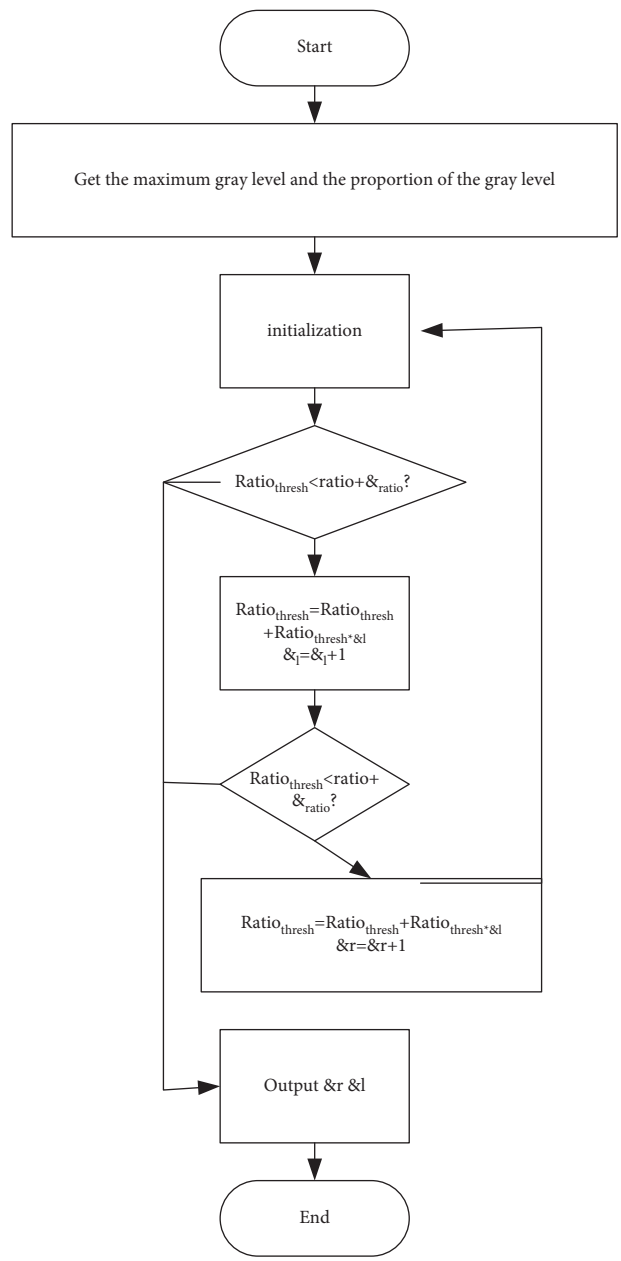


Figure 7: Adaptive threshold acquisition.

Table 4: Color defect analysis results table.

	Logo segmentation	Prospect mean	Prospect variance	Background mean	Background variance	Block determination	Overall determination
Normal logo image	1	28	1	251	363	OK	OK
	2	34	304	253	325	OK	
	3	32	313	250	325	OK	
	4	32	289	253	120	OK	
	5	31	266	252	192	OK	
	6	31	255	252	192	OK	
Color defect logo picture	1	254	0	242	0	NG	NG
	2	254	2	242	1	NG	
	3	254	2	242	1	NG	
	4	254	2	242	1	NG	
	5	254	2	242	1	NG	
	6	254	2	242	1	NG	

shown in Table 5. It can be seen from Table 5 that, compared with the traditional algorithm, the accuracy of the algorithm in this paper has been significantly improved. The reason why the accuracy rate is less than 100% is that the algorithm in this paper cannot distinguish small logo morphological defects in the final image difference and postprocessing, and these defects are mistakenly regarded as noise by the algorithm and removed. In general, the logo morphological defect detection algorithm in this paper still achieves good results.

4.3.3. Logo Image Blur Defect Detection. Aiming at the problem of logo image blur, this paper introduces the logo image blur detection algorithm from the mathematical calculation method based on structural similarity coefficient and the method based on image morphology and compares and analyzes it.

From the test results in Figure 8, the SSIM results all decrease as the blur radius of the logo image increases, indicating that the blur degree of the image is inversely correlated with the SSIM results. Through this anti-correlation change trend, it is found through experiments that the set threshold is around 0.9, and if the threshold is greater than this threshold, it can be considered as a normal logo; otherwise, it is a fuzzy logo.

The experimental results show that whether for out-of-focus blur or distortion blur, the results of SSIM will be affected by the reference template. Choosing different reference templates will result in different SSIM results, which adds a lot of uncertainty to logo fuzzy detection.

4.4. Logo Image Recognition Classification Test. For the logo fine-grained classification task, the Logo-2K+ classification dataset constructed in this paper is used for logo classification, and the data only contain the label information of the logo category. The Logo-2K+ dataset contains 167,140 images collected from different social networking sites. Figure 9 shows a picture example of the Logo-2K+ dataset, summarizing the statistics of the existing logo dataset.

The classification evaluation index of this experiment adopts the accuracy rate. The results of the multiclassification

Table 5: Comparison of the accuracy of the algorithm in this paper and the traditional image difference algorithm.

Algorithm	Accuracy (%)
Image direct difference method	81.4
Image moving difference method	85.5
Algorithm	97.4

of logo images are evaluated by calculating the accuracy with the first confidence and the accuracy with the top five confidences; that is, the Top-1 accuracy and the Top-5 accuracy are used as the classification evaluation indicators. The classification accuracy rate represents the proportion of correctly classified samples in all samples, and the calculation formula is:

$$\text{Accuracy} = \frac{\text{TP} + \text{FN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}. \tag{10}$$

The experimental results are shown in Table 6. It can be seen from the table that the classification network with the best performance is ResNet-152, the accuracy of Top-1 is 67.65%, and the accuracy of Top-5 is as high as 91.52%. After adding efficient and label smoothing regularization tricks, a Top-1 accuracy of 67.99% is achieved. The algorithm method in this paper exhibits the best Top-1 accuracy rate of 72.09% and Top-5 accuracy rate of 93.45%, surpassing the NTS-Net method by about 1%. The experimental results of this group show the effectiveness of the region-guided data augmentation strategy.

5. Logo Design Process Based on Property Rights Protection

The trademark search process of logo design includes three stages, namely the retrieval stage of the existing trademark big data, the design stage, and the protection stage of the design results, as shown in Figure 10.

5.1. Search Stage of Existing Trademark Big Data. First, determine the search scope. The search stage of existing trademark big data refers to the categories of goods and

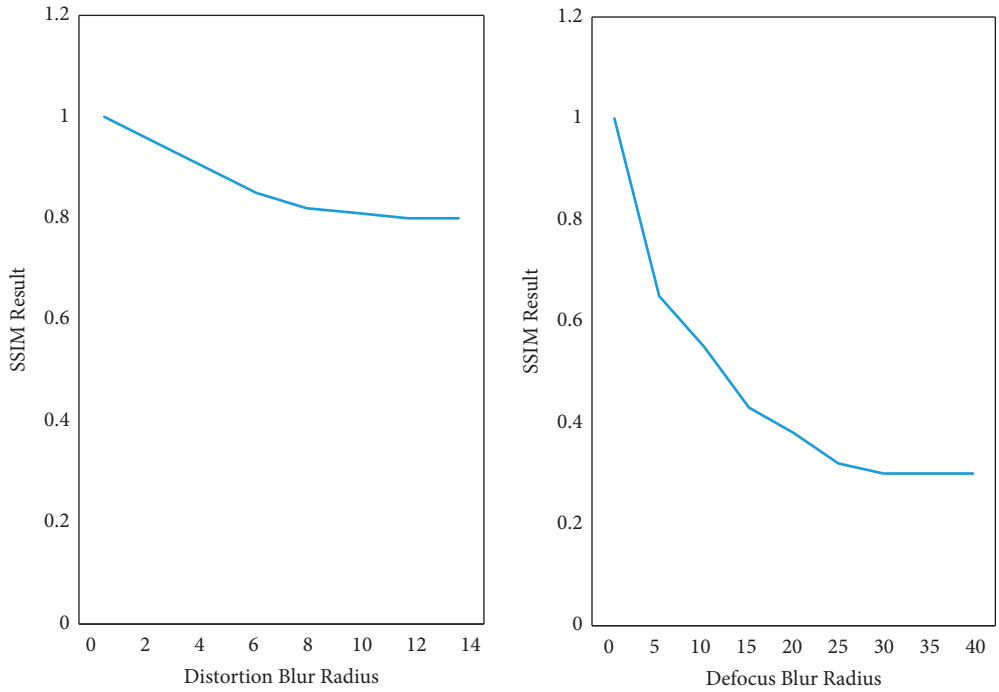


Figure 8: SSIM results for different blur radii.

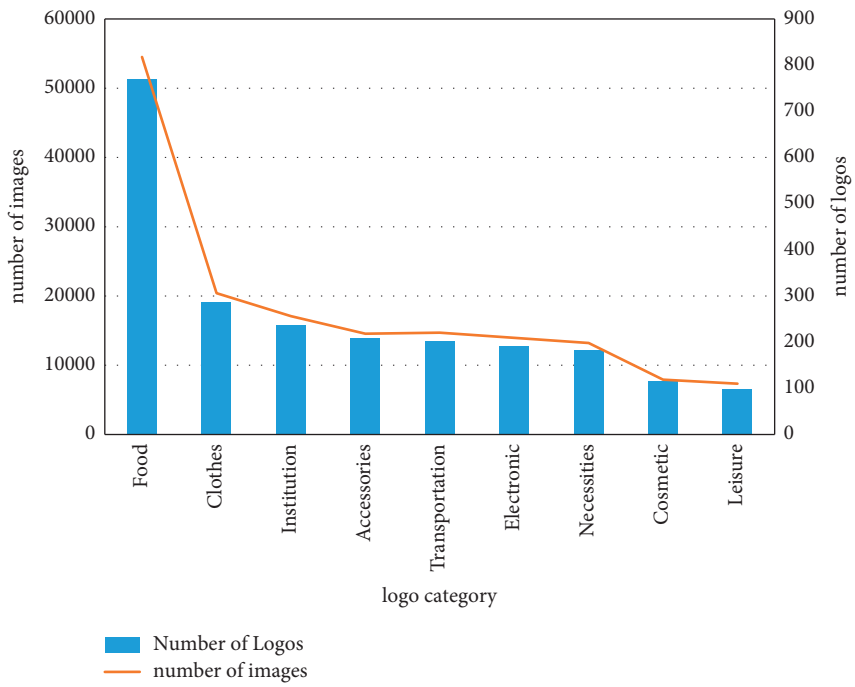


Figure 9: Dataset statistics.

Table 6: Experimental results of Logo-2K+ dataset (%).

Method	Top-1 accuracy	Top-5 accuracy
GoogLeNet	62.36	88.33
NTS-net (ResNet-50)	69.41	91.95
Algorithm	72.09	93.45

services for which the trademark is pre-applied. According to the business scope and service scope of the enterprise, find and lock the search scope by keywords in the classification table of similar goods and services. If the category of goods and services cannot be determined, people can search for the names of larger enterprises in the same industry in the applicant's "Comprehensive Query" column and refer to the

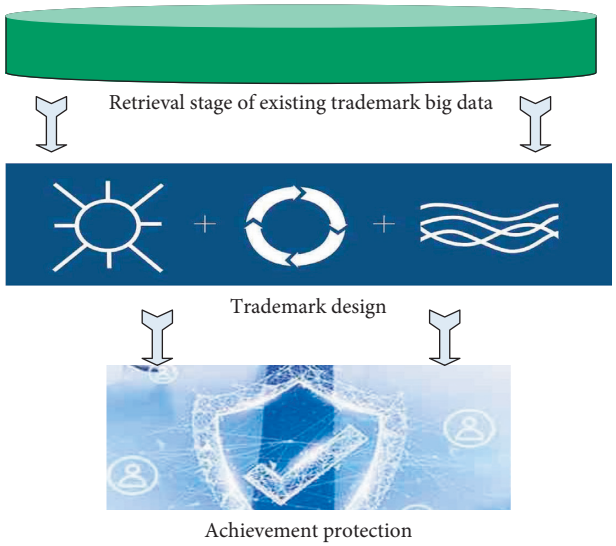


Figure 10: Logo design process.

categories of goods and services applied for by peer companies to determine the search scope.

Second, filter the elements of the design one by one within the specified search scope. According to the definition of a trademark, it consists of a combination of a single word symbol, a single graphic symbol, a single letter symbol, a single number symbol, a single sound symbol, a single three-dimensional symbol, and a single color, as well as a combination of the above single design elements. The design direction is finally determined according to the trademark search results.

5.1.1. Filter Chinese Characters. As the most direct information in corporate or product promotion, Chinese characters determine the recognition and acceptance of trademarks. Logos lacking Chinese information will be greatly hindered in publicity and promotion. At the beginning of trademark search, priority should be given to the availability of Chinese characters, and the original Chinese characters should be submitted for trademark protection as soon as possible. Especially at the beginning of the industrial and commercial registration of a newly established enterprise, the Chinese name of the enterprise should be comprehensively considered, combined with the trademark search. It is necessary to avoid the conflict between industrial and commercial registration and trademark registration and to prevent the name of the industrial and commercial registered enterprise from being preemptively registered as a trademark. In general, compared with two-character Chinese names, three-character or four-character Chinese names require fewer data to search and filter, and are more likely to make a difference.

The availability of Chinese characters can be filtered through the Chinese character query method in the trademark similarity query. When the search result shows that the original Chinese character has been approved to be registered in the same or similar category, the application made in this Chinese character may be rejected. It is recommended to reselect the Chinese name to fundamentally solve similar problems. If the Chinese name cannot be replaced or changed, it can be added on the basis of the existing Chinese characters; that is, graphics processing is performed on the basis of the original Chinese characters. Or add elements such as Pinyin or English or graphics to adjust the text, and increase the combination with other elements on the appearance to improve the distinctiveness of the trademark and reduce the similarity with the existing trademark.

5.1.2. Filter Combinations of Letters, Pinyin, and Initials. Generally speaking, the alphabet involves phonetic trademarks, English, and letter combinations. The selection of Pinyin and English names is related to the Chinese name of the enterprise, and its availability can be filtered through the Pinyin query and English query in the trademark similarity query. The initial query can filter for a single letter or two letters. Based on the search results, by removing silent letters, or substituting other letters and words with similar pronunciation, and or replacing the meaning with Chinese characters, when the combination of the same or similar trademarks in Pinyin or English in the preapproved categories of goods and services the method of the associated English words, the name is adjusted from the transliteration and free translation to the trademark registration of the letters and their combinations.

5.1.3. Screening Graphics. Graphics can be filtered by the graphics query pattern in trademark similarity search. Cognitive differences in the same graph can result in very different search results. Graphical searches should be comprehensive and should retrieve and compare graphics as a whole as well as individual elements. But it is different from the internal screening system of the trademark office. Externally, there is a lack of graphic screening systems suitable for public use. For ordinary people, it is very difficult to filter the similarity of graphs. With the continuous development of information technology, it is hoped that artificial intelligence technology can help trademark screening in the future, improve the accuracy and depth of screening, and solve the asymmetric problem of trademark query information.

5.1.4. Screening Synthetic Graphics. For compound graphics, factors such as graphics, word pronunciation, and word meaning should be compared from the whole and main parts. Based on the search results, adjust the proportion and combination of certain elements or elements to increase the likelihood of registration.

5.2. Design Phase. Through the preliminary screening of logo elements, the accurate design direction is determined, and the design practice is carried out in combination with the traditional logo design method. In addition, in design

practice, trademark search tools should be used to monitor the stability of design proposals through various search methods. If a high degree of similarity is found in the search results, the design direction should be adjusted in time until the final design scheme is determined.

5.3. Protection Stage of Design Results. Once the design scheme is determined, it will enter the critical stage of achievement protection. For the protection of logo graphics, it is necessary to focus on the future development of the enterprise and achieve comprehensive and timely protection.

Comprehensive protection refers to a comprehensive trademark filing class and a comprehensive trademark filing strategy. The class of trademark application should cover all products and services that are related or similar to the future development of the business.

Timely protection means that applications for trademark registration should be submitted promptly and promptly. Company leaders should strengthen the awareness of trademark protection and avoid being sued for using others' trademarks or preemptively registering trademarks.

6. Discussion

Based on image recognition technology, the color detection algorithm in this paper quantifies the foreground and background of each area, combines the subjective judgment of human eyes with the actual numerical analysis, and then detects the color defect of logo. Generally speaking, the algorithm in this paper plays a good role in the color defect detection of logo. Moreover, the detection of image morphological defects and image blur can achieve good results. This shows that the logo identification technology in this paper can effectively check and verify the existing image trademarks and can effectively avoid the phenomenon of trademark intellectual property infringement.

Aiming at the design process of logo, this paper uses new media technology to increase data technology, which can effectively improve the efficiency of logo design, which is very meaningful in business. In particular, the use of big data technology to generate logo in batches to avoid infringement is revised by designers, which not only improves the efficiency but also improves the quality.

7. Conclusion

Taking big data as the object to study its role and influence in the current wave of social informatization is an inevitable requirement for the intellectual property system to adapt to social development. It is also the basic premise for the law to realize the sharing, full circulation, and rational utilization of social information through institutional design. With the rapid development of multimedia information and mobile Internet, data such as videos and pictures have grown on a large scale, and the information contained in these massive multimedia data are useful. Through the analysis of these visual information, the analysis of commodity brands, user preference analysis, and commodity personalized recommendation can be realized. Logo classification and detection have attracted the attention of more researchers with the impetus of deep learning. Of course, this paper also has some defects, such as the analysis of the design process and identification of picture trademarks in the research, but the research on word mark is seldom mentioned, so the design scope of trademarks will be expanded in future research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Social Science Fund of China "Research on the National Image of Chinese Film and Television in Overseas Communication" (20CXW010) and the Social Science Fund of Zhejiang "Research on the Cultural Cognition and Production Strategy of Transnational Film and Television Production" (18NDJC160YB).

References

[1] Z. Zhu, H. Cao, and B. Li, "Research on logo design and evaluation of youth education brands based on visual representation," *The Journal of Product and Brand Management*, vol. 26, no. 7, pp. 722–733, 2017.

[2] A. Mahmood, J. Luffarelli, and M. Mukesh, "What's in a logo? The impact of complex visual cues in equity crowdfunding," *Journal of Business Venturing*, vol. 34, no. 1, pp. 41–62, 2019.

[3] J. A. Tessensohn, "Japan confers Unfair competition protection on 'big data," *European Intellectual Property Review*, vol. 42, no. 2, pp. 134–136, 2020.

[4] C. B. Deere, "The implementation game: the TRIPS agreement and the global politics of intellectual property reform in developing countries," *Social Science Electronic Publishing*, vol. 8, no. 3, pp. 303–410, 2018.

[5] M. W. Peng, D. Ahlstrom, S. M. Carraher, and W. Shi, "History and the debate over intellectual property," *Management and Organization Review*, vol. 13, no. 1, pp. 15–38, 2017.

[6] J. P. Kesan, "Intellectual property protection and agricultural biotechnology," *American Behavioral Scientist*, vol. 44, no. 3, pp. 464–503, 2000.

[7] M. F. Niculescu, D. J. Wu, and L. Xu, "Strategic intellectual property sharing: competition on an open technology platform under network effects," *Information Systems Research*, vol. 29, no. 2, pp. 498–519, 2018.

[8] C. Huang, "Recent development of the intellectual property rights system in China and challenges Ahead," *Management and Organization Review*, vol. 13, no. 1, pp. 39–48, 2017.

[9] S. Huamin, "Examination of the salient features of stereoscopic trademarks," *China Trademark*, vol. 7, no. 3, pp. 33-34, 2019.

[10] L. Cong, "Research on legal protection of mobile Internet APP logo design," *Design*, vol. 56, no. 4, pp. 96-97, 2018.

[11] Y. Zhushun, "The function and application of subjective intention in judging the possibility of trademark confusion," *Intellectual Property*, vol. 38, no. 5, pp. 37–45, 2019.

[12] B. Knezevic, M. Falat, and I. S. Mestrovic, "Differences between X and Y generation in Attitudes towards online book purchasing," *Journal of Logistics, Informatics and Service Science*, vol. 7, no. 1, pp. 1–16, 2020.

[13] D. Ying and X. Zhaolong, "Analysis of the legislative purpose of trademark law- from the perspective of content design and logical level," *China Trademark*, vol. 26, no. 3, pp. 49–52, 2019.

[14] H. Yulin and C. Limin, "Research on brand change- how to redesign the brand name better," *Design*, vol. 32, no. 3, pp. 136-137, 2019.

[15] K. Shufang and H. Hairui, "Research on cultural and creative product development and intellectual property strategy-taking the application design of inner Mongolia cultural symbols as an example," *Design*, vol. 32, no. 23, pp. 81–83, 2018.

[16] Z. Ming, "The main influencing factors of trademark Approximation- reflections on the trademark dispute between "Jingdong double eleven" and "double eleven"," *China Trademark*, vol. 34, no. 1, pp. 40–42, 2019.

[17] S. Heqin and L. Sisi, "On the indicative fair use of trademarks," *Intellectual Property*, vol. 45, no. 3, pp. 47–59, 2020.

[18] L. Qiang, "Research on artificial intelligence judgment mechanism of trademark similarity-taking the similarity judgment of graphic trademark as an example," *Western Law Review*, vol. 34, no. 1, pp. 57–69, 2020.

[19] H. Cheng, "On the significance of non-traditional trademarks: value stand and Argumentation framework," *Intellectual Property*, vol. 24, no. 1, pp. 39–50, 2020.

[20] R. Mekvabidze, "From business modeling to business management: an exploratory study of the optimal decision making on the modern university level," *Journal of Logistics, Informatics and Service Science*, vol. 7, no. 1, pp. 67–86, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6086191, 17 pages
https://doi.org/10.1155/2022/6086191

Research Article

Corporate Liquidity Management in Emerging Economies under the Financial Constraints: Evidence from China

Fahmida Laghari,[1] **Ye Chengang**,[2] **Ye Chenyun**,[3] **Yiding Liu**,[4] **and Li Xiang**[5]

[1]*School of Accounting, Xijing University, 1 Xijing Road, Chang'an District, Xi'an, 710123, Shaanxi, China*
[2]*Business School, Centre for Business Ethics(CBIE), University of International Business and Economics (UIBE), Beijing, China*
[3]*School of Accounting, University of Shandong Management, Shandong, Jinan, China*
[4]*Business School, University of International Business and Economics (UIBE), Beijing, China*
[5]*Huanggang Normal University, Huanggang, Hubei Province 438000, China*

Correspondence should be addressed to Fahmida Laghari; fahmida.laghari@yahoo.com and Ye Chenyun; ycy7290@163.com

Received 22 March 2022; Accepted 24 May 2022; Published 18 June 2022

Academic Editor: Lele Qin

The main purpose of this article is to investigate the impact of the optimum level of cash holdings on corporate performance. Moreover, in this paper, the impact of financial constraints is tested as moderating factor between the relationship of cash holdings and corporate performance. The present study uses the system generalized method of moments (GMM) as the main estimation methodology. Using a sample of companies listed on stock exchanges of China, empirical pieces of evidence find that cash holdings-corporate performance relation is a nonlinear concave and depicts similar evidence for firms with financial constraints. The financially constrained firms maintain optimal cash holding at a higher level, which corresponds to debt rationing, difficulty to access financial markets, and the high cost of external finance. Moreover, propensity-score-matching depicts statistically significant differences in the level of cash holdings amid financially constrained and unconstrained firms. Finally, the difference-in-difference estimator shows that financial crisis affects less financially constrained firms due to low reliance on external financing.

1. Introduction

One of the imperative corporate financial policies is the management of liquidity [1]. Firms manage liquidity using credit lines or cash holdings [2–4]. According to existing literature, cash is highly significant and the most liquid corporate asset [5]. Emerging markets are characterized by market imperfections which lead to the issue of information asymmetry among market participants. Therefore, in the presence of information asymmetry and agency costs, the outside capital becomes costly relatively to internally generated funds [6]. In this scenario, outside capital may not be the perfect substitute for internal funds. In the absence of market imperfections, firms have no restriction to gain external finance; and firms' investment does not depend on the availability of internal finance.

As in the case of China, financial markets are not efficient in allocating resources and releasing financial constraints that lead financially constrained firms to underinvest [7]. In addition, access to capital markets, external financing cost, and availability of internal finance are the financial factors on which a firm's investment depends. Thus, nonstate-owned enterprises in China face difficulty to raise external capital from banks due to their discrimination. Moreover, non-state-owned enterprises face discrimination to gain funding from the equity market. However, some authors [8] suggest that firms that borrowed from state banks slightly increase employment, short-term debts, and cash holdings. Due to hindering financial constraints, private firms' investment deeds depend profoundly on cash relative to companies owned by the state. Therefore, privately held firms face more financial constraints and distress than state-

owned enterprises. Accordingly, the previous literature [9] suggests that a liquid balance sheet benefits firms to carry out valuable projects when they arise. Accordingly, it is evidenced that firms of China also hold 19.4 percent of their total assets in cash, which suggests cash holdings significantly affect a company's profitability, growth prospects, and business [10].

The present study provides a significant rationale to understand the cash holding behavior of Chinese financially constrained and unconstrained enterprises. A growing body of literature focuses on liquidity management through the antecedents of corporate cash holdings. [11–13] give the evidence for the existence of an optimal level of cash holding and verified that cash decisions track the partial adjustment model. The cash holdings and corporate value relationship are roots to maintain the optimal cash holding level to maximize firm value [14]. Therefore, on the basis of pieces of evidence of prior literature our study highlighted the following objectives:

(i) How does corporate optimal level of cash holding influence firm performance?

(ii) How does the effect of deviation from the optimal level of cash holding influence firm performance?

(iii) How do cash holdings above and below the optimal level influence firm performance?

(iv) What is the influence of financial constraints on the optimal level of cash holding and firm performance relationship?

However, despite the great importance of this topic, a limited number of studies focus on the cost and benefits of cash holding and its impact on firm value. Such as Tong [15] works on the effect of the diversification of a firm on the firm cash holding value by following the methodology of Faulkender and Wang [16] to measure the marginal value of cash holding. Alnori [13] and Martínez-Sola et al. [17] provide evidence that the optimal cash holding level exists, which maximizes firm value. Specifically, in developing and emerging economies, this area of research is not considered at a large scale. The present study focuses on to systematically investigate the critical role of the optimum level of corporate cash holding in maximizing firm value, to examine the role of financial constraints as a contextual factor, and financial fluctuations on the firms' cash holding behavior and the value from the perspective of the economy of China.

Firstly, the main contribution of the present paper is to study the functional form of the relation between cash holdings and firm performance from the perspective of the nonlinear effect. The analysis of the present paper, which literature has not considered previously in the case of China, reveals that there is a nonlinear inverted U-shaped relationship between cash holding and corporate performance. This finding supports precautionary and transaction motives of cash holding at a low level. Conversely, at the high cash holding level, the firm's value declines due to free cash flow and agency costs.

Secondly, to the best of our knowledge, this study is among the few to study the cash holdings and corporate performance relationship with a trade-off model with the linkage of financial constraints as a moderating factor. Especially in the case of Chinese nonfinancial firms, the present study provides novel insights to indicate that in the presence of a firm's financial constraints, the inverted U-shaped relation between cash holding and corporate performance always holds

Third, using the partial adjustment model, the study analyses the firms' speed of adjustment (SOA) to cash targets. The findings indicate that both financially constrained and unconstrained firms actively adjust their cash holdings towards levels of their cash targets. However, the speed of adjustment of financially constrained firms is faster than unconstrained.

Fourth, the findings of propensity score matching (PSM) and difference-in-difference (DID) estimator results show that financially constrained and unconstrained firms have statistically significant differences in their level of cash holdings. Consistently with [18], financially constrained firms are sensitive to macroeconomic shocks, and this effect is considered more pronounced in constrained firms [19].

Finally, the present study extends the prior literature on the firm optimal level of cash holding and its influence on firm value [12, 15, 17], financial constraints, and macroeconomic and financial fluctuations [3, 6]. Following [20], the study uses the system-generalized method of moments (GMM) estimation technique which is robust to capture endogeneity problems in panel data models.

A number of aspects distinguish emerging marketplaces from established markets. Business monetary strategies and rehearses for instance; management of cash are inclined by institutional influences, containing players' approaches and sluggish institutional growth and rules are significantly fragile in emerging economies relatively to advanced economies [21]. The emerging markets severely face these issues. As stated important imperfections of capital market exemplifying it and its underprivileged circumstance of governance of corporates, the circumstantial of the economy of China delivers tranquil experiment epicenter to study business choices of investment in cash holdings with the existence of financial constraints and agency issues together. Due to the unique institutional context, the government has a central effect on the credit assets circulation in the credit market of the economy of China and the maximum number of credit is granted to state-owned companies. This issue leads to a rise in uncertainty stages about business activities for instance; cash holding and the implementation of a traditional monetary path. Moreover, the companies' investment decision is influenced by information asymmetry, control and financial organizations' agency dispute, firms' majority and minority shareholders' sentiments, and firms' shareholders and control agency issues [22]. As cash flow sensitivity of cash correlates with a firm ability to access capital markets [3], the importance of balance sheet liquidity inclines by the degree to which firms have access to external capital markets. If a firm is unconstrained no need to safeguard against future needs, this scenario makes corporate liquidity irrelevant. Conversely, financially constrained firms with difficulty in accessing external capital have always

liquidity management as the central concern for corporate policy. Still, studies on companys' cash holdings and performance have disregarded serious matters related to emerging economies. Firstly, in the case of China research on the role of optimal level of cash holding on firm performance as a nonlinear relationship is scarce. Especially, how above or below the optimal level of cash holdings influence firm performance has not been carried out. Secondly, financial constraints play a significant role in the cash management policies of firms, which to the best of our knowledge has not been used as moderating factor in the optimal level of cash holdings and performance relationship for the economy of China with trade-off theory and levels of target cash holdings. In addition, the role of business cycle fluctuation's influences firm cash holding arrangements and the value of financially constrained and unconstrained firms', which to the best of our knowledge has not been well uncovered in the case of China with propensity score matching and difference in difference estimators. Specifically, in the case of China, the response of business cycle shocks on cash holding behavior of the firms and firm performance has not been well examined. As the business cycle fluctuations significantly influence financially constrained and unconstrained firms' cash holding measures in emerging economies. Therefore, the present study uncovered all these gaps for the economy of China.

2. Review of Related Literature

There are mixed pieces of evidence for the relationship between cash holdings and firm performance in emerging economies. In the developing and emerging economies, cash literature depicts a positive relationship between cash holdings and performance [23, 24]. Besides, cash literature related to the MENA region finds a bidirectional relationship [25] a nonlinear inverted U-shaped relationship linked to trade-off theory [13], and a positive relationship between cash holdings and firm performance with the influence of stronger institutional settings [26].

For instance, Alnori [13] using data of nonfinancial firm from the economy of Saudi Arabia finds an inverted U-shaped relationship between cash holding and corporate performance. They validate the trade-off theory and suggest an optimal level of cash holdings provides a cost and benefits balance. Nguyen et al. examined the nonlinear association amid companies' value and business holdings of cash for nonfinancial firms sample of Vietnam from 2008–2013. Writers focused on equally regression models of dynamic and static in order to check the nonlinear relation. Authors declared the relation of firm cash holdings and the value of the firm as inverted U-shaped even in the presence of financial constraints as moderating factors which corresponds to the theory of trade-off [27].

Cho et al. used a model of partial adjustment for holding cash with data of Korean firms and find that the influence of managerial capability is not noteworthy while holdings of cash are lesser than the level of the target. They further suggest that this may cause the issue of liquidity shortage and firms' financial distress as a result of the lower level of cash [28].

A number of studies have investigated the cash holdings and the policies of the firms. Das et al. investigated that how a country specific environment towards business significantly influences the policies of liquidity and cash management. With the seven Asian emerging economies panel of sample from 2001 to 2019. Their study concludes that the significance of variables specific to countries plays a significant part in the mechanism of cash adjustment. They reveal that the financial development of the country plays a significant role in cash management and adjustment of firm cash dynamics. They also validate that with an excess of cash holdings firms usually have a faster speed of adjustment towards the target level of cash. They find that firms usually adjust cash from investment in the case of cash in excess and in the case of cash deficit firms adjust through financing channels [29].

Apart from other studies Jiang and Lie [30] examined the firms' speed of cash adjustment to the level of target and suggests that managers should manage the target cash level at the optimum best because deviation from optimum can harm the firm performance. They also find that on the mean level, the companies near to 31% of the breach amid target and real cash ratio of cash every year. Jiang et al. investigated the cash holdings and relationship of firm performance with several moderators by taking the sample of Chinese firms. Their findings reveal that firm specific characteristics highly influence the cash holdings and firm performance relationship if the firm has a strong governance mechanism. Conclusively, they declare that specific firm attributes are significant to impact the cash holdings and corporate performance relationship [31]. Diaw investigated the cash holdings and corporate relationship with panel data for the firms of emerging economies. Their study reveals that in emerging economies firms with higher liquidity have a bigger size and capital expenditure at low levels. Moreover, the study finds that firm growth opportunities show an inverse relationship, which leads the firm to moral hazard issue. He used the dynamic methodology of system generalized method of moments and declare a slow speed of adjustment towards the target cash level [32].

Batuman and Karan examined the influence of the global financial crisis on the elements of business cash holdings and alterations concerning the level of the target with data of firm from Eastern Europe. They used the two estimation methodologies of GMM and fixed effect estimators to analyze the findings. They find that determinants of cash holdings at the firm level have significant differences in the level of cash holdings pre and postperiod of crisis. They also find that the speed of adjustment postcrisis period is at a slower rate. This study is significantly robust to the issue of endogeneity and reveals that Eastern European firms have a profound effect of the global financial crisis due to a shortage of liquidity and the limited access to funds [33]. A study by Tran [34] examined the cash holdings and the shareholders' protection relationship using an international sample of firms from 40 countries during the global financial crisis. They reveal that the influence of shareholder security on

holdings of cash balances is considerably alleviated by the overall economic crunch. Yildiz finds that after the financial crisis the adjustment speed towards the target level of the capital structure showed the slow movement. Moreover, they declare that the financial crisis is an important aspect not only to explain the clues that hit the decisions regarding firm capital structure but also had a profound impact on the adjustment behavior of firms towards the level of the target [35].

Tsai et al. find that a CEO with a high level of managerial skills and experience can help to lessen the financial constraints of firms and enhance the value of holdings of cash. The study provides a significant rationale to understand the powerful influence of managers' ability in cash management of constrained firms. This study uses the robust method of instrumental variable regression [36]. Jiang and Wu declare that two significant aspects of precautionary motive for cash holdings for funding are: investment and recovery from potential losses of operating activities. They mainly investigated the behavior of the firm in case it deviates from the target level of cash. Moreover, they confirm that firms' speed of adjustment is faster when the firm cash holding level is above the target level. They propose that the dynamics of cash management are highly influenced by cash holding motivations [37].

Existing literature has provided enough rationale to understand the cash holdings and the firm performance relationship. However, the literature from the nonlinear perspective is scant. Therefore, in the present study, our main motivation is to evaluate cash holdings and firm performance from the nonlinear perspective and to know how the chief explanatory variable cash holding at different levels of optimum influences firm performance. Moreover to know how financial constraints as moderator influence cash holdings and firm performance relationship. We follow the well-established literature to measure firm performance with Tobin's-q and return on assets. As we know, ROA illustrates the effective and efficient use of firm assets, which is a measure of earnings before interest and taxes (EBIT) divided by total assets [24]. However, Tobin's-q indicates the true picture of firm value, which is a measure of equity value plus book value of long-term debt plus net current liabilities divided by the value of total assets [2]. Therefore, keeping all aspects of the literature in mind further discussion is carried out in the study.

3. Theoretical Framework and Hypotheses Development

3.1. Influence of Cash Holding on Firm Performance. There are several theories regarding the influence of firms' investment decisions on cash holding. The stakeholder theory encourages firms to hold more cash to build a sound relationship with firms' stakeholders [38]. The pecking order theory concludes that there is no optimum level of cash. Firms use cash as a buffer amid retained earnings and investment necessities. The free cash flow theory endorses holding a large amount of cash by managers to enhance the control on firms' substantial assets and gain more discretionary hold for investment doings [22], and such corporate policy may result in over-investment. Many research studies on cash holding followed trade-off, pecking order, and free cash flow theories to work on the determinants of cash holding and target cash holding towards adjusting at the optimum. However, there is no clear picture of cash holding level and its impact on firm performance. Therefore, the present study uses a conception of a target cash level derived from the theoretically justified and empirically seasoned seminal work of Kim et al. [12]. Agency cost literature raised two opposing views for holding the liquid balances. As to get away from raising external capital, firms ideally carry cash balances in large amounts since plenty of cash balances put forward no agency cost but give a financial benefit. Conversely, Jensen [39] concludes that large cash balances contain agency costs and provide no advantage of financial flexibility due to this, firms optimally carry liquid balances at the lower levels. Firms' cash holdings involve both agency costs and also confer financial flexibility benefits.

Empirical evidence suggests that the marginal value of cash diminishes with large cash holding [16]. The precautionary motive suggests that firms overcome or hedge cash shortage risk in the future by holding cash. The transaction cost motive illustrates that there is a cost associated with buying and selling of real and financial assets, therefore to carry out the regular day-to-day operation, firms need cash. This discussion of the literature suggests that there is a trade-off between the costs and benefits of holding liquid assets [12]. The present study follows the trade-off theory and assumes that there is a nonlinear inverted U-shaped relationship between cash holding and firm performance. This relationship is shown in Figure 1. Therefore, hypothesis 1 is submitted as follows.

H1: There is a nonlinear concave relationship between cash holdings and corporate performance.

3.2. Influence of Financial Constraints on Cash Holding and Firm Performance Relationship. There is a lot of discussion in existing literature regarding a firm faces financial constraints [40]. To mitigate the risk of distress, financially constrained firms to hold large amounts of cash balances. Financially constrained firms that are unlisted face more financial constraints than listed firms, find it hard to access capital markets, and have a high level of short-term debt.The asymmetric information among firms and external investors drives the high cost of raising external finance [15]. The substitution effect and low investment stimulate high agency issues. External finance becomes costly due to high transaction costs and additional financial constraints. Therefore, in the presence of market imperfections, the manager of firms lowers the cost of external finance and finds it expedient to bring about adequate availability of internal funds. Modigliani and Miller [7] show that in the perfect capital markets, firms can get external financing without any hindrance, and firms do not need to hoard internal finance for investment in this scenario. On the other hand, in the

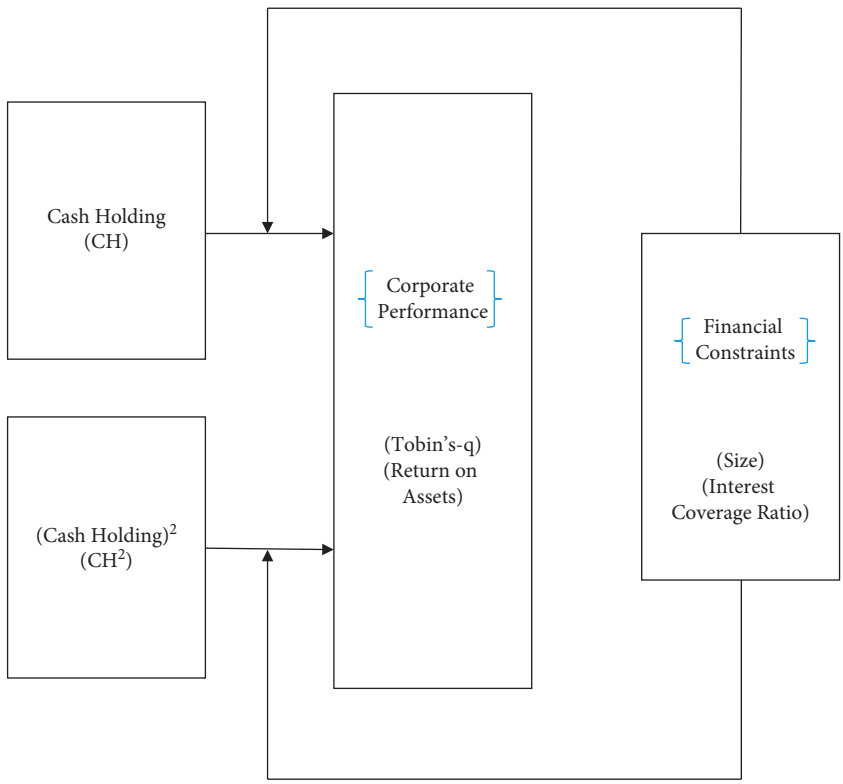


Figure 1: Impact of optimal level of cash holdings on corporate performance with the influence of financial constraints as moderating factor.

presence of capital market imperfection, external finance becomes costly relative to funds generated internally [6, 7]. And firms' investment highly depends on financial factors, for instance, capital market access, availability of internal finance, and financing cost. The main advantage of cash holding is to prevent the cost of external finance, and a decline in the external financing cost drives firms to enhance their value. According to Keynes [10], firms hold cash balances to hedge the risk of cash shortage in the future for precautionary purposes. Firms restricted to access capital markets hoard large cash balances to deal with liquidity shortages. Moreover, firms hold large cash balances and liquid assets that expose to high cash flow volatility on average to the industry [2]. And find it hard to access capital markets and have a high level of short-term debt. As holding large cash balances save firms to underperforming relatively to their counterparts with fewer cash holdings. The large cash holding is not just limited to big firms, but small-size firms and risky firms also hold more liquid reserves in their financial statements over time. Accordingly, Bates, Kahle, and Stulz [4] declared that the big companies also have piles of cash, and this record level of cash holding has increased over time. Hence, the above discussion suggests that in the presence of financial constraints relationship between cash holding and corporate performance is likely to be nonlinear concave. This relationship is shown in Figure 1. Therefore, hypothesis 2 is suggested as follows.

H2: In the presence of financial constraints there is a nonlinear concave relationship between cash holdings and corporate performance.

4. Research Design

4.1. Sources of Data and Selection of Sample. The China Stock Market and Accounting Research (CSMAR) database is the prime source of the database of A-share nonfinancial firms of China listed on the Shanghai Stock Exchange (SHSE) and the Shenzhen Stock Exchange (SZSE) over the period 2005 to 2019. This sample window well covers the financial crisis of 2007–2008 for our analysis of business cycle fluctuation's effect on firms' optimal cash holdings. The original sample of the present study covers data range from 2005 to 2019, but for the difference-in-difference approach, the reduced data sample covering the period 2005 to 2010, with 2008–2010 being considered the crisis period. Since, this time window is compatible scrutinizes the effect of liquidity shocks. Moreover, the paper further screened the data samples according to the following criterion: (1) due to industry characteristics and distinction in accounting standards, the present study excluded listed firms in financial industries, (2) the study also omits firms with missing observations for the variables and incorrect data, (3) excluded firms' data with zero equity values and traded period less than five years because five years data is an essential condition of the

number of observations of periods to test for second-order serial correlation, and (4) following Faulkender and Wang [16], the study winsorized data up to one percent tail to safeguard from the potential influence of outliers.

4.2. Model Specifications. The study proposes that the relationship between cash holdings and corporate performance may be nonlinear and the following equation is estimated:

$$\begin{aligned} cp_{i,t} &= \beta 0 + \beta 1 cpi_{,t-1} + \beta 2 ch_{i,t} + \beta 3 ch^2_{i,t} + \beta 4 sz_{i,t} \\ &+ \beta 5 gr_{i,t} + \beta 6 levi_{i,t} t \\ &+ \beta 7 cf_{i,t} + \beta 8 fa_{i,t} + \lambda t + \eta i + \varepsilon_{i,t}. \end{aligned} \tag{1}$$

Next, by following the support of existing literature on antecedents of cash holdings, [2, 3, 12, 17], computed the residuals according to the following equation:

$$\begin{aligned} ch_{i,t} &= \beta 0 + \beta 1 chi_{,t-1} + \beta 2 sz_{i,t} + \beta 3 gr_{i,t} \\ &+ \beta 4 levi_{i,t} + \beta 5 cf_{i,t} + \beta 6 liq_{i,t} \\ &+ \lambda t + \eta i + \varepsilon_{i,t}. \end{aligned} \tag{2}$$

Here, the dependent variable is cash holding (chi,t), and (liqi,t) represents the liquid assets of the firm [17] (note: see details of empirical findings on (2) in Table 12.

Following existing literature on the optimum level of cash holding such as [12], we further investigate the effect of deviation from the optimum level of cash holdings on the firm in the following equation:

$$\begin{aligned} cp_{i,t} &= \beta 0 + \beta 1 cpi_{,t-1} + \beta 2\ de\ v_{i,t} + \beta 3 sz_{i,t} \\ &+ \beta 4 gr_{i,t} + \beta 5 lev_{i,t} + \beta 6 cf_{i,t} \\ &+ \beta 7 fa_{i,t} + \lambda t + \eta i + \varepsilon_{i,t}. \end{aligned} \tag{3}$$

Next, we investigate how deviation from above and below optimum levels of cash holding impacts corporate performance. We calculate a dummy variable named (Above Optimal Dummy) considering positive values of residual obtained from the benchmark specifications for antecedents of cash holdings from the estimation (2) as 1, and 0 otherwise. The following equation is computed:

$$\begin{aligned} cp_{i,t} &= \beta 0 + \beta 1 cpi_{,t-1} + \beta 2\ de\ v_{i,t} + \beta 3\ de\ v * Int_{i,t} \\ &+ \beta 3 sz_{i,t} + \beta 4 gr_{i,t} + \beta 5 lev_{i,t} \\ &+ \beta 6 cf_{i,t} + \beta 7 fa_{i,t} + \lambda t + \eta i + \varepsilon_{i,t}. \end{aligned} \tag{4}$$

Next, following well-established literature for proxy of financial constraints we use two measures: size (sz) [2, 12] and interest coverage ratio (Icr). The proposed equation is

$$\begin{aligned} cp_{i,t} &= \beta 0 + \beta 1 cpi_{,t-1} + \left(\beta 2 + \delta 1 fc_{i,t}\right) ch_{i,t} \\ &+ \left(\beta 3 + \delta 2 fc_{i,t}\right) ch^2 i, t + + \beta 3 sz_{i,t} + \beta 4 gr_{i,t} + \beta 5 lev_{i,t} \\ &+ \beta 6 cf_{i,t} + \beta 7 fa_{i,t} + \lambda t + \eta i + \varepsilon_{i,t}. \end{aligned} \tag{5}$$

In Equations (1), (3), (4), and (5), dependent variable corporate performance ($cp_{i,t}$) represents two measures the Tobin's-q (q) and returns on assets (roa). Following Opler et al. [2] study uses cash holding ($ch_{i,t}$) as the independent variable. The size ($sz_{i,t}$), growth opportunities ($gr_{i,t}$), firm leverage ($lev_{i,t}$), firms' cash flow ($cf_{i,t}$) [13], and fixed assets ratio ($fa_{i,t}$) represent control variables (note: see Table 11 for the detailed definitions of variables).

Next, the study investigates the speed of with a partial adjustment model as follows:

$$\begin{aligned} \Delta ch &= \alpha + \beta 1 fc\_\text{firms} * (ch \cdot -\text{lagged}\, ch) \\ &+ \beta 2 (ch \cdot -\text{lagged}\, ch) \\ &+ \beta 3 fc\_\text{firms} + \varepsilon. \end{aligned} \tag{6}$$

Here, (Δch) is the dependent variable, and the dummy variable (fc_firms) denotes the financially constrained firms. The variable (ch●) illustrates the predicted values of cash holding, and the term (ε) represents the error term.

5. Results and Empirical Analysis

5.1. Summary Statistics and Correlation Analysis. Table 1 presents the descriptive statistics of the main variables. The average value for the variable Tobin's-q (q) is 1.94 for Chinese nonfinancial firms, on average, have 15.86 cash holdings (ch). The variable size (sz) shows an average of 21.78. The mean value of the growth (gr) is 4.86 and the mean value of the variable leverage (lev) is 53.19. The average cash flow (cf) is 9.69 and the average ratio of fixed assets (fa) of Chinese nonfinancial firms is 1.21. The mean value of variable liquidity (liq) is 18.02 percent.

Table 2 signifies the correlation matrix and variance inflation factor (VIF) results for variables of the study. Moreover, correlation coefficients between all the variables are below the threshold level of 0.80, thereby indicating multicollinearity may not be the case. However, multicollinearity cannot be ignored and may still exist to some degree, although all the variables show low correlation coefficient results. The VIF test also shows no sign of multicollinearity, and the largest (VIF) value is 1.14 in the sample. These results imply that multicollinearity does not exist because the highest value of (VIF) is far from the threshold value of 5.

5.2. Regression Results and Analysis. In Table 3, the study investigates the impact of the optimal level of cash holdings on corporate performance by using model (1), which estimates the functional form. In Table 3, columns 1 and 2 present results for the dependent variables Tobin's-q (q) and return on assets (ROA), respectively. In Model (1) of Table 3, the study finds that the coefficients ($\beta 2 > 0$) of cash holding (ch) at the low level are positive and statistically significant at 1% in columns 1 and 2, and the coefficients ($\beta 3 < 0$) of cash holding ($ch2$) at a high level are negative and statistically significant at 10% and 1% in columns 1 and 2, respectively. The coefficients of the cash holding also determine the target or inflection point for cash holding and corporate performance relationship, this optimum comes from the coefficients of ch and $ch2$ ($-\beta 2/2\beta 3$).

Table 1: Summary statistics of variables.

Variables	Mean	St. dev.	Percentile 25	Median	Percentile 75
q	1.94	2.03	0.72	1.31	2.35
ch	15.86	11.79	7.54	12.86	21.03
sz	21.78	1.30	20.88	21.69	22.58
gr	4.86	6.33	1.02	2.98	5.99
lev	53.19	25.52	36.79	52.13	66.72
roa	2.47	3.52	0.06	1.80	5.13
cf	9.69	16.71	5.72	10.00	15.35
fa	1.21	2.27	0.20	0.33	0.57
liq	18.02	17.74	5.00	15.00	27.00

Notes: this table shows the results of the summary statistics.

Table 2: Correlation matrix and variance inflation factor (VIF) of variables.

	Q	*Ch*	*sz*	*gr*	*lev*	*roa*	*cf*	*fa*
q	1.000							
ch	0.2171***	1.000						
sz	−0.4554***	-0.0999***	1.000					
gr	0.0758***	−0.1311***	−0.0900***	1.000				
lev	−0.1525***	−0.2699***	0.0999***	0.0193**	1.000			
roa	−0.1030***	0.0319***	0.0960***	−0.0319***	−0.0654***	1.000		
cf	0.0945***	0.1187***	0.0791***	−0.0155***	−0.0824***	0.1741***	1.000	
fa	0.0335***	0.0938***	0.0533***	−0.0934***	0.0591***	0.0123	−0.0178**	1.000
VIF		1.14	1.06	1.04	1.11	1.05	1.06	1.03

Notes: subscripts ** and *** indicate the level of significance at the5% and 1%, respectively.

Table 3: Regression results for functional form estimation for cash holding and corporate performance.

	Dependent variable Tobin's-q (1)	Dependent variable (ROA) (2)
ch	0.0213*** (2.89)	0.1875*** (2.59)
ch^2	−0.0003* (−1.93)	−0.0034*** (−2.73)
sz	−0.6397* (−1.77)	1.1528*** (2.58)
gr	−0.2693*** (−3.82)	0.1036 (1.01)
lev	0.0427*** (2.67)	−0.0358* (−1.75)
cf	0.011 (1.41)	0.0400*** (3.14)
fa	0.0935 (1.34)	−0.1150 (−0.63)
IFE and TFE	Yes	Yes
p-value of m_2	0.373	0.561
*F*1	8.35	6.73
*F*2	3.73	7.46
Hansen test (df)	260.99 (134)	107.82 (100)
Wald Test (*p*-value)	55.18 (0.000)	8.72 (0.000)
Diff. in Hansen Test-*p*-value	0.948	0.458
Obs.	13993	14357

Notes: the *t*-statistics are in the brackets. *, **, and *** indicate the level of significance at the10%, 5%, and 1%, respectively.

In sum, the empirical analysis confirms that the value of the firms is influenced by two distinctive means because of their cash holdings. At the low level of cash holdings, the precautionary and transaction motivations take over, and firm value increases as firms' cash holding increases. Conversely, at a high level lead to opportunity cost and free cash flow issues. This finding is consistent with the research of Alnori [13]. Moreover, based on the cut-off formula for optimal level of cash holdings ($-\beta 2/2\beta 3$) on nonlinear inverted *U*-shape for *ch* and ch^2, the cut-point on the curve swift for the relationships of cash holdings and Tobin's-*Q* is (35.50) and for the relationship of cash holdings and ROA is (27.57).

In Table 4, columns 1 and 2 present results for the deviation (dev) and Tobin's-q relationship, and the relationship of deviation (dev) and return on assets (ROA), respectively. The coefficients of deviation (dev) are negative and significant at the 5% level and 1% level, respectively. In Table 4, columns 3 and 4 present the results for the relationship of deviation from above and below the optimal level of cash holding and corporate performance. In Table 4, columns 3 and 4 show results for dependent variables Tobin's-q (*q*) and return on assets (ROA), respectively. The results show negative and significant coefficients of deviation (dev) at the 5% level in columns 3 and 4, respectively. The results show positive and significant coefficients for

Table 4: Regression results for the effect of deviation, and deviation from above and below the optimal level of cash holding on firm performance.

	Effect of deviation from optimum level		Effect of deviation from above and below the optimum level	
	(1)	(2)	(3)	(4)
dev	−0.0399**(−2.23)	−0.1785***(−3.60)	−1.6324**(−2.49)	−0.4806**(−2.84)
*dev*Int*			1.6007**(2.50)	0.2648*(1.77)
lev	0.0211*(1.80)	−0.0698**(−2.65)	0.0553*(1.74)	−0.1064***(−4.01)
sz	−0.7439***(−4.45)	−0.2637*(−1.67)	−1.1478***(−3.39)	−0.3184*(−1.89)
gr	−0.2456***(−3.89)	−0.2434**(−2.28)	−0.6663***(−3.45)	−0.2212**(−2.17)
cf	0.0069*(1.78)	0.0038(0.19)	0.0050(1.05)	−0.0203(−1.22)
fa	−0.1881***(−3.79)	0.03219(0.17)	−0.2980***(−3.01)	0.0588 (0.34)
IFE and TFE	Yes	Yes	Yes	Yes
p-value of m_2	0.632	0.687	0.094	0.236
F1 (p-value)			3.12 (0.0446)	8.28 (0.0003)
Hansen test (df)	86.32 (78)	71.33(71)	31.42 (25)	62.42 (58)
Hansen test-*p*-value	0.243	0.467	0.175	0.322
Wald Test (*p*-value)	34.65 (0.000)	77.37(0.000)	35.48 (0.000)	2.37 (0.000)
Diff. in Hansen Test *p*-value	0.498	0.997	0.542	0.596
Obs.	8190	8386	13992	9904

Notes: the t-statistics are in the brackets. *, **, and *** indicate the level of significance at the10%, 5%, and 1%, respectively.

interaction (dev*Int) at 5% and 10% levels in columns 3 and 4, respectively.

Collectively, these findings of results indicate a negative relationship between deviation (dev) and corporate performance. Moreover, interaction (dev*Int) shows a positive association with firm performance. The findings of the results are per expectations as positive and negative residuals offset each other. In columns (3) and (4) F1 test shows the addition of two coefficients for $\beta 1$ and $\beta 2$ as $(\beta 1 + \beta 2)$, and the addition of these two coefficients should be negative and statistically significant [15, 17]. The F1 test indicates that the sum of these two coefficients is statistically significant at the 5% and the 1% level as can be seen in columns 3 and 4, respectively. In Table 4, the analysis shows that the firm value declines due to a deviation on either side of the firms' optimum level of holding cash balances. These results are consistent with those of Alnori [13].

Table 5 reports the results for the relationship of an optimum level of cash holdings and corporate performance with the linkage of financial constraints. In column (1) results for the relationship of cash holdings and Tobin's-q (q) show a positive and significant coefficient at a 10% level of significance for the low level of cash holdings (ch^*sz), and a negative and significant coefficient for a high level of cash holding ($ch2^*sz$) at the 5% level of significance. In column (2) results for the relationship of cash holdings and return on assets (ROA) show significant negative coefficient values at the low level of cash holding (ch^*sz) with a 1% level of significance, and a significant positive coefficient at the high level of cash holding ($ch2^*sz$) with a 5% level of significance.

In Table 5, column 3 the results for the relationship of cash holding and Tobin's-q (q) for financially constrained firms with high bankruptcy risk show a significant and positive coefficient at the low level of (ch^*Icr) with a 5% level of significance and significant negative coefficient at the high level of ($ch2^*Icr$) with a 10% level of significance. In Table 5, column 4 the results for the relationship of cash holding and return on assets (ROA) for financially constrained firms with high bankruptcy risk show a significant negative coefficient at the low level of (ch^*Icr) with a 5% significance level and a significant positive coefficient at the high level of ($ch2^*Icr$) with a 5% significance level. Collectively, these findings of results suggest a nonlinear concave relationship between cash holdings and Tobin's-q (q) for financially constrained firms based on size and interest coverage ratio groups. On the contrary, the results indicate the U-shaped relationship between cash holding (ch) and return on assets (ROA) for financially constrained firms based on size and interest coverage ratio groups. These empirical findings are consistent with the existing literature and show that small-size firms and firms with high business risk hold high cash balances [2, 3, 12]. Therefore, In 2019, the additional significance of trades above the nominated size enlarged by means of 6.7 percent in comparison to 2018 [41].

The previous section's results show that financially constrained firms are more reliant on internal funds, and these firms hold a large number of cash holdings than firms with ease of access to financial markets to raise funds when they need it [16]. Table 6, Panel A, presents results for the size (sz) group, and Panel B presents results for the interest coverage ratio (Icr) group. Empirical evidence finds that there is a significant difference between the mean values of financially constrained and unconstrained firms in their cash holding levels. In Table 6, Panel (A) results show that firms constrained on size (sz) have significantly higher mean values of the level of cash holdings (ch) than unconstrained firms.

5.3. Additional Analysis. Following the methodological scheme of Gao, Harford, and Li [42] with a partial adjustment model (6) study provides estimates of the model with empirical findings. In Table 7, columns 1 and 4 present results for a full sample of firms. In column 1, results show

Table 5: Regression results for the effect of financial constraint on cash holding and corporate performance relationship.

	Size (sz) group		(Icr) group	
	(1)	(2)	(3)	(4)
ch	0.0163**(2.15)	0.2782***(3.94)	0.0257***(3.19)	0.3146***(3.44)
ch^2	−0.0002*(−1.65)	−0.0049***(−3.12)	−0.0004**(−2.43)	−0.0070***(−3.58)
*ch*sz*	0.0452*(1.86)	−0.2753***(−3.34)		
ch^2*sz	−0.0009**(−2.10)	0.0049**(2.55)		
*ch*Icr*			0.0503**(2.16)	−0.1851**(−2.05)
ch^2*Icr			−0.0008*(−1.83)	0.0054**(2.39)
sz	−1.5795***(−4.02)	−0.3235(−0.92)	−0.7230*(−1.82)	1.0716**(2.42)
gr	−0.2577***(−3.66)	0.0845(1.12)	−0.2663***(3.70)	0.0769(0.70)
lev	0.0337***(3.14)	−0.0545***(−3.82)	0.0514***(3.27)	−0.0375**(−1.97)
cf	−0.0033 (−0.27)	0.0317***(5.61)	0.0110 (1.26)	0.0345**(2.60)
fa	−0.0552 (−0.94)	0.0622(0.48)	0.0289 (0.36)	−0.1317 (0.70)
IFE and TFE	Yes	Yes	Yes	Yes
p−value of m_2	0.301	0.381	0.245	0.596
*F*1	4.61	15.51	10.15	11.84
*F*2	2.74	9.71	5.89	12.80
Hansen test (df)	254.87 (132)	218.34 (220)	245.73(132)	92.87 (98)
Wald Test (*p*-value)	54.38 (0.000)	10.56 (0.000)	48.47(0.000)	6.10 (0.000)
Diff. in Hansen Test -*p*-value	0.817	0.789	0.927	0.572
Obs.	13993	14360	13993	14357

Notes: the *t*-statistics are in the brackets. *, **, and *** indicate the level of significance at the10%, 5%, and 1%, respectively.

Table 6: Group comparison based on financial constraints.

Panel (A): group comparison based on financial constraints of (size) group				
	Financially unconstrained firm (1)	Financially constrained firm (2)	Difference (3)	*t*-statistics (4)
q	1.2892	2.6197	−1.3305***	−43.22
ch	14.9494	16.7775	−1.8280***	−9.95
sz	22.7908	20.7565	2.0343***	161.51
gr	4.4477	5.2851	−0.8374***	−8.48
lev	56.4031	49.9603	6.4428***	16.27
ROA	2.7665	2.17644	0.5901***	10.77
cf	10.9361	8.42544	2.5106***	9.61
fa	1.3340	1.0919	0.2421***	6.83
Panel (B): group comparison based on financial constraints of interest coverage ratio (ICR) of firms				
Variables	Financially unconstrained firm (1)	Financially constrained firm (2)	Difference (3)	*t*-statistics (4)
q	1.8479	2.0409	−0.1930***	−5.98
ch	15.1589	16.5612	−1.4022***	−7.62
sz	21.8440	21.7115	0.1325***	6.54
gr	5.1319	4.5974	0.5345***	5.40
lev	50.4569	55.9345	−5.4775***	−13.80
ROAa	2.8100	2.1350	0.6749***	12.33
Cf	11.7146	7.6556	4.0589***	15.64
Fa	0.9946	1.4368	−0.4422***	−12.46

Notes: *** indicates the level of significance at the 1%.

significant and positive coefficients for (ch●-lagged ch) at the 1% level of significance, and the coefficient on fc_firms*(ch●-lagged ch) is significant and positive at the 1% level of significance. In column 4, results show significant and positive coefficients for (ch●-lagged ch) at the 1% level of significance, and the coefficient on fc_firms*(ch●-lagged ch) is significant and positive at the 5% level of significance. These findings depict that both classes of firms are dynamically adjusting their cash holdings towards target levels, and financially constrained firms' speed of adjustment is faster than unconstrained firms. Since firms with cash shortages rebalance their cash holdings slower than cash surplus firms. Existing literature also suggests that small-size firms are more financially constrained and face difficulty in accessing capital markets than large firms [3]. The results for financially constrained small-size firms show a faster speed

Table 7: Regression results for the speed of adjustment to the target cash holding level.

	Financially constrained firms (*fc_firms*) based on size			Financially constrained firms (*fc_firms*) based on interest coverage ratio (ICR)		
	Full sample (1)	(*ch*●-*lagged ch*) < P25 (2)	(*ch*●-*lagged ch*) >P75 (3)	Full sample (4)	(*ch*●-*lagged ch*) < P25 (5)	(*ch*●-*lagged ch*) >P75 (6)
fc_firms(ch*●-*lagged ch)*	0.1211*** [0.0246]	0.3324*** [0.0947]	2.76515*** [0.4749]	0.0563** [0.0273]	−0.6374*** [0.1063]	0.4058*** [0.1236]
ch●-*lagged ch*	0.11645*** [0.0083]	0.2209*** [0.0239]	2.7246*** [0.3404]	0.1153*** [0.0176]	0.6958*** [0.1016]	4.3808*** [0.5704]
fc_firms	86.6454*** [13.3105]	278.4421*** [70.9736]	292.7663*** [40.1739]	48.1824*** [13.7483]	−368.6265*** [65.7636]	41.9335*** [21.7204]
Constant	45.8904*** [3.3406]	150.7038*** [15.1939]	222.9311*** [22.8151]	56.4788*** [7.2909]	443.3974*** [65.9452]	384.1316*** [42.2947]
R-Squared	0.0208	0.0590	0.0572	0.0108	0.0752	0.0410
F-Stats (prob > *F*)	100.33 (0.0000)	40.69 (0.0000)	29.17 (0.0000)	36.77 (0.0000)	20.68 (0.0000)	22.74 (0.0000)
Obs.	14811	3109	3702	13282	3109	3702

Notes: quartiles bottom (P25) and top (P75). Robust (vec) standard errors stated in parentheses. *, **, and *** represent the level of significance at 10%, 5%, and 1%, respectively.

of adjustment to target cash level than unconstrained firms. In columns 2, 3, 5, and 6, for a subsample of financially constrained and unconstrained firms with their real cash holding level dropping above or below their level of cash targets, equation (6) is separately estimated. To diminish the fear of not knowing the accurate model for the target cash, by the measure of (ch●-lagged ch), the study states two subsamples as "excess cash" and "cash shortfall" by two quartiles bottom (P25) and top (P75) of the population of the study. These results show that financially constrained firms adjust their cash holdings towards their target cash levels much faster than financially unconstrained firms when holding less cash than the target levels.

To examine the differences in the cash holding levels between financially constrained and unconstrained firms, the study employs the propensity score matching (PSM) technique. The technique of PSM is useful to control the selection bias grounded on the observable firm characteristics. In the analysis, the study applies the nearest neighbor matching technique following Heckman et al. [43].

Table 8, Panel A shows the results for the propensity score matching estimation. The results in columns 1 through 4 show that financially constrained and unconstrained firms have statistically significant differences in their level of cash holdings. As the coefficient of cash holdings (*ch*) obtained from the probit regression is positive and statistically significant in all estimations of columns 1 through 4, suggesting that firms with high cash holdings are more likely to be financially constrained. The findings of results for average treatment effect on treated (ATT) obtained from nearest neighbor matching in columns 1 through 4 show statistically significant and positive values.

Next, the study employed a difference-in-difference (DID) estimator as the uncontrolled firm-level heterogeneity may influence and confound inferences. Therefore, to verify the robustness, the present study addresses the potential problem of firm-level heterogeneity with a matching estimator. The sample consists of financially constrained and unconstrained firms; therefore, to keep the study sample in mind, the study employed financially constrained firms as "treated" and the matched unconstrained firms as control firms.

Table 8, panel B shows the results for the difference-in-difference (DID) estimation analysis. The original sample of the present study covers data range from 2005 to 2019, however, for the difference-in-difference approach, the study reduced the data sample covering the period 2005 to 2010, with 2008–2010 being considered the crisis period, as this time window is compatible to scrutinize the effect of liquidity shocks. The results for the interaction (*ch*Dct*) show significant and positive coefficients in columns 1 through 4. These results suggest that for unconstrained firms' the value of cash holdings increases in a financial crisis. These findings of results are consistent with that of Chang et al. [18]. Moreover, the coefficients of (*ch*fc*) are significant and positive in columns 1 through 4, indicating that cash holdings are of higher value to financially constrained firms. These findings of results are consistent with the existing literature [18]. The findings of triple-interaction (i.e., *ch*Dct*fc*), the coefficients are statistically significant and negative in columns 1 through 4. These results of triple-interaction submit that for financially constrained firms, the impact of cash holdings on firm value turns into less positive at the time of financial crisis and reduces demand for investment during the financial crisis.

6. Robustness Analysis

In addition, to check the robustness of results, the present study applied an alternate fixed effect estimator and sensitivity analysis on the baseline model (1) for functional form estimation and on the model (5) to investigate the influence of financial constraints as a moderating factor. Table 9 demonstrates the results of the fixed effect estimator. In Table 9, Panel (A) reports results for the functional form

Table 8: Propensity score matching (PSM) and difference-in-difference (DID) estimation results.

Panel (A): propensity score matching (PSM) analysis				
	Financial constraints criteria = size (sz)		Financial constraints criteria = interest coverage ratio (ICR)	
	(1)	(2)	(3)	(4)
ch	0.0061*** [6.83]	0.0054*** [5.69]	0.0044*** [5.08]	0.0088*** [9.50]
ATT(NN)	1.208*** (25.52)	1.182*** (25.20)	0.095** (2.08)	0.199*** (3.84)
Panel (B): difference-in-difference (DID) estimation analysis (reduced sample 2005–2010)				
	Financial constraints criteria = SIZE (sz)		Financial constraints criteria = interest coverage ratio (ICR)	
	(1)	(2)	(3)	(4)
ch	0.0163*** (8.42)	0.0132*** (6.73)	0.0125*** (6.51)	0.0094*** (4.88)
*ch*Dct*	0.0120*** (6.71)	0.0112*** (6.35)	0.0173*** (3.96)	0.0193*** (4.47)
*ch*fc*	0.0265*** (10.60)	0.0267*** (10.76)	0.0306*** (11.10)	0.0239*** (8.69)
*ch*Dct*fc*	−0.01460*** (−3.96)	−0.0146*** (−4.01)	−0.0163*** (−2.77)	−0.0187*** (−3.23)
*Dct*fc*	0.2711*** (3.10)	0.2886*** (3.32)	0.2014* (1.67)	−0.2622** (−2.20)
Fc	1.0568*** (22.67)	1.0208*** (22.03)	−0.3433*** (−5.90)	−0.1336** (−2.27)
Dct	−0.1446*** (−2.84)	−0.1486*** (−2.94)	−0.0744 (−0.87)	−0.1119 (−1.33)
Controls	No	Yes	No	Yes
Constant	0.9809*** (27.02)	1.0189*** (17.46)	1.6767*** (41.79)	1.9567*** (32.40)
Adj. *R*-squared	0.1689	0.1854	0.0408	0.0669
Obs.	14,374	14,359	14,374	14,359

Notes: the *t*-statistics are in the brackets. *, **, and *** indicate the level of significance at the10%, at 5%, and 1%, respectively.

estimation results, and Panel (B) reports results for the financial constraints estimation. The study finds similar results to those presented in Tables 3 and 5. In Table 9, Panel (B) columns 3 and 5, the findings of results indicate that in the presence of financial constraints, at a low level of cash holdings, the relationship between cash holdings and firm performance is positive and significant. Moreover, at a high level of cash holdings, the relationship between cash holdings and corporate performance is negative and significant. Conclusively, the findings of fixed effect estimator results also confirm the robustness of the core estimation results of Tables 3 and 5. In Table 10, we further employ sensitivity analysis specifications and applied an alternate pooled ordinary least square (OLS) estimator on the baseline models (1) and (5) with lagged variables to check the influence of the previous period on firm performance. We find similar results to our previously reported findings for alternative fixed effect estimator in Table 9 for robustness checks and empirical findings of Tables 3 and 5.

7. Discussions of Findings

The main objective of the present research is to investigate the relation between cash holdings and corporate performance with the linkage of financial constraints as a moderating factor. In the study, hypothesis 1 suggests that there is a nonlinear concave relationship between cash holdings and corporate performance. Theoretically, first, the empirical evidence of the findings supports the precautionary and transaction motives [10], where managers would prefer to increase the cash holding at lower levels of cash holdings to overcome or hedge against cash shortage risk in the future. To avail future investment projects, to carry out a routine operation of the firm, and to buy and sell financial and fixed assets at a lower level of cash holdings. However, there is a level of cash holding at which a higher cash holding begins to be negative in terms of value creation due to the free cash flow [39], that involves agency cost of managerial discretion [6], and opportunity cost. Therefore, at a high level of cash holdings, an increase in cash holding decreases firm performance. Theoretically, secondly, our study justifies the trade-off theory, which suggests that a firm's holding of cash balances at an optimum level is the consequence of the trade-off between firm costs and benefits of holding liquid assets balances to drive an optimal level of cash. Our first hypothesis of the study is accepted and it is consistent with the studies of [13, 27].

Hypothesis 2 proposed that in the presence of financial constraints there is a nonlinear concave relationship

Table 9: Estimation results for financial constraints, cash holding, and corporate performance (fixed effect estimator).

	Panel (A) : functional form estimation results		Panel (B) : financial constraints estimation results			
	Full sample		Size group		(ICR) Group	
	(1)	(2)	(3)	(4)	(5)	(6)
ch	10.1792*** (10.13)	0.0224** (2.28)	0.0148*** (5.04)	4.2293*** (8.56)	4.3679*** (3.62)	4.1055*** (8.31)
ch^2	−0.1989*** (−11.94)	−0.0004** (−2.03)	−0.0001* (−1.84)	−0.1118*** (−13.94)	−0.0785*** (−3.15)	−0.1157*** (−14.43)
*ch*sz*			0.0118*** (7.09)	−3.0201*** (−5.45)		
ch^{2*} *sz*			−0.0001* (−1.83)	0.0838*** (6.93)		
*ch*Icr*					1.3420*** (3.35)	−2.2420*** (−5.29)
$ch^{2*}Icr$					−0.0296*** (−3.08)	0.0966*** (9.08)
sz	−57.9744*** (−7.93)	0.1636*** (2.89)	−1.2341*** (−44.65)	−26.7746*** (−7.27)	−49.3141*** (−6.75)	−23.1762*** (−6.68)
gr	−0.2302761 (−0.35)	−0.0119* (−1.64)	−0.0023 (−0.72)	−0.3526 (−0.79)	−0.3680 (−0.41)	−0.3522 (−0.79)
lev	0.0928*** (19.15)	0.0020 (1.13)	0.0005*** (6.15)	0.0122*** (5.04)	0.0950*** (19.54)	0.0126*** (5.20)
cf	−0.1268*** (−23.51)	0.0319*** (17.51)	0.0076*** (9.61)	−0.0165*** (−12.06)	−0.1270*** (−23.45)	−0.0164*** (−12.00)
fa	1.1578 (0.61)	0.0251* (1.64)	0.0082 (1.31)	0.6361 (0.66)	−0.9120 (−0.48)	0.5151 (0.53)
Constant	1141.969*** (7.33)	−0.3814 (−0.20)	28.8466*** (48.72)	556.3671*** (7.01)	997.2424*** (6.39)	471.452*** (6.36)
IFE and TFE	Yes	Yes	Yes	Yes	Yes	Yes
*F*1	102.63	5.20	50.31	29.71	11.20	27.98
*F*2	142.45	4.13	3.33	47.96	9.47	82.44
Wald Test (prob. > *F*)	74.56 (0.0000)	22.41 (0.0000)	289.57 (0.0000)	28.05 (0.0000)	60.58 (0.0000)	32.00 (0.0000)
Hausman Test (prob. > Chi^2)	84.38 (0.0000)	67.52 (0.0000)	201.59 (0.0000)	368.39 (0.0000)	56.82 (0.0000)	146.94 (0.0000)
R-squared	0.0579	0.0157	0.3599	0.0147	0.0821	0.0153
Obs.	14355	14805	12569	14802	14355	14802

Notes: the *t*−statistics are in the brackets. *, **, and *** indicate level of significance at the 10%, 5%, and 1%, respectively.

Table 10: Sensitivity analysis: estimation results for financial constraints, cash holding, and corporate performance.

	Panel (A): functional form estimation results		Panel (B): financial constraints estimation results			
	Full sample		Size group		(ICR) Group	
	(1)	(2)	(3)	(4)	(5)	(6)
ch_{t-1}	8.5189*** (7.99)	0.0643*** (8.64)	11.3724*** (6.91)	1.4536*** (3.32)	7.72214*** (6.32)	0.0655**** (10.80)
ch^2_{t-1}	−0.1252*** (−5.68)	−0.0013*** (−8.99)	−0.1649*** (−4.88)	−0.0316*** (−3.83)	−0.0614** (−2.17)	−0.0009*** (−8.33)
$ch^* sz_{t-1}$			2.1193*** (2.86)	−4.1643*** (−7.53)		
$ch^{2*} sz_{t-1}$			−0.0754*** (−4.97)	0.1086*** (7.85)		
$ch^* Icr_{t-1}$					0.9528** (2.40)	−0.0349*** (−5.25)
$ch^{2*} Icr_{t-1}$					−0.0906*** (−6.50)	0.0006*** (3.09)
sz_{t-1}	−23.7906*** (−7.55)	0.2469*** (10.45)	−17.7487*** (−3.48)	−14.0528*** (−7.24)	−18.6234*** (−5.24)	0.2618*** (11.37)
gr_{t-1}	−0.4353 (−0.68)	−0.0086* (−1.89)	−1.0855 (−1.14)	−0.3321 (−1.11)	−0.5220 (−0.73)	−0.0098** (−2.13)
lev_{t-1}	1.4332*** (8.66)	0.3329*** (9.60)	0.0005*** (6.15)	0.0363*** (15.35)	0.2422*** (10.34)	−0.0001*** (−2.55)
cf_{t-1}	0.5660** (2.34)	0.0300*** (17.63)	−0.0133* (−1.81)	0.0002 (0.16)	0.0008 (0.13)	−0.0003 (−1.17)
fa_{t-1}	−2.0551 (−1.14)	0.0174 (1.35)	−5.4655** (−2.08)	−0.8549 (−1.02)	−2.6533 (−1.32)	0.0093 (0.71)
Constant	349.2226*** (5.05)	−3.2835*** (−6.35)	229.1919* (1.84)	305.0992*** (7.16)	252.354* (1.81)	−3.7703*** (−6.36)
IFE and TFE	Yes	Yes	Yes	Yes	Yes	Yes
Wald Test (prob. > F)	10.46 (0.0000)	34.38 (0.0000)	9.49 (0.0000)	17.58 (0.0000)	9.74 (0.0000)	15.47 (0.0000)
R− squared	0.0159	0.0466	0.0294	0.0283	0.0265	0.0235
Obs.	12,965	14,808	8,504	13,286	11,502	14,808

Notes: the t−statistics are in the brackets. *, **, and *** indicate level of significance at the 10%, 5%, and 1%, respectively.

between cash holdings and corporate performance. Since our study shows that the nonlinear concave relationship between cash holding and corporate performance still holds in the presence of financial constraints at a lower level of cash holdings due to difficulty to access capital markets and high information asymmetries and high cost of capital. The evidence shows that firms with financial constraints at the low level of cash holdings would prefer to increase cash holdings, and an increase in cash holdings increases firm performance. Because cash flow sensitivity of cash correlates with a firm ability to access capital markets [3], and the importance of balance sheet liquidity inclines by the degree to which firms have access to external capital markets [10]. However, there is an optimum level of cash holding at which above the optimum level of cash a rise in the cash holding in the presence of financial constraints declines firm performance. Theoretically, due to agency cost and free cash flow, an increase in cash holdings decreases firm performance. Practically, since, firms with higher information asymmetries find it troublesome to raise funds outside because financial markets make sure the marketable securities they buy are not overpriced and accordingly discount them applicably. Moreover, due to these issues customer loyalty towards these firms declined [44]. Our second hypothesis of the study is accepted and it is consistent with the study of [27].

In addition, to validate the findings, the present study applied additional analysis with a partial adjustment model, propensity score matching, and difference in difference estimators. The empirical findings of the partial adjustment model reveal that the speed of adjustment of financially constrained firms is faster than unconstrained firms to their target cash levels when holding cash below the target levels. This evidence of the empirical findings presents that financially constrained firms of China more promptly adjust their cash holdings to their target level of cash while their actual cash holding level is below their target level. Since it is relaxed and not much more costly to decrease holdings of cash over liability settlement and repurchase of stock than to enhance the level of cash holding with costly external financing. Moreover, practically, Firms small in size are more financially constrained and face difficulty accessing the capital markets than large firms. Therefore, firms small in size show a faster speed of adjustment to target cash level than financially unconstrained firms and depict a greater propensity to return to optimal cash holding levels than large firms. These empirical findings of our study are consistent with the studies of [29, 30].

The empirical evidence of the propensity score matching estimator shows that firms more likely to be financially constrained are higher in value and hold more cash than unconstrained firms. Since a higher level of cash holdings is associated with a higher level of investment. Therefore, financially constrained firms with high hedging need investment and value show, a significantly stronger positive association than unconstrained firms. Practically, these findings of our study conclude that constrained firms with high cash holdings have a value-increasing response to costly external finance. As in this scenario, high cash holdings help financially constrained firms to undertake potential positive net present value projects that otherwise have bypassed. These empirical findings of our study are consistent with the study of [33].

The empirical findings of the difference in difference estimator show that for unconstrained firms' value of cash holdings increases in a financial crisis. Theoretically, these empirical findings indicate that cash holdings value is high to constrained firms due to the high cost of external finance. Moreover, financially constrained firms heavily rely on internally generated funds for precautionary and transaction motives [13]. This ultimately leads financially constrained firms to market value addition (in terms of the high market to book ratio) and economic value addition (in terms of investment in new projects) due to the availability of internal finance. Practically, these empirical results submit that for financially constrained firms, the impact of cash holdings on firm value turns into a lesser positive at the financial crisis time due to a decrease in investment demand [33]. Moreover, a financial crisis impacts more to unconstrained firms more due to heavy reliance on external financing. Since financially unconstrained firms most probably use cash holdings for debt retirement to diminish the default risk. Therefore, at the time of a financial crisis, high cash holdings value more to financially unconstrained firms and offer more benefits. These empirical findings of our study are consistent with the study of [18].

8. Conclusion, Limitations, and Guidance for Future Research

8.1. Conclusion. The main contribution of the present research is to investigate the relationship between cash holdings and corporate performance with the linkage of financial constraints as a moderating factor. Using a balanced panel of non-financial companies listed on the Shanghai and the Shenzhen stock exchanges from 2005 to 2019, the study finds nonlinear inverted U-shaped relation between cash holdings and firm value. The evidence of the empirical findings supports the precautionary motive, as managers would prefer to increase the cash holding at lower levels to overcome or hedge against cash shortage risk in the future. Secondly, for transaction motive to avail future investment projects to carry out a routine operation of the firm and to buy and sell financial and fixed assets.

The empirical findings also illustrate that the nonlinear concave relationship between cash holding and corporate performance still holds in the presence of financial constraints. The evidence shows that firms with financial constraints at the low level of cash holdings would prefer to increase cash holdings. Since firms with higher information asymmetries find it troublesome to raise funds outside. The results show a higher level of cash holdings for financially constrained firms relative to unconstrained firms. The former have high financial constraints. As cash flow sensitivity of cash correlates with a firm ability to access capital markets and the importance of balance sheet liquidity inclines by the degree to which firms have access to external capital markets.

The study results also find the speed of adjustment of financially constrained firms that is faster than for

Table 11: Definition of variables.

Variable	Abbreviation	Description
Tobin's-q	*q*	Equity value plus book value of long-term debt plus net current liabilities divided by the value of total assets.
Return on assets	*ROA*	Earnings before interest and taxes (EBIT) divided by total assets.
Cash holdings	*ch*	Cash and cash equivalents are divided by total assets.
Firm size	*sz*	Natural logarithm of total assets.
Growth opportunities	*gr*	The ratio of the book value of intangible assets to total assets.
Firm leverage	*lev*	The ratio of total debt to total assets.
Cash flows	*cf*	Earnings before interest and taxes (EBIT) plus depreciation divided by total assets.
Fixed assets	*fa*	The tangible fixed assets is a ratio of fixed assets to total assets.
Liquidity	*liq*	Liquidity is measured as working capital minus total cash and short-term investment divided by total assets.
Interest coverage ratio	*Icr*	Earnings before interest and taxes (EBIT) divided by financial expense.
Deviation	*dev*	The (dev) represents absolute values of residuals obtained from the model (2).
Interaction	*Int*	A dummy variable represents the cash holdings at above optimal level computed as a dummy variable indicating 1 for positive values of residuals, and 0 otherwise.
Cash holding ($CH^{\bullet}$)	$ch^{\bullet}$	The variable ($ch^{\bullet}$) illustrates the predicted values of cash holding.
Financially constrained firms	*fc_firms/fc*	The dummy variable to indicate financially constrained firms represents a dummy variable indicated by 1 for financially constrained firms, and 0 otherwise.
Dummy variable for financial crisis time	*Dct*	The dummy variable to indicate crisis time (Dct) equals 1 for the financial crisis period (2008 to 2010), and 0 for before the crisis period (2005 to 2007)
Industry fixed effects	*IFE*	Dummies of industries to control the potential influence of industries.
Time/Year fixed effects	*TFE*	Dummies of years to control the effect of time or years.

unconstrained firms to their target cash levels when holding cash below the target levels. This evidence of the empirical findings suggests that financially constrained firms of China more promptly adjust their cash holdings to their target level of cash while their actual cash holding level is below their target level. The present study provides additional evidence on the cash holding with the propensity score matching and difference-in-difference estimators. The propensity score matching estimator shows that firms more likely to be financially constrained are higher in value and hold more cash than unconstrained firms. The empirical findings of difference-in-difference estimator show that for unconstrained firms' value of cash holdings increases in a financial crisis. Practically, the findings of our research assist firm managers and policymakers to optimally carrying the liquid balances and developing effective and efficient strategies to balance the cost and benefits of cash holding to maximize firms' value.

Table 12: Calculation of residuals for cash holding deviation estimation (GMM estimator).

Variables and empirical tests	Dependent variable (cash holding)
lev	−0.1315***(−4.11)
sz	−1.775 (−1.62)
gr	−0.4450***(−2.85)
cf	0.0212**(2.31)
liq	−22.1479***(−3.02)
TFE and IFE	Yes
p-value of m_2	0.969
Hansen test (degrees of freedom)	129.62 (122)
Hansen test-*p*-value	0.122
Wald Test (*p*-value) [degrees of freedom]	146.13 (0.000) [21]
Difference in Hansen Test (p-value)	0.925
Obs.	14363

Notes: values in the parentheses are t-values. *, **, and *** indicates the level of significance at the 10%, 5%, and 1%, respectively.

8.2. Limitations and Guidance for Future Research. The empirical investigations of this study support the vital role of financial constraints in investment decisions. Several limitations may be relevant for our study regarding cash holding and liquidity management. First, the data and missing values in the sample are striking issues due to exit and entry of firms in the sample window. Second, our study uses Tobin's-*Q* an return on assets as the dependent variables; as other performance variables can also be used. Third, our study considers only secondary data, however primary and survey data can also be used to uncover the hidden dynamics of cash holdings for the economy of China.

The present study proposes two measures, size (*Sz*) and interest coverage ratio (ICR), as criteria for financial constraints; however, as future research directions researchers may also use other financial constraints proxies as a contextual factor to uncover the unknown changing aspects. Moreover, financial constraints proxies as a contextual factor for corporate cash holdings and firm value relationship should be considered from the view point of emerging economies by taking the market imperfection framework. Tables 11 and 12

Data Availability

The data used in this study are in the public domain, and the relevant sources are cited in the text.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This study was supported by the National Social Science Foundation of China (Grant No. 20BGL079).

References

[1] W. Li, "The role of accounting quality in corporate liquidity management," *Accounting and Finance*, vol. 61, no. 2, pp. 2631–2670, 2021.

[2] T. Opler, L. Pinkowitz, R. Stulz, and R. Williamson, "The determinants and implications of corporate cash holdings," *Journal of Financial Economics*, vol. 52, no. 1, pp. 3–46, 1999.

[3] H. Almeida, M. Campello, and M. S. Weisbach, "The cash flow sensitivity of cash," *The Journal of Finance*, vol. 59, no. 4, pp. 1777–1804, 2004.

[4] T. W. Bates, K. M. Kahle, and R. M. Stulz, "Why do U.S. Firms hold so much more cash than they used to?" *The Journal of Finance*, vol. 64, no. 5, pp. 1985–2021, 2009.

[5] H. V. Phan, N. H. Nguyen, H. T. Nguyen, and S. Hegde, "Policy uncertainty and firm cash holdings," *Journal of Business Research*, vol. 95, pp. 71–82, 2019.

[6] M. C. Jensen and W. H. Meckling, "Theory of the firm: managerial behavior, agency costs and ownership structure," *Journal of Financial Economics*, vol. 3, no. 4, pp. 305–360, 1976.

[7] F. Modigliani and M. H. Miller, "The cost of capital, corporation finance and the theory of investment," *The American Economic Review*, vol. 48, no. 3, pp. 261–297, 1958.

[8] A. Guariglia and J. Yang, "A balancing act: managing financial constraints and agency costs to minimize investment inefficiency in the Chinese market," *Journal of Corporate Finance*, vol. 36, pp. 111–130, 2016.

[9] M. Spatareanu, V. Manole, and A. Kabiri, "The real effects of banks nationalization - evidence from the UK," *Applied Economics Letters*, vol. 29, no. 7, pp. 579–583, 2021.

[10] J. M. Keynes, "The general theory of employment," in *Interest and Money*"Harcourt, Brace, London, UK, 1936.

[11] X. Li and D. Luo, "Increase in cash holdings of U.S. firms: the role of healthcare and technology industries," *Journal of Business Research*, vol. 118, pp. 286–298, 2020.

[12] C.-S. Kim, D. C. Mauer, and A. E. Sherman, "The determinants of corporate liquidity: theory and evidence," *Journal of Financial and Quantitative Analysis*, vol. 33, no. 3, pp. 335–359, 1998.

[13] F. Alnori, "Cash holdings: do they boost or hurt firms' performance? Evidence from listed non-financial firms in Saudi Arabia," *International Journal of Islamic and Middle Eastern Finance and Management*, vol. 13, no. 5, pp. 919–934, 2020.

[14] J. Lim and S. C. Lee, "Relationship between the characteristics of CEOs and excess cash holdings of firms," *Emerging Markets Finance and Trade*, vol. 55, no. 5, pp. 1069–1090, 2019.

[15] Z. Tong, "Firm diversification and the value of corporate cash holdings," *Journal of Corporate Finance*, vol. 17, no. 3, pp. 741–758, 2011.

[16] M. Faulkender and R. Wang, "Corporate financial policy and the value of cash," *The Journal of Finance*, vol. 61, no. 4, pp. 1957–1990, 2006.

[17] C. Martínez-Sola, P. J. García-Teruel, and P. Martínez-Solano, "Corporate cash holding and firm value," *Applied Economics*, vol. 45, no. 2, pp. 161–170, 2013.

[18] Y. Chang, K. Benson, and R. Faff, "Are excess cash holdings more valuable to firms in times of crisis? Financial constraints and governance matters," *Pacific-Basin Finance Journal*, vol. 45, pp. 157–173, 2017.

[19] C. Schauer, R. Elsas, and N. Breitkopf, "A new measure of financial constraints applicable to private and public firms," *Journal of Banking & Finance*, vol. 101, pp. 270–295, 2019.

[20] M. Arellano and S. Bond, "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *The Review of Economic Studies*, vol. 58, no. 2, pp. 277–297, 1991.

[21] M. Guizani, "The financial determinants of corporate cash holdings in an oil rich country: evidence from kingdom of Saudi Arabia," *Borsa Istanbul Review*, vol. 17, no. 3, pp. 133–143, 2017.

[22] D. Zhu and Y. Li, "Empirical research on seasoned equity offerings, board member characteristics, and corporate investment efficiency," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 3365840, 13 pages, 2022.

[23] R. M. Iftikhar, "Impact of cash holding on firm performance: a case study of non-financial listed firms of KSE," *University of Haripur Journal of Management*, vol. 2, no. 1, pp. 189–199, 2017.

[24] T. T. T. Doan, "The effect of cash holdings on firm performance: evidence from Vietnam listed firms," *Accounting*, vol. 6, no. 5, pp. 721–726, 2020.

[25] S. El-Halaby, S. Aboul-Dahab, and N. B. Qoud, "Bidirectional relationship between cash holdings and financial performance for banks in the MENA region," *International Journal of Customer Relationship Marketing and Management*, vol. 12, no. 1, pp. 28–43, 2021.

[26] I. Jabbouri and H. Almustafa, "Corporate cash holdings, firm performance and national governance: evidence from emerging markets," *International Journal of Managerial Finance*, vol. 17, no. 5, pp. 783–801, 2021.

[27] T. L. H. Nguyen, L. N. T. Nguyen, and T. P. V. Le, "Firm value, corporate cash holdings and financial constraint: a study from a developing market," *Australian Economic Papers*, vol. 55, no. 4, pp. 368–385, 2016.

[28] H. Cho, S. Choi, and M.-O. Kim, "Cash holdings adjustment speed and managerial ability," *Asia-Pacific Journal of Financial Studies*, vol. 47, no. 5, pp. 695–719, 2018.

[29] S. Das, A. Kumar, and A. Bhattacharyya, "The impact of institutional factors on corporate mechanism of cash adjustment - new evidence from emerging Asia," *International Journal of Managerial Finance*, 2022.

[30] Z. Jiang and E. Lie, "Cash holding adjustments and managerial entrenchment," *Journal of Corporate Finance*, vol. 36, pp. 190–205, 2016.

[31] J. Yun, H. Ahmad, K. Jebran, and S. Muhammad, "Cash holdings and firm performance relationship: do firm-specific factors matter?" *Economic Research-Ekonomska Istraživanja*, vol. 34, no. 1, pp. 1283–1305, 2021.

[32] A. Diaw, "Corporate cash holdings in emerging markets," *Borsa Istanbul Review*, vol. 21, no. 2, pp. 139–148, 2021.

[33] B. Batuman, Y. Yildiz, and M. B. Karan, "The impact of the global financial crisis on corporate cash holdings: evidence from Eastern European countries," *Borsa Istanbul Review*, 2021.

[34] Q. T. Tran, "Financial crisis, shareholder protection and cash holdings," *Research in International Business and Finance*, vol. 52, Article ID 101131, 2020.

[35] Y. Yildiz, "Adjustment to target capital structure and global financial crisis: evidence from Turkey," *Business and Economics Research Journal*, vol. 9, no. 3, pp. 543–557, 2018.

[36] J.-F. Tsai, N. T. Mai, and D. G. Bui, "Managerial ability, financial constraints, and the value of cash holding," *Applied Economics Letters*, vol. 29, no. 5, pp. 462–468, 2022.

[37] J. Jiang and S. Wu, "The effects of cash-holding motivation on cash management dynamics," *Research in International Business and Finance*, vol. 59, Article ID 101542, 2022.

[38] P. Dimitropoulos, K. Koronios, A. Thrassou, and D. Vrontis, "Cash holdings, corporate performance and viability of Greek SMEs," *EuroMed Journal of Business*, vol. 15, no. 3, pp. 333–348, 2019.

[39] M. C. Jensen, "Agency costs of free cash flow, corporate finance, and takeovers," *The American Economic Review*, vol. 76, no. 2, pp. 323–329, 1986.

[40] B.-J. Chang and M.-W. Hung, "Corporate debt and cash decisions: a nonlinear panel data analysis," *The Quarterly Review of Economics and Finance*, vol. 81, pp. 15–37, 2021.

[41] L. Zhang, Y. Yan, W. Xu, J. Sun, and Y. Zhang, "Carbon emission calculation and influencing factor Analysis based on industrial big data in the "double carbon" era," *Computational Intelligence and Neuroscience*, vol. 2022, Article ID 2815940, 12 pages, 2022.

[42] H. Gao, J. Harford, and K. Li, "Determinants of corporate cash policy: insights from private firms," *Journal of Financial Economics*, vol. 109, no. 3, pp. 623–639, 2013.

[43] J. J. Heckman, H. Ichimura, and P. E. Todd, "Matching as an econometric evaluation estimator: evidence from evaluating a job training programme," *The Review of Economic Studies*, vol. 64, no. 4, pp. 605–654, 1997.

[44] R. Zhang, M. Jun, and S. Palacios, "M-shopping Service Quality Dimensions and Their Effects on Customer Trust and Loyalty: An Empirical Study," *International Journal of Quality & Reliability Management*, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8255444, 7 pages
https://doi.org/10.1155/2022/8255444

Research Article

Analysis on the Independent Innovation Path and Development Trend of Emerging Marine Industry Based on DEA Model

Yufeng Liu [1,2]

[1]*School of Economics and Management Beijing Jiaotong University, Beijing, China*
[2]*School of Economics and Management Inner Mongolia University, Hohhot 010021, Inner Mongolia, China*

Correspondence should be addressed to Yufeng Liu; 16120516@bjtu.edu.cn

Received 11 April 2022; Revised 8 May 2022; Accepted 23 May 2022; Published 9 June 2022

Academic Editor: Lele Qin

The development trend of the emerging marine industry affects the development of the marine economy, to study the independent innovation path of the emerging marine industry and the empirical analysis of its development trend. Based on the independent innovation path of the emerging marine industry, explore the development trend of the emerging marine industry. Select the added value of the emerging marine industry as the dependent variable; R&D personnel and R&D funds as the intermediary variables; innovation efficiency as the explanatory variable; and technical capabilities, technical management capabilities, technical strategies, and network capabilities as control variables, using data packets. The network analysis method establishes a development trend measurement model and analyzes the independent innovation path and development trend of the emerging marine industry through the established model. The four independent innovation paths of technological capability, technological management capability, technological strategy, and network capability have a positive incentive effect on the development of emerging marine industries, and technological capability has a higher incentive for the development of emerging marine industries. Based on the results of empirical analysis, it proposes strategies to promote the development of emerging marine industries, such as enhancing public awareness of emerging marine industries, improving long-term mechanisms for the development of emerging marine industries, and enhancing the independent innovation capabilities of emerging marine industries.

1. Introduction

Emerging industries are an important choice for China to achieve sustainable economic development. Emerging marine industries are of great significance to driving the transformation of the marine economy, enhancing the core competitiveness of the marine economy, and adjusting the structure of the marine economy [1–3]. Independent innovation of emerging marine industries has high urgency and necessity [4]. To study the path of independent innovation of emerging marine industries, it is necessary to clarify the current state of marine economic development, recognize the main characteristics of emerging marine industries, and understand how emerging marine industries influence the marine economy and the important significance of China's economic development. Marine high-tech is an important part of the emerging marine industry. Marine high-tech can speed up the upgrading of marine economic structure and realize the optimization of marine economic structure. At present, all countries in the world attach great importance to the development of marine high-tech [5, 6].

In 2010, the director of the State Oceanic Administration pointed out that the emerging marine industry is an important part of the marine high-tech industry, and it is of high strategic significance to include the emerging marine industry in the marine high-tech industry. The marine biomedicine industry, marine renewable energy industry, seawater comprehensive utilization industry, marine power industry, seawater desalination industry, deep sea industry, and marine equipment industry are all important parts of the emerging marine industry. Vigorously developing the above-mentioned industries can achieve rapid marine technology development. Emerging marine industries can demonstrate the country's marine strategic intentions [7], using marine high-tech to tap the development

potential of the marine economy, so that it has broader market prospects, and emerging marine industries have long-term, dynamic, and overall and oriented characteristics, and it can lead the rapid development of the marine economy.

Current research on emerging marine industry depth, part of the study was underpowered and in the research process, the paper analyzes the current situation of new ocean industries, only puts forward the strategy but did not predict development trend, for the future development direction of master degree is low, but the results credibility is low, and the imperfection of the resolution strategy.

In view of the above problems, in order to improve the credibility of the independent innovation path and accurately predict the development trend of the marine industry, study the independent innovation path and development trend of the emerging marine industry, fully analyze the independent innovation path of the emerging marine industry, verify its development trend through empirical research, propose development strategies that can promote the independent innovation path of emerging marine industry based on the empirical research results, and promote the continuous development of the marine economy.

2. Literature Review

Emerging marine industries have high environmental friendliness and advanced technology and have huge development potential. Emerging marine industries have become an important decision point to promote marine economic growth. In recent years, the annual output value of emerging marine industries has increased year by year. Many researchers have conducted a lot of research on emerging marine industries. Zaehringer et al. believe that higher technological capabilities can improve the competitiveness of industries and enterprises [8], which can be used as an important indicator to measure the efficiency of enterprise innovation. The results of research scholars such as Bendjama et al. show that corporate sales capabilities can be reflected through the network [9], and network capabilities have a high impact on the success of independent innovation; Wangmo et al. believe that the accumulation of effective technical resources can be achieved through corporate technology strategies [10], and effective technical resources can improve the core technical level of the enterprise. Through the above-given research, the present stage by attention gradually emerging marine industry and obtained the recognition of people, the present study has obtained certain achievements, but the emerging marine industry studies have limitations, its independent innovation path, and the development trend analysis in-depth; by its development trend is not very accurate budget, lead to study the effect not beautiful. Therefore, this paper puts forward an empirical analysis on the independent innovation path and development trend of China's emerging Marine industry.

3. Research Method

Select the relevant data applied by a marine biomedical company in independent innovation in 2019 as the empirical analysis data source, and use the development trend calculation model to study the independent innovation path and development trend of the emerging marine industry [11, 12].

3.1. Development Trend Estimation Model. Data Envelopment Analysis (DEA) is an evaluation method based on relative efficiency using linear planning and convex analysis as tools [13]. When the input and output of the decision-making unit of empirical analysis have not changed, comparing the relative efficiency between decision-making units through mathematical programming models and statistical data can clarify the more effective elements [14] and obtain the relative effects of different variables.

Suppose there are s decision-making units. The output and input quantities contained in each decision-making unit are m and n, respectively. Y_{ij} and X_{ij}, respectively, represent the total output and total input of type j of the i decision-making unit. The output vector of the unit is $Y_{ij} = (y_{1j}, y_{2j}, j_{3j}, \ldots, y_{nj})^T$, and the input vector is $X_{ij} = (x_{1j}, x_{2j}, x_{3j}, \ldots, x_{mj})^T$.

Suppose the constraint of the development trend measurement model is the efficiency index of the decision-making unit, and the available development trend measurement model takes the efficiency index of j_1 decision-making units as the target formula as follows:

$$\begin{cases} s.t. \sum_{j=1}^{n} \lambda_j x_j \le \theta x_0, \\ \min\theta, \\ \sum_{j=1}^{n} \lambda_j x_j \ge y_0, \\ \lambda_j \ge 0, j = 1, 2, \ldots, n. \end{cases} \tag{1}$$

Here, the decision coefficient θ is unconstrained, and λ_j represents the combined weight of the decision-making unit. The slack variables S^+ and S^+ are introduced into the formula, and the formula is as follows:

$$\begin{cases} \min\theta, \\ s.t. \sum_{j=1}^{n} \lambda_j x_j + S^+ \le \theta x_0, \\ \sum_{j=1}^{n} \lambda_j x_j - S^- \ge y_0, \\ \lambda_j \ge 0, j = 1, 2, \ldots, n. \end{cases} \tag{2}$$

Here, θ is unconstrained, $S^+ \ge 0$, $S^- \le 0$.

Analyzing formula (2), let $\min\theta = 1, S^+ = 0$, $S^+ = 0$, $S^- = 0$. The available decision-making unit is DEA valid. At this time, the economic activity scale and technology of the decision-making unit are valid; when $\min\theta = 1, S^+ = 1, S^- = 1$ and at least one of the inputs or outputs is greater than or equal to 0, the decision unit λ_1 can be obtained at this time for weak DEA to be effective, the decision-making unit has only one effective economic activity with effective scale or technically effective and cannot satisfy the two economic activities at the same time; when $\min\theta \le 1$, the decision-making unit is invalid DEA at this time, and the size of the decision-making unit λ_1 and technology are invalid.

3.2. Variable Definition. Select the added value of the emerging marine industry that can directly reflect the development trend of the emerging marine industry as the dependent variable for the empirical analysis [15, 16], and select the R&D personnel and R&D funds that can affect the results of independent innovation as the intermediary variables of the established development trend measurement model; select the innovation efficiency that can be obtained through different independent innovation paths as the explanatory variable; select technological capabilities, technological management capabilities, technological strategies, and network capabilities in the path of independent innovation as the control variables for the empirical analysis of the development trend measurement model.

3.2.1. Interpreted Variables. Set the added value of the emerging marine industry as the explained variable [17], and reflect the innovation efficiency of independent innovation through the four aspects of the independent innovation path: technical capabilities, technical management capabilities, technical strategies, and network capabilities, and use innovation efficiency to measure the added value of emerging marine industries, and clarify emerging industry development trend of the marine.

3.2.2. Control Variables

(1) *Technical Ability*. Technological capabilities are of great significance to the independent innovation of enterprises in the emerging marine industry [18, 19]. Bao Gongmin and others believe that when an enterprise has a high level of technological capability, its chance of success in innovation is higher than that of a low-level technological capability enterprise. Enterprise independent innovation is an important development stage of enterprise technological innovation, and the improvement of technological capabilities has a positive impact on enterprise independent innovation.

(2) *Network Capability*. The path of independent innovation is the whole process of innovative conception, innovative research and development, innovative product production, and the commercialization of innovative products. Enterprises need a lot of resources to achieve independent innovation. Different enterprises often have limited resources, and all the resources needed for innovation can be obtained through the network of relationships. Network capability is an important indicator for evaluating the access to different resources of enterprises, and enterprises can use different channels to solve resource problems through the network.

(3) *Technology Strategy*. The technological choice of an enterprise is the focus of the technological strategy of an enterprise. A reasonable technological choice can determine the major decisions of enterprise technology acquisition, maintenance, and utilization. The technological decision of the enterprise affects product and process innovation. The advanced development stages and goals of enterprise technological innovation are determined by independent innovation [20]. The independent innovation of enterprises is directly related to the technological strategy of enterprises. Enterprises use technological strategic planning to determine the training mode and accumulation of technological resources, which affect the technological level of the enterprise. When an enterprise formulates a reasonable technological strategy, it will form a large number of R&D resources and train many high-level R&D personnel. High-level R&D personnel can effectively enhance the company's corporate culture of learning technology and enhance the company's technical level.

(4) *Technical Management Ability*. There is a close theoretical relationship between independent innovation of enterprises and technological management capabilities. The technological strength of enterprises determines the level of technological innovation of enterprises [21]. The implementation of technological management of enterprises can improve the success rate of enterprise innovation. After investigating and studying the results of many companies, Cooper came to the conclusion: high-quality management is an important factor for the success of independent innovation of an enterprise, and the performance of an enterprise's technological innovation can promote its technological management ability. The advanced development stage and goal of enterprise technological innovation is independent innovation, and independent innovation of enterprises can bring positive guidance through technological management capabilities.

The management of technological resources of an enterprise can enhance the competitive advantage of an enterprise. The adjustment of an enterprise's organizational structure, the quality of management models, and the level of technical resource management are important manifestations of the level of technical management. The formulation of corporate technology strategy determines the level of corporate technology management. The emerging marine industry is a new industry. With the improvement of marine industry competitiveness and the emergence of many high-tech levels, the network environment determines the technological acquisition of enterprises, and the enterprise network environment affects the external management methods of enterprises and determines the network status of enterprises. The network status of an enterprise determines the network capability of the enterprise in the process of independent innovation [22, 23]. When the enterprise is at the center of the network, the enterprise has a higher ability to control network resources. The planning of enterprise technology resources and the created corporate culture are also important factors that determine network capabilities.

4. Results Analysis

The development trend calculation model established was used to analyze the independent innovation path and development trend of the emerging marine industry. The experimental computer was configured with 2.0 GHz Core Pentium, DDRI memory of 2 GB, and notebook hard disk of 7500 speed of 300 GB. The operating system is WindowsXP, the database is SQL, the development tool is C++, the development environment is VC, and the data isolation tool is v0.8.3. libpcap. Use the libpcap tool to collect about 500 MB of data packets from the network. The analysis results are shown in Table 1.

Analyzing the results of the empirical analysis in Table 1, it can be seen that with the increase of the set variables, the significance of each variable has improved, which verifies that the set development trend measurement model has high feasibility. The regression coefficient of each variable passed the t-test at the 10% significance level, indicating that the results of studying the development trend of emerging marine industries through independent innovation paths are credible.

In order to further determine the effectiveness of the proposed design method, improve the credibility, and verify the design method of forecast accuracy, in the form of contrast analysis of the experimental verification, contrast method for literature [21], the method using the panel vector autoregressive model (PVAR) analysis of marine science and technology innovation, marine dynamic relationship between total factor productivity and the development of the marine economy. The specific experimental results are shown in Table 2.

According to Table 2, the prediction accuracy of the design method reaches more than 99.0%, and that of the PVAR method is about 90.0%, and the maximum value is only 90.5%. Compared with the two methods, the accuracy of the design method is improved by more than 8.5%. Therefore, the prediction accuracy of the design method is high, and it is effective and feasible.

Analyzing the experimental results in Table 1, technical capabilities have significantly stimulated the innovation efficiency of emerging marine industries, improved technological capabilities, and obtained higher added value of emerging marine industries, effectively promoting the development of enterprises in emerging marine industries. The efficiency of independent innovation of enterprises has been improved, the cost of independent research and development of independent innovation activities of enterprises and the risk of independent research and development have been reduced, and the safety guarantee of enterprises in the emerging marine industry has been improved.

The network capabilities in the independent innovation path of enterprises have a higher incentive effect on the development of enterprises in the emerging marine industry. That is, the enterprises in the emerging marine industry have higher network capabilities in the process of independent innovation, and the stronger the independent innovation capabilities of enterprises. The network is the main channel for the dissemination of many high-tech technologies. The enhancement of corporate network capabilities will provide enterprises with more materials for independent innovation, improve the efficiency of independent innovation, and promote the further development of emerging marine industries.

The technological strategy in the independent innovation path of enterprises has a high incentive effect on the development trend of emerging marine industries. Emerging marine industries mainly include the marine power industry, seawater utilization industry, and marine biomedicine industry. Enterprises have good technological strategic planning for the industries involved, which will promote the further development of enterprises' independent innovation, enhance the level of independent innovation of enterprises, and promote further development of emerging marine industries.

The technological management ability in the independent innovation path of enterprises has a significant incentive effect on the development trend of the emerging marine industry. Enterprise technology management capabilities are mainly reflected in three aspects: personnel management capabilities, information management capabilities, and equipment management capabilities. Enterprises have high technical management capabilities and can provide hardware and software support for independent innovation of enterprises and use superior technical management capabilities to promote independent innovation of emerging marine industries and promote the development of emerging marine industries. If there are problems of low management efficiency and redundant personnel within the enterprise, it will affect the independent innovation ability of the enterprise. Relevant studies have shown that compared with other types of enterprises, state-owned enterprises have lower innovation capabilities. The main reason is that state-owned enterprises usually have lower management efficiency, which reduces the independent innovation ability and vitality of state-owned enterprises, and to promote the development of emerging marine industries, the enterprise should start from the improvement of enterprise technology management capabilities.

The independent research and development funds of enterprises have a significant positive effect on the development trend of the emerging marine industry. The increase in independent research and development funds of enterprises can encourage enterprises to actively carry out independent innovation. The increase in R&D funds of enterprises and the support of R&D funds for independent innovation of enterprises effectively promote enterprise development and innovation. The larger the scale of the enterprise, the more R&D funds the enterprise can invest in, and the more R&D personnel the enterprise has, which can further promote the development of emerging marine industries.

Enterprise R&D personnel have a significant positive effect on the development trend of the emerging marine industry. The independent R&D funds of enterprises are increased. Enterprises can use R&D funds to hire more R&D personnel with professional and technical level. Enterprise R&D personnel have an incentive effect on independent

Table 1: The incentive effect of independent innovation paths on the development trend of emerging marine industries.

Variable name	Technical skills	Network capability	Technology strategy	Technical management ability
Technical skills	0.095*	0.452*	0.387**	0.652*
Network capability	0.852*	0.765**	0.523*	0.782***
Technology strategy	0.462*	0.858*	0.654**	0.184**
Technical management ability	0.658*	0.474*	0.384**	0.964***

Note: *, **, and *** represent the significance of 10%, 5%, and 1%, respectively.

Table 2: Prediction accuracy analysis of different methods.

Number of experiments (times)	Accuracy (%)	
	PVAR method	This paper method
1	90.2	99.0
2	89.7	99.3
3	88.6	99.7
4	90.5	99.4
5	90.3	99.1

innovation of enterprises and can promote the development of emerging marine industries.

5. Discussion

Through an empirical analysis of the independent innovation of the emerging marine industry and discussing the incentive effect of the independent innovation path on the development of the emerging marine industry, the following conclusions can be drawn.

Different independent innovation paths have different incentive effects on the development trend of the emerging marine industry, and technological capabilities have a more significant role in promoting the development trend of the emerging marine industry. The path of independent innovation can promote the development of emerging marine industries. The higher the R&D investment of enterprises in the emerging marine industry, the stronger their independent innovation capabilities. The independent innovation path of the emerging marine industry, namely, technological capability, technological management capability, technological strategy, and network capability, has a positive incentive effect on the development of the emerging marine industry. Compared with network capabilities, technical management capabilities, and technological strategies, technological capabilities have a higher incentive for the development of emerging marine industries.

In view of the empirical analysis results of the independent innovation path and development trend of the emerging marine industry, the following measures are proposed to promote the development of the emerging marine industry.

5.1. Raise Public Awareness of Emerging Marine Industries. A good combination of companies, media, government, and the public, vigorously promote the emerging marine industry and raise public awareness of the emerging marine industry. Promoting knowledge about emerging marine industries through the Internet, TV stations, newspapers, etc., to enhance public awareness of emerging marine industries. Seawater desalination and comprehensive utilization industry, marine equipment industry, marine biomedicine industry, deep sea industry, etc., are all emerging marine industries. The public should understand the development trends of many emerging marine industries and clarify that the development of emerging marine industries has implications for the marine economy and the development of my country's national economy. To clarify the significance of developing emerging marine industries for the marine economy and the development of China's national economy [24], marine administrative departments should provide an economic foundation and reliable guarantee for the development of emerging marine industries and always pay attention to the independent innovation achievements of emerging marine industries, professionalism, and incubation mechanisms of the industry to create better social, environmental, and economic benefits of the emerging marine industry.

5.2. Improving the Long-Term Mechanism for the Development of Emerging Marine Industries. The emerging marine industry takes the State Oceanic Administration as the development benchmark, has a higher standard and a higher starting point, and a relevant emerging marine industry development system should be formulated. The State Oceanic Administration should promote the development of emerging marine industries in terms of projects, finances, taxation, and investment promotion, establish a sound mechanism with independent innovation, sound infrastructure, and ecological environment protection, actively assist emerging marine industry-related companies to go public, and promote the development of emerging marine industries. At present, the level of marine development in my country is relatively low [18, 25, 26], and it is very difficult to promote the development of emerging marine industries. The coordination of industrial policies can effectively promote the development of emerging marine industries.

The government should establish relevant management agencies to coordinate the development of marine science and technology, coordinate and coordinate policies related to emerging marine industries, realize the macromanagement of emerging marine industries, promote the industrialization and applicability of many high-tech applications in emerging marine industries, strictly control the development trend of emerging marine industries, establish a long-term mechanism that can maintain the sustainable

development of emerging marine industries, and maintain the growth of emerging marine industries.

5.3. Improving the Independent Innovation Capability of Emerging Marine Industries. Marine technological innovation and the development of independent intellectual property rights can effectively enhance the development potential and competitiveness of emerging marine industries. Deeply develop the key technological achievements of the emerging marine industry and apply the developed achievements to more fields. The government and marine management departments should encourage the development of marine biotechnology, marine equipment technology, and marine renewable energy power generation technology and promote the marine economy from a resources-dependent type develops to a technology-driven type. For the comprehensive utilization of seawater and marine biological engineering, enterprises, universities, scientific research institutions, and intermediary organizations promote marine scientific and technological innovations [27] and use training institutions, intermediary institutions, and technology promotion stations to promote marine scientific and technological achievements obtained through independent innovation technology. Through the development of national high-tech industrial development zones, promote the development of emerging marine industries, establish important carriers that can cultivate emerging marine industries, and create emerging marine industrial bases with international competitiveness.

5.4. Increasing R&D Funds for Emerging Marine Industries. In the process of independent innovation of emerging marine industries, relevant national policies should be fully utilized to guide the development of emerging marine industries, create an innovative emerging marine industry system, promote the development of emerging marine industries through a good investment and financing environment, and mobilize large amounts of funds to develop emerging marine industries. Industry [28], to promote the sound development of emerging marine industries. By improving the investment environment, relaxing investment fields, increasing policy input, many enterprises, credit funds, and foreign capital are attracted to actively develop emerging marine industries.

5.5. Training Highly Innovative Talents. The cultivation and use of independent innovative talents determines the development opportunities of emerging marine industries. In the development of the emerging marine industry, it is necessary to focus on cultivating independent innovative talents, attach importance to entrepreneurial management talents, and create a development environment for talents with independent innovation capabilities. It is necessary to strengthen the training of technological leaders and high-level innovative and entrepreneurial talents and develop a platform that can cultivate talents with independent innovation ability [29]. Through the talent incentive mechanism, cultivate new energy technology talents in emerging marine industries, enhance the enthusiasm of independent innovation talents, and enable more independent innovation talents to vigorously develop emerging marine industries and achieve sustainable development of the marine economy.

6. Conclusion

The development of emerging marine industries should aim at building an environment-friendly and resource-saving society, and the emerging marine industries should be taken as a major strategic measure to achieve sustainable development of the marine economy. Aiming at the problems emerging marine industry development at the present stage, puts forward China's emerging marine industry independent innovation path and trend of development of the empirical analysis, the research study emerging from the depth of the independent innovation path of marine industry development trend, using data envelopment analysis, marine industries, as well as the development trend of measuring model construction by predicting marine development trend. It is clear that the five independent innovation paths of technological capability, technological management capability, technological strategy, network capability, and R&D fund have a positive guiding effect on the development of the emerging marine industry. Test analysis to develop new marine industry should promote technology ability, technology, management capacity, level of technology strategy, and the network capacity and increase the research and development; the research according to the results of the analysis put forward the development strategy, can effectively maintain the emerging marine economy sustainable development of the marine industry, to build a world leading level of the marine technology innovation system.

Due to the limitation of the research time, the research method did not analyze the operation time of the ocean development trend calculation model. Therefore, the subsequent research and analysis of the prediction time were conducted in order to reduce the development trend calculation time and improve the operation efficiency of the research method.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] H. Xu, J. Y. Chen, H. Fang et al., "Chinese marine fishery transformation and strategic emerging industry of deep ocean fishery," *Fishery Modernization*, vol. 47, no. 3, pp. 1–9, 2020.

[2] L. X. Jian, Y. L. Su, and S. S. Cao, "Research on the digital economy driving the high-quality development of marine

industry in coastal areas," *Statistics & Information Forum*, vol. 36, no. 11, pp. 28–40, 2021.

[3] C. J. Wang, Q. Wang, D. H. Liu, and X. Wang, "Co-integration analysis on China marine science and technology innovation, transformation and upgrading of marine industrial structure and marine economic development based on ARDL model," *Science and Technology Management Research*, vol. 41, no. 24, pp. 136–142, 2021.

[4] G. N. Xu, Y. Zhou, and X. B. Wu, "Building multi-layered innovation ecosystems in emerging industries: theoretical framework and empirical study," *Science of Science and Management of S.&.T*, vol. 7, pp. 98–115, 2020.

[5] T. Liu, F. Wu, Q. Gao, and L. Gao, "Efficiency measurement and spatial optimization of collaborative innovation in Marine high-tech industry," *Statistics & Decisions*, vol. 37, no. 6, pp. 109–112, 2021.

[6] J. Y. Ji, H. W. Guo, and Z. C. Lin, "Marine science and education, venture capital and marine industry structure upgrading," *Science Research Management*, vol. 41, no. 3, pp. 23–30, 2020.

[7] X. Shi, "DEA research on financial support efficiency of Chinas marine industry," *Journal of Coastal Research*, vol. 115, no. sp1, p. 175, 2020.

[8] J. G. Zaehringer, G. Wambugu, B. Kiteme, and S. Eckert, "How do large-scale agricultural investments affect land use and the environment on the western slopes of Mount Kenya? Empirical evidence based on small-scale farmers perceptions and remote sensing," *Journal of Environmental Management*, vol. 213, pp. 79–89, 2018.

[9] H. Bendjama, S. Merouani, O. Hamdaoui, and M. Bouhelassa, "Efficient degradation method of emerging organic pollutants in marine environment using UV/periodate process: case of chlorazol black," *Marine Pollution Bulletin*, vol. 126, pp. 557–564, 2018.

[10] T. Wangmo, S. Hauri, E. Gennet, E. Anane-Sarpong, V. Provoost, and B. S. Elger, "An update on the "empirical turn" in bioethics: analysis of empirical research in nine bioethics journals," *BMC Medical Ethics*, vol. 19, no. 1, p. 6, 2018.

[11] J. Zhang, X. Xu, and Y. H. Sui, "Evolution of land-use landscape pattern in coastal zone driven by marine economy: simulation and prediction based on Ca-markov model," *On Economic Problems*, vol. 487, no. 3, pp. 100–104, 2020.

[12] G. P. Zhu and M. X. Zhou, "Progress of numerical ocean model and its application in dispersal modelling of marine organisms:A review," *Marine Fisheries*, vol. 42, no. 2, pp. 245–256, 2020.

[13] S. Y. Ma, Z. X. Ma, J. Zhang, and J. Qiao, "Fundamental generalized stochastic data envelopment analysis method," *Operations Research and Management Science*, vol. 29, no. 11, pp. 138–143, 2020.

[14] Y. Cao, "Research on the efficiency of Chinas marine industry financial support based on DEA," *Journal of Coastal Research*, vol. 115, no. sp1, p. 217, 2020.

[15] Q. B. D and L. X. Xu, "Spatial effect measurement of scientific and technological innovation on marine economic development: empirical study based on multiple weight matrix," *Science and Technology Management Research*, vol. 41, no. 6, pp. 63–70, 2021.

[16] B. Wang, L. Zhai, L. M. Han, and H. Zhang, "Adjustment of industrial structure, fluctuation of Marine space resources and economic growth of Marine fishery," *Statistics & Decisions*, vol. 36, no. 17, pp. 96–100, 2020.

[17] D. S. Liao and R. He, "Study on the development path of Guangxi Marine industry from the perspective of sea and land integration," *China Market arketing*, vol. 22, no. 2, pp. 50-51, 2020.

[18] X. M. Jie, H. Wang, Y. S. Wang et al., "Measurement and spatial characteristics of Chinas marine S&T innovation capability:empirical analysis based on 36 sea-related cities," *Science and Technology Management Research*, vol. 40, no. 10, pp. 65–71, 2020.

[19] J. H. Xiang, "Laying solid foundation of marine biology, innovating marine biotechnology, and enabling blue bioindustry," *Oceanologia et Limnologia Sinica*, vol. 51, no. 4, pp. 673–683, 2020.

[20] J. Wu, "The construction of the evaluation system of regional marine industry investment benefit," *Journal of Coastal Research*, vol. 103, no. sp1, p. 199, 2020.

[21] L. Ning and Z. M. Song, "Dynamic relationship between marine science and technology innovation, marine total factor productivity and marine economic development:empirical analysis based on panel vector autoregressive model," *Science and Technology Management Research*, vol. 6, pp. 171–177, 2020.

[22] K. R. Sheng, Y. Yang, and W. Sun, "Network position and underlying factors of cities in China: a study from corporate networks of the largest 500 public companies," *Scientia Geographica Sinica*, vol. 40, no. 5, pp. 740–750, 2020.

[23] S. J. Chen and H. Song, "Impact of business network and capabilitieson SMEs Financing performance:A chain mediation model," *Journal of Business Economics*, vol. 41, no. 4, pp. 18–28, 2020.

[24] J. Liu and X. L. Ma, "Research on the path of innovation-driven development of xiong an new area:from the perspective of innovation ecosystem," *Science & Technology Progress and Policy*, vol. 8, pp. 32–37, 2018.

[25] S. J. Ye, X. H. Bao, and X. Wen, "Competitiveness measurement and economic effect evaluation of marine industry in guangxi beibu gulf economic zone," *Journal of Guangxi University for Nationalities (Philosophy and Social Science Edition)*, vol. 5, pp. 145–152, 2019.

[26] Z. Wang, L. H. Wang, and Y. T. Ma, "The economic growth effect of the coordinated industrial development —An empirical analysis based on the coupling of strategic emerging industries and traditional industries," *Journal of Southwest University (Social Sciences Edition)*, vol. 3, pp. 69–78, 2020.

[27] Y. Zhang, "Meng feirong. Development trend of basic research competitiveness of marine strategic emerging industries ——evidence from marine biological medicine industries," *Science & Technology Progress and Policy*, vol. 16, pp. 67–76, 2019.

[28] Z. M. Shi and D. X. Xu, "An empirical analysis on the promotion for agglomeration to innovative ecosystem of strategic emerging industries," *Science & Technology Progress and Policy*, vol. 23, pp. 92–98, 2018.

[29] H. C. Liu and H. Liu, "Research on cultivation mode and development path of strategic marine emerging industry from the perspective of innovation double spiral: a case study of Jiangsu province," *Science and Technology Management Research*, vol. 14, pp. 131–139, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2048367, 6 pages
https://doi.org/10.1155/2022/2048367

Research Article

Analysis on the Adjustment of Marine Economic Industrial Structure Based on the Least Square Regression Model

Zhen Ma

Xi'an Fanyi University, Xi'an, China

Correspondence should be addressed to Zhen Ma; mazhen@xafy.edu.cn

Received 10 March 2022; Revised 24 April 2022; Accepted 14 May 2022; Published 6 June 2022

Academic Editor: Lele Qin

In order to intuitively analyze and clearly understand the effect of industrial structure adjustment of the marine economy in recent years in China, modeling and empirical research on industrial structure adjustment of the marine economy are carried out. Three comparisons of marine economic industrial structure and per capita output value coefficient of the marine industry are selected as scientific measurement indexes, the ratio of regional entropy to the output value of marine scientific research management service industry is selected as the height analysis index, and the econometric model is constructed according to the influence of the scientificity and advancement of marine economic industrial structure on marine economic GDP. Based on the empirical analysis of the relevant economic data of China's marine industry from 2008 to 2018, the model variable stationarity test and least squares regression analysis showed that the fitting degree of the model was good and significant; with every 1% increase in the scientificity and height of marine economic industrial structure adjustment, the marine economy increased by 1.88% and 2.80%, respectively. The development of marine science and technology can promote the rise of the marine economy. According to the model, the adjustment strategy of the marine economy industrial structure is made to further promote the development of the marine economy.

1. Introduction

In recent years, the adjustment of marine economic industrial structure has led to the rapid growth of marine economic industrial output value [1]. Taking the marine economic industry along the Yellow Sea as an example, in the 1980s, the total output value of the marine economic industry along the Yellow Sea coast was about 6.5 billion, which rose rapidly to about 89 billion in the mid-1990s and reached more than 117 billion by the end of the 1990s, accounting for 32% of the total output value of China's marine economic industry [2]. At the beginning of the 21st century, the output value of the marine economic industry along the Yellow Sea rose to nearly 130 billion, accounting for 31% of the total output value of the national marine economy industry [3]. During the same period, the output value of the fishery, salt, marine transportation, and oil and gas in the region accounted for 39.6%, 74.0%, 23.3%, and 18.9% of the national total output value, respectively. In order to intuitively analyze and clearly understand the effect of China's marine economic industrial structure adjustment in recent years, the modeling and empirical research of marine economic industrial structure adjustment are carried out.

Scholars Wang and Zhai analyzed the adjustment of marine industrial structure, spatial spillover, and coastal economic growth [4] and obtained that coastal economic growth and marine industrial structure adjustment have obvious spatial dependence and marine industrial adjustment can promote the development of the marine economy; scholars Ning and Song have studied marine scientific and technological innovation and the dynamic relationship between marine total factor productivity and marine economic development [5] and obtained that marine economic development has an important impact on marine total factor productivity, so as to promote marine economic development. Strengthening the self enhancement mechanism can promote the promotion effect between marine total factor

productivity and scientific and technological innovation and enhance the development of the marine economy. Scholars Di and others studied the spatiotemporal coordination mode of marine economic development under the background of high-quality growth through the average model of spatiotemporal coordination degree based on the empirical results of prefecture level cities around the Bohai Sea [6]. They found that the economic system, ecosystem, and comprehensive system of the marine economy showed an alternating upward trend of small-scale concentration and dispersion, and the spatiotemporal clustering area of coordination degree had both spatial differentiation and overlap. However, the above-given three methods only analyze the influencing factors of the development of marine economic industry and do not consider the impact of the upgrading of marine economic industrial structure, so the analysis results have certain limitations.

Based on the above-described research, this paper constructs the regression model of industrial structure adjustment of the marine economy based on the least square method from the two aspects of scientific measurement indicators and high analysis indicators and makes an empirical study. The stationarity test of the model is carried out to verify the effectiveness of the model. Through the research of this paper, it is helpful to intuitively analyze and clearly understand the effect of industrial structure adjustment of the marine economy. At the same time, it can provide a basis for the industrial structure adjustment scheme of the marine economy.

2. Literature Review

China's economy is in a critical period of transformation from a traditional land economy to a marine economy. China is rich in marine resources and faces important development opportunities and challenges. The adjustment of marine economic industrial structure is of great significance to promote the development of China's marine economy. Li expounds the relevant theories of the linkage mechanism of marine and land industries, then analyzes the evolution and characteristics of Liaoning marine industry and land industry, measures the correlation between Liaoning marine and land industries through the grey correlation index, explores the corresponding relationship and correlation degree between marine and land industries, and finally puts forward countermeasures and suggestions from the aspects of extending the marine and land industrial chain, developing and utilizing the coastal zone, and enhancing the ability of scientific and technological innovation [7]. Xiaodan and Wu put forward the concept of an ecological industry network, analyzed four ecological industry levels of Poyang Lake Ecological Economic Zone: point, slice, line, and surface, analyzed the three-dimensional ecological industry network structure according to the characteristics of each network level, expounded the applicability of three different evolution paths of point slice surface, point line surface, and point surface, introduced the ecological industry network model into the path of ecological industry development of Poyang Lake Ecological Economic Zone, and identified four modes of eco-industrial network in the region to improve the ability of enterprises in the region to coordinate economic and environmental management; at the same time, based on the network structure and mode of ecological industry, this paper puts forward corresponding countermeasures and suggestions to enrich the construction content of ecological industry development in the region [8]. Jiaxin et al. measured the adjustment of China's marine industrial structure from the perspective of "two modernizations" and used Eviews 8.0 software to test the stability, cointegration, and least square regression between the "two modernizations" of China's marine industrial structure and marine economic growth from 2005 to 2015. According to the cointegration equation, every 1% increase in the rationalization and upgrading of marine industrial structure will drive the marine economy to rise by 1.87% and 2.96%, respectively; from the directionality of the regression coefficient of the least square method, it can be seen that the rationalization and upgrading of the marine industrial structure will promote the growth of the marine economy [9]. From the above-mentioned analysis, it can be seen that reasonable adjustment of marine economic industrial institutions is conducive to the further development of the marine economy. In addition to the above-given research, scholars Du et al. analyzed the relationship between marine industrial structure upgrading, marine scientific and technological innovation, and marine economic growth based on the provincial data panel vector autoregressive (pvar) model [10]. Scholars Ning et al. analyzed the marine industrial structure and employment effect based on the dynamic panel GMM estimation model [11].

3. Methods

The least squares regression model has the advantage of a simple solution, so this paper puts forward the analysis of industrial structure adjustment of the marine economy based on the least squares regression model. It is expected to provide data reference for making adjustment strategy of marine economy industry structure.

3.1. Modeling of Industrial Structure Adjustment of Marine Economy

3.1.1. Main Industrial Structure and Industrial Structure Adjustment of Marine Economy. The industrial structure of the marine economy mainly includes marine fishery, marine transportation, marine salt, marine oil and gas industry, and marine tourism. At present, the growth rate of the marine economic industry output value is higher than the overall development speed of the national economy, the development mode has changed from single project plane development to overall industry three-dimensional development, and the development scope gradually moves from coastal to shallow water.

(1) Marine Fisheries. As the first mock exam of marine economy, the development of marine fishery has changed from single mode to multimode and common development.

The backbone and main body of China's marine fishery development are state-owned fishery and mass fishery. Taking the Bohai Sea economic industry as an example, there are nearly 100000 fishing motor boats in this region and the labor force of mass fishery covers 170 towns and nearly 1500 fishing villages along the coast of the Bohai Sea. In the field of marine fishery in China, the Bohai Sea, the Yellow Sea, the East China Sea, and the ocean and other sea areas account for 30%, 50%, 10%, and 10%, respectively.

(2) Marine Transportation. China's coastline is the fourth largest in the world, reaching more than 32000 square kilometers. The rich marine resources provide the basic conditions for the development of the marine transportation industry. The development of China's marine transportation industry has a long history. Since Zheng He's voyages to the West in the Ming Dynasty, China's marine transportation industry has radiated to the south of Asia and involved some regions such as Africa and Europe. After that, due to the relevant policies of the government, the development of China's marine transportation industry once declined. After the founding of new China, affected by the reform and opening up policy, China's marine transportation industry has developed rapidly. In 2014, the overall throughput of China's ports increased by more than 5% compared with the previous year and the total trade volume of the marine transportation industry reached 4159 billion US dollars.

(3) Marine Salt Industry. The marine salt industry is also a traditional marine industry in China and plays an important role in the industrial structure of the marine economy, mainly including the production activities of sea salt drying, underground brine salt drying, and salt product processing [12]. The marine salt industry is the main source of salt production in China. Liaoning, Shandong, Jiangsu, Changlu, and other coastal areas are the main production areas of sea salt in China, and the annual output accounts for more than three-quarters of the total output.

(4) Offshore Oil and Gas Industry. Bohai oilfield is the earliest offshore oil field in China. Shengli, North China, and Liaoning oil and gas fields in the Bohai Sea area are connected with Bohai offshore oil fields and develop a lot of oil and gas resources. At present, the geological reserves of Jinzhou 9–3 oil and gas field, 20–2 oil and gas field, and Penglai 19–3 oil and gas field in Laizhou Bay in the Liaodong Peninsula are as high as 200 million tons, and the reserves of Bozhong 28–1 and 34–2 oil and gas fields in Central Bohai Sea are also high. At the end of the 20th century, the output of crude oil in the Bohai Sea was nearly 60 million tons, and it reached more than 6.5 million tons in the early 21st century, accounting for 30.5% and 31% of the national crude oil production, respectively. This shows that the offshore oil and gas industry in the Bohai sea has stepped from exploration to development.

(5) Marine Tourism. Marine tourism is one of the main modes of tourism development in China. For example, the Bohai Sea has famous coastal tourism cities such as Dalian, Qingdao, and Weihai, the Yellow Sea has coastal tourism cities such as Nantong, Lianyungang, and Rizhao, and the East China Sea includes famous tourist cities such as Shanghai, Xiamen, and Quanzhou. The development of the national economy drives the rapid development of tourism. At present, the infrastructure of coastal tourism cities is gradually improved, and the comprehensive tourism reception capacity is gradually improved.

3.1.2. Evaluation Index of Marine Economic Industrial Structure Analysis. In the analysis of marine industrial structure, this paper considers the availability of relevant data of the marine economic industry [13] and analyzes the scientificity and advancement of China's marine economic industrial structure adjustment from the aspects of three marine economic industrial structure comparisons. The main data sources used in the analysis are "China Marine Statistical Yearbook" and "China Marine Economic Statistics Bulletin."

3.1.3. Scientific Industrial Structure of Marine Economy. The scientificity of marine economic industrial structure is used to describe the enhancement of coordination ability and the improvement of correlation level among marine economic industries. When measuring the scientificity of marine economic industrial structure, three comparisons of marine economic industrial structure and per capita output value coefficient of the marine industry can be selected as measurement indexes.

(1) Comparison of Three Marine Economic Industrial Structures. The relative coordination of three marine economic industrial status is the basic requirement for the scientificity of marine industrial economic structure. The international comparison method is selected to measure the scientificity of marine economic industrial institutions, and the standard of Chenery is to standardize the industrial structure. Under the condition of the same GNP, the value of marine economic industrial structure and standard industrial structure of a country or region is compared. When the comparison results show that there is no deviation or the deviation is small, it is scientific to define the marine economic industrial structure of the country or region. On the contrary, it is not scientific to define the marine economic industrial structure of the country or region when the comparison results show that the deviation is large. As a part of the economic industrial structure, the marine economic industry has the characteristics of strong dependence on capital and technology [14]. Therefore, the development and adjustment of marine economic industrial structure is obviously different from that of ordinary economic industrial structure.

(2) Coefficient of Per Capita Output Value of Marine Economy Industry. The scientificity of marine economic industrial structure of a country or region requires that the technical level of marine economic industry in different regions should be kept in a coordinated state for a long time, that is to say, the numerical distribution of comparative

labor productivity of marine economic industries in different regions has the characteristics of concentration and hierarchy. The coefficient of per capita output value C is used to reflect the labor productivity of an industry in a region compared with the same industry in China. The calculation formula is as follows:

$$C = \frac{C_q}{C_g}. \tag{1}$$

Here, C_q and C_g, respectively, describe the per capita output value of an industry in a certain region and the per capita output value of similar industries in China.

Formula (1) is used to calculate the coefficient of per capita output value of the marine economy industry. When the calculation result is greater than 1, it means that the labor productivity of the research industry in the research area is higher than the national average level and it belongs to the specialized department of the research area. When the calculation result is less than 1, it means that the labor productivity of the research industry in the research area is lower than the national average level.

For a certain sea area, the per capita output value coefficients of marine economic industries in different provinces and cities in the sea area are compared, so as to measure the coordination of the technical level of marine economic industries among different provinces and cities in the sea area, and whether it meets the scientific requirements of the economic and industrial structure in the sea area.

3.1.4. Upgrading of Industrial Structure of Marine Economy

(1) Location Entropy. The industrial structure of the marine economy evolves in accordance with the dominant position of the three marine industries, which is the basic requirement for the upgrading of the industrial structure of the marine economy [15]. The development status of three marine industries can be judged by location entropy. The regional concentration index, i.e., location entropy, is used to describe the production. It can judge the relative specialization degree of different industrial sectors in different regions. Output value is a commonly used measurement index in location entropy. Therefore, location entropy, which uses output value as an indicator, can also be defined as output value concentration. The following formula shows the calculation formula of location entropy output value:

$$\begin{aligned} S &= \frac{f/F}{w/W} \\ &= \frac{f/w}{F/W}. \end{aligned} \tag{2}$$

Here, f and F describe the output value and GDP of an industry in the region and w and W, respectively, describe the output value and national GDP of the industry in China. In the process of determining the location entropy of marine economic industrial institutions, due to the fact that there are marine economic structure industries in 11 provinces and cities in China without considering Hong Kong, Macao, and Taiwan, the W value in formula (2) can be converted into China's coastal regional GDP. The result of the location entropy calculation is greater than 1, which means that the industrial development intensity of this region is higher than the average level of similar industries in China; on the contrary, it shows that the industrial development intensity in this region is low.

(2) Proportion of Output Value of Marine Scientific Research, Education, and Management Service Industry. In different periods, the ratio of high-tech industry in all industries of a country or a region can describe the level of the industrial structure of the marine economy. The higher the ratio is, the higher the industrial structure of the marine economy is. The development of the high-tech industry can be reflected by the level of marine scientific research and education management service industry. Comparing the proportion of marine scientific research and management service output value in the marine GDP of the region with the economic development level can describe the high level of the regional marine economic industrial structure.

4. Construction of the Industrial Structure Adjustment Model of Marine Economy

4.1. Model Construction. According to the view of structuralism, the transfer of production factor resources from departments with low utilization rate to departments with high utilization rate can promote economic upgrading [16]. At the same time, according to Solow's surplus theory, the improvement of the scientific and technological level also has a positive impact on economic promotion. Therefore, the scientific and technological project factors of marine scientific research institutions reflecting the level of marine science and technology can be used as auxiliary explanatory variables of the econometric model to improve the rationality of the measurement model. Thus, the econometric model of the impact of marine economic industrial structure adjustment on marine economic growth is obtained as follows:

$$\ln P_t = c_t + \alpha \ln R_t + \beta \ln H_t + \delta \ln T_t + y_t. \tag{3}$$

Here, P and t describe the growth and time of marine economy, R and H describe the scientificity and advancement of marine economic industrial structure, T and y describe scientific and technological projects and random interference items of marine scientific research institutions, ln describes logarithmic sequence, and c is constant.

4.2. Description of Variables and Data. In the econometric model shown in formula (3), there are four main variables: P (gross marine product), R (scientific nature of marine economic industrial institutions), H (upgrading of marine economic industrial structure), and T (scientific and technological projects of marine scientific research institutions). In the research process, the relevant data from 2008 to 2018 are selected as samples.

5. Results

5.1. Stability Test of Variables. In the process of empirical analysis, some economic variables are unstable, which easily leads to pseudo-regression. In order to avoid the phenomenon of pseudo-regression, the ADF unit root test method can be selected to test the stationarity of the model variables before using the model for regression analysis. Before testing the stationarity of variables, logarithm processing can be applied to the initial economic data to prevent heteroscedasticity in the initial economic data. The unit root test results of model variable ADF are shown in Table 1.

From the analysis of Table 1, the initial sequence of the four main variables in the model is shown as an unstable state. Therefore, the initial economic data are treated by differential processing. Thus, the four main variables are shown to be second-order stationary at the 5% significance level.

Table 1: ADF unit root test results of model variables.

Variable	lnP	ddlnP	lnR	ddlnR
ADF value	7.718	−4.271	−0.766	−3.391
1% threshold	−2.927	−4.693	−2.927	−4.693
5% threshold	−2.093	−3.431	−20.93	−3.431
10% threshold	−1.712	−2.912	−1.712	−2.912
Is it stable	NO	YES	NO	YES
Variable	lnH	ddlnH	lnT	ddlnT
ADF value	1.771	−4.393	2.947	−5.366
1% threshold	−2.927	−4.693	−2.927	−6.403
5% threshold	−2.093	−3.431	−20.93	−3.431
Variable	−1.712	−2.912	−1.712	−3.812
ADF value	NO	YES	NO	YES

Data source: 2008–2018 China Ocean Statistical Yearbook.

5.2. The Impact of Marine Economic Industrial Structure Adjustment on Marine Economic Growth. The least square regression analysis is used to analyze the influence of industrial structure adjustment of the marine economy on marine economic growth in China. The results are shown in Table 2.

Table 2: Analysis results.

Variable	C	lnR	lnH	lnT
Coefficient	2.9763	1.8810	2.7979	0.7690
Standard error	0.6523	2.6395	2.1448	0.0783
T value	4.6349	0.7225	1.4322	9.9192
P value	0.0024*	0.4999	0.2391	0.0000*

Note. *Rejection of the original hypothesis at the 5% significance level.

From the analysis of Table 2, the fitting degree of the model in this paper is good, which shows that the model is significant. Therefore, the regression model of the least square method is determined as follows:

$$\ln P_t = 2.9763 + 1.8810 \ln R_t + 2.7979 \ln H_t + 0.7690 \ln T_t + u_t. \quad (4)$$

It can be seen from Table 2 that the coefficients of constants and auxiliary variables in the model passed the significance test, while the scientific and advanced coefficients did not pass the significance test. Every 1% increase of independent variables ln R, ln H, and ln T will lead to the increase of dependent variable ln P by 1.88%, 2.80%, and 0.77%, respectively. Based on the regression coefficient, the scientific and advanced marine economic industrial structure can enhance the marine economic growth more than its own proportion and the development of marine science and technology can also promote the rise of the marine economy.

6. Discussion

The traditional economic growth theory holds that when the economy is in equilibrium, economic growth is subject to capital, labor, and technology and the industrial structure has no impact on the efficiency of economic growth. Due to the interference of government intervention, market obstacles, and institutional factors, the market is difficult to achieve equilibrium. Therefore, this paper puts forward the analysis of industrial structure adjustment of the marine economy based on the least square regression model, in order to provide some help for the development of the marine industry in the future.

Firstly, this paper summarizes the main structure of the marine economic industry and the industries of industrial structure adjustment, including marine fishery, marine transportation, marine salt industry, marine oil and gas industry, and marine tourism. Analyzing the marine economic industry from many aspects will help to solve the singleness of the analysis results of industrial structure adjustment with a single industry as the starting point in the existing research.

Secondly, it analyzes the scientificity and height of China's marine economic industrial structure adjustment from the three comparisons of marine economic industrial structure. Among them, the scientific aspect is compared from the industrial structure of three marine economies and the per capita output value coefficient of the marine economy industry and the high degree is analyzed from the two aspects of location entropy and the output value proportion of marine scientific research, education, and management service industry.

Finally, based on the least square method, this paper constructs the regression analysis model of industrial structure adjustment of the marine economy and makes an empirical analysis by using the time series data from 2008 to 2018. According to the results of empirical analysis, the following conclusions are drawn: the scientificity and upgrading of China's marine industrial structure has a positive effect on China's marine economy. According to the empirical analysis results, the scientific and advanced marine industrial structure is conducive to the improvement of marine economic growth efficiency; that is, the scientific and advanced marine industrial structure has a positive effect on China's marine economy.

7. Conclusion

This paper constructs an econometric model from the scientific and advanced aspects of the industrial structure of the

marine economy, analyzes the impact of the industrial structure adjustment of the marine economy on the increase of the marine economy, and makes an empirical analysis based on the time series data from 2008 to 2018. The results show that the scientific and advanced industrial structure of the marine economy has a positive effect on marine economic growth.

However, this study failed to pass the significance test. The reason is that the relevant data volume does not meet the sample size required for multiple regression analysis, resulting in insignificant regression results. It may also be that the scientific and highly oriented adjustment of marine economic industrial structure in the time series data used in the process of model analysis is not obvious, resulting in insignificant regression results.

Therefore, the next research will focus on the significance test to further improve the scientificity of the model.

Data Availability

The data used to support the study are included in the paper.

Acknowledgments

One of the achievements of the Shaanxi Port Economic Coordinated Development Research Team (XFUKYTDA02) under the new opening pattern.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] B. Wang and L. Han, "The impact of changes in China's marine industrial structure on Marine Economic Growth -- Based on the panel threshold effect regression analysis of 11 coastal provinces and cities," *Resources Science*, vol. 39, no. 6, pp. 1182–1193, 2017.

[2] J. Liu and J. Tu, "Research on the impact of China's industrial structure adjustment on low carbon logistics efficiency: An Empirical Analysis Based on super efficiency DEA low carbon logistics efficiency evaluation model," *Price theory and practice*, vol. 012, pp. 130–133, 2017.

[3] Z. Zhang and S. Qin, "Spatial effects of environmental regulation and industrial structure adjustment on green development: An Empirical Study Based on cities in the Yangtze River economic belt," *Discussion on modern economy*, vol. 443, no. 11, pp. 85–92, 2018.

[4] Y. Wang and R. Zhai, "Adjustment of marine industrial structure, spatial spillover and coastal economic growth: An analysis based on spatial panel data of China's coastal provinces," *Journal of Nantong University (SOCIAL SCIENCE EDITION)*, vol. 036, no. 1, pp. 97–104, 2020.

[5] L. Ning and Z. Song, "Dynamic relationship between marine science and technology innovation, marine total factor productivity and marine economic development -- an Empirical Analysis Based on panel vector autoregressive model," *Science and technology management research*, vol. 040, no. 6, pp. 164–170, 2020.

[6] Q. Di, Z. Yu, and L. Xu, "Research on the spatiotemporal coordination model of marine economic development under the background of high-quality growth: An Empirical Study Based on prefecture level cities in Bohai Rim region," *Geographic Sciences*, vol. 39, no. 10, pp. 1621–1630, 2019.

[7] J. Li, "Analysis on the linkage development of sea-land industry——A case study of liaoning," *Special Zone Economy*, vol. 02, pp. 102–106, 2018.

[8] L. I. Xiaodan and Y. Wu, "The structure and model of ecological industry network in Poyang Lake eco economic zone," *Journal of Jiujiang University (Natural Science Edition)*, vol. 33, no. 1, pp. 1–6+22, 2018.

[9] L. I. Jiaxin, C. Tan, and S. O. University, "An empirical study of marine industrial structure adjustment and marine economy in China," *Ocean Development and Management*, vol. 36, no. 3, pp. 81–87, 2019.

[10] J. Du, J. Kou, and P. Zhao, "Upgrading of marine industrial Structure,Innovation of marine science and technology and marine economic growth:analysis based on panel vector autoregressive (PVAR) model of interprovincial data," *Science and Technology Management Research*, vol. 39, no. 21, pp. 137–146, 2019.

[11] L. Ning, L. I. Le, and G. O. University, "An empirical study on China's marine industrial structure and employment effect: GMM estimation analysis based on dynamic panel," *Ecological Economy*, vol. 35, no. 1, pp. 43–47+78, 2019.

[12] R. Yang and H. Yu, "Suitability of talent structure of higher education with industrial demand -- Based on empirical analysis of structural deviation degree of Hunan Province from 2008 to 2017," *University Education Science*, vol. 006, no. 6, pp. 74–80, 2019.

[13] J. Du, J. Kou, and P. Zhao, "Upgrading of marine industrial structure, marine scientific and technological innovation and marine economic growth: An analysis based on the provincial data panel vector autoregressive (pvar) model," *Science and technology management research*, vol. 021, pp. 137–146, 2019.

[14] X. Jie, H. Wang, Y. Wang et al., "Measurement and spatial characteristics of China's marine S&T innovation capability: empirical analysis based on 36 sea-related cities," *Science and Technology Management Research*, vol. 040, no. 10, pp. 65–71, 2020.

[15] P. Zhou, "Relationship between the industrial structure of marine economy and the development of macroeconomy: An exploratory study," *Journal of Coastal Research*, vol. 106, pp. 9–12, 2020.

[16] X. Wei, Q. Hu, W. Shen, and J. Ma, "Influence of the evolution of marine industry structure on the green total factor productivity of marine economy," *Water*, vol. 13, no. 8, p. 1108, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4000024, 8 pages
https://doi.org/10.1155/2022/4000024

Research Article

Does Shanghai International Financial Center Promote RMB Internationalization?

Lijun Li and Feng Xu

Business College of Beijing Union University, Beijing 100025, China

Correspondence should be addressed to Feng Xu; feng.xu@buu.edu.cn

Received 15 March 2022; Accepted 5 May 2022; Published 6 June 2022

Academic Editor: Lele Qin

The construction of the Shanghai International Financial Center was completed in 2020, which signaled the new age of financial reforms in China. The Shanghai International Financial Center plays a significant part in the progress of RMB internationalization. However, empirical proof of the impacts remains few. So, we conducted an empirical analysis to determine if the Shanghai International Financial Center promoted RMB internationalization effectively. To obtain robust results, we conducted regressions with Newey–West standard errors, Cochrane–Orcutt estimation, and Prais–Winsten estimation. We observed that the Shanghai International Financial Center has significant positive effects on RMB internationalization by expanding financial scale and activity. The findings give adequate evidence to support the theories advanced in prior research, and the methodology and indicators used in the study may serve as a guide for future research. We made several policy discussions of the findings regarding the continued expansion of the offshore market and capital liberalization within Shanghai.

1. Introduction

In 2009, the Chinese government announced its plan to elevate Shanghai to the International Financial Center (IFC) status to pioneer international renminbi (RMB) trade settlement and financial market reforms. The Shanghai Pilot Free Trade Zone (FTZ) was established in 2013 and has played a critical role in furthering the RMB's internationalization and financial reforms. Shanghai IFC's construction was completed in 2020.

The GDP of Shanghai reached 3.87 trillion yuan in 2020, in which the output of the financial industry increased by 716.63 billion yuan or 25.32 percent of the total tertiary industrial output. Financial services have developed into one of the most vital sectors of Shanghai's economy. The highly developed financial market in Shanghai plays a significant role in financial reforms. In 2020, Shanghai was placed third in the world in the Global Financial Centers Index for the first time.

With China's economy and trade expanding, the RMB's use in global markets rose considerably. The status of the Dollar is deteriorating, particularly in the aftermath of the subprime mortgage crisis in 2007–2008, and the global monetary system is progressively shifting toward a leaderless and multipolar currency system (B. J. Cohen [1] and B. Eichengreen [2]). China began promoting RMB internationalization in response to the shifting worldwide financial architecture to alleviate the challenges associated with the reliance on the Dollar [3].

RMB internationalization began in 2009, with the announcement in 2018 of pilot programs enabling the use of the RMB in cross-border trade settlement. As the world's largest exporter and second-largest importer, China has the potential to expand the RMB's use in global markets due to the volume of trade. The RMB was adopted as a composition currency for the Special Drawing Rights (SDR) in 2016, accounting for 10.92 percent of the total. According to the 2019 BIS Triennial Central Bank Survey, global RMB usage increased from 0.1 percent to 4.3 percent, boosting the currency's ranking from 29th to eighth. China has made headway toward the internationalization of the RMB, although its global use remains limited in comparison with the USD, ERO, and JPY.

Shanghai IFC plays the role of the pilot zone for RMB cross-border settlement for trade and capital liberalization. So Shanghai IFC must give credible experiences in policy formulation and implementation to advance financial reforms and RMB internationalization in China. Thus, it is critical to determine if the Shanghai IFC is capable of promoting RMB internationalization. However, there are few studies devoted to this critical subject.

Numerous studies have been conducted on the RMB's potential as an international currency since 2010. Multiple studies proposed that China's massive economy and cross-border trade will result in the RMB emerging as a new worldwide currency (B. J. Cohen [1]; Wu et al. [4]; Chen and Peng [5]; J.-W. Lee [6]). Eichengreen and Kawai [7] noted that significant progress had been made on RMB settlements for trade and RMB-denominated bond issuance. T. Ito [8] stated that the RMB's weight in the private and public sectors had increased significantly. McNally and Gruin [9] argued that China adopted a unique mode of monetary governance, which may result in the RMB gaining a more significant market share in the global markets. However, the road to internationalization for RMB will be bumpy [10], and capital liberalization is necessary for the currency's further expansion (J.-W. Lee [6]; Eichengreen and Kawai [7]; T. Ito [8]).

Shanghai IFC was highlighted multiple times in these studies and was viewed as an effective technique to promote the worldwide use of RMB. However, in comparison with Hong Kong's offshore market, the Shanghai IFC primarily serves as an onshore market, which may hinder capital liberalization and weaken the contribution to RMB internationalization [11]. Zhao and Wang [12] and Huang et al. [11] conducted empirical analyses of the effects of Shanghai FTZ (a critical component of Shanghai IFC) on international RMB use. They discovered that the effects were not substantial, contrary to earlier theoretical research. Pan et al. [13] discovered that Shanghai IFC plays an increasing role in global markets and contributes to the internationalization of the RMB.

The findings of Zhao and Wang [12] and Huang et al. [11] are unsurprising, given the difficulty of observing the effects of Shanghai IFC's comprehensive policies over a one- or two-year period and the data sample size. Additionally, these researches concentrated on the Shanghai FTZ, distinct from the IFC. Pan et al. [13] gave some reasonable results on the subject, but indirectly. In 2020, the construction of the Shanghai IFC was completed, and policies and markets would have been stable and effective. We feel that the moment has come to examine whether Shanghai IFC aided in the progress of RMB internationalization during the last decade.

We conducted an empirical analysis using RMB data spanning 2012 to 2021. We began the study by looking at previous studies, in which we discovered the fundamental theories that would support the corresponding analysis. In the theoretical analysis section, we identified cross-border trade settlements and cross-border investment and finance as the primary factors of RMB internationalization. We examined the impact of the Shanghai IFC on these two variables. We used financial scale and activity to quantify the Shanghai IFC's characteristics, and RMB cross-border settlements for general trade and RMB cross-border direct investment were used to quantify the determinants of RMB internationalization. We applied regressions with Newey–West standard errors, Cochrane–Orcutt estimation, and Prais–Winsten estimation to conduct the analysis. The results indicated that the establishment of the Shanghai IFC had a significant effect on RMB internationalization. Our research addressed the unresolved question from prior studies and provided empirical evidence and discussions for future policy formulation and implementation.

2. Theoretical Foundation

2.1. The Determinants of Currency Internationalization. Numerous research studies have been conducted on the determinants of currency internationalization. Strange and Cohen [14] offered six roles for "fully developed" international currency, based on the fundamental argument about currency's functions such as medium of exchange, store of value, and unit of account, in both the private and official sectors. P. Krugman [15] examined the Dollar's international role in light of the previous theory and proposed that a country's importance in the global market and the self-reinforcement of the international currency's usefulness were two determinants of the Dollar's internationalization, laying the groundwork for subsequent research. Bacchetta and Van Wincoop [16] discovered that the exporting country with a larger market share and more varied goods tends to possess greater power in using its currency in the settlements for trade, which is consistent with P. Krugman's [15] findings.

Chinn and Frankel [17] identified four determinants of currency internationalization: (a) output and trade patterns, (b) the country's financial markets, (c) currency confidence, and (d) network externalities. These determinants were utilized in part or entirely in empirical studies on currency internationalization (J.-W. Lee [6]; Goldberg and Tille [18]; He et al. [19]; Cui et al. [10]). Chen and Peng [5] classified variables into three categories: ancestry, acceptability, and availability, covering more specific indicators, such as economic size, trade volume, stock market capitalization, and currency volatility. Some studies included macro- and microeconomic indicators to validate the primary factors of the choice of invoicing currency, which is considered a form of currency internationalization (Goldberg and Tille [18]; Batten and Szilagyi [20]; W. Chung [21]; Li et al. [22]).

H. Chey [23] classified the determinants of currency internationalization into two categories: economic and political. Economic considerations are primarily concerned with currency confidence and convenience, which are mostly consistent with the determinants identified by Chinn and Frankel [17] and comparable studies. Political issues influence currency internationalization in both direct and indirect ways. Politics either has an indirect effect on currency internationalization through improving economic conditions or has an immediate effect on currency internationalization without affecting economic factors.

2.2. The IFC's Effect on Currency Internationalization. The financial market is a critical factor in determining a currency's international use, and a large, liquid, open, and deep financial market helps a currency achieve international status [17]. Numerous studies have established that a well-developed financial system considerably boosts the currency's global market power, and a deep and liquid financial market attracts international investors, hence expanding the currency's use [24]. According to some research, the Chinese financial market still needs further progress toward the creation of an effective financial system (Chen and Peng [5]; J.-W. Lee [6]; Huang et al. [11]; T. Ito [8]).

Offshore markets play essential roles in the progress of currency internationalization. He and McCauley [25] discovered that offshore markets contribute to the currency's recognition and adoption by facilitating trade settlement, investment, and finance outside the country, which benefits the capital account liberalization process. They also suggested that offshore markets could have an effect on the domestic economy's financial stability. Y. Cheung [26] proposed that offshore markets could enhance the currency's convenience and confidence. The effectiveness of offshore markets should be evaluated in light of several factors, including the economy's size and trade volume, the financial market's structure, capital account openness, and economic and political stability. There are two RMB markets in China: the offshore market in Hong Kong and the onshore market in Shanghai, which are connected via the Shanghai-Hong Kong Connect [8]. Since July 2021, Shanghai has also begun to organize RMB offshore trading, which will enable Shanghai to contribute more to the internationalization of the RMB as a domestic offshore market.

In 2008, the Chinese government announced the establishment of five pilot cities (including Shanghai) to test RMB-based trade settlement with foreign counterparties, and the plan to build the Shanghai IFC in 2019 to expedite financial reforms. Chen and Peng [5] suggested that these actions might strengthen the currency's ancestry and acceptability and boost RMB internationalization. Zhao and Wang [12] concentrated on the effects of the Shanghai FTZ and found it effectively promotes the use of RMB in theory, but the empirical findings were insignificant. Huang et al. [11] discovered that the rates of RMB onshore and offshore markets are pretty close, implying that the contribution of the Shanghai FTZ is negligible. Pan et al. [13] discovered that China's financial centers (including the Shanghai International Financial Center) are becoming increasingly important in global financial markets, and Chinese financial service firms can leverage financial infrastructure and networks to expand the use of the RMB in financial transactions.

3. Theoretical Analysis

In previous research, the IFC was seen as an efficient technique to encourage the international use of a currency. Specifically, a well-constructed IFC could provide superior financial markets and network externalities and attract foreign institutions and investors. In traditional economics, foreign currency has six roles in the economy, including the medium of exchange, store of value, and unit of account, both in private and official use. Shanghai IFC may expand the RMB's functions of medium of exchange and unit of account through RMB cross-border settlement for trade and RMB cross-border investment and financing.

3.1. RMB Cross-Border Settlement for Trade. With the continuous rise of China's economy, the size of China's foreign trade kept expanding. This boosted the demand for RMB as the settlement currency. In 2009, as the IFC, Shanghai was designated as one of four cities in China that performs trials of RMB settlement of cross-border trade. In 2013, Shanghai launched the first FTZ in mainland China, in which both foreign and domestic funds are all settled in RMB. These initiatives strengthened the pricing function of RMB, fostered the development of RMB trade settlement, and widened the RMB adoption by neighboring nations. In Shanghai FTZ, RMB takes the lead in realizing the opening-up of the capital account and later realizing the convertibility of capital. The establishment of Shanghai FTZ is a milestone in RMB internationalization.

According to the data released by the People's Bank of China, after establishing the Shanghai FTZ in 2013, the amount of RMB cross-border settlement of trade surged dramatically, reaching 4.63 trillion yuan in 2013, soaring 57.48 percent year-on-year. In 2019, RMB cross-border trade settlement climbed to 6.04 trillion yuan. In 2020, notwithstanding the impact of COVID-19, RMB cross-border trade settlement reached 4.29 trillion yuan.

3.2. RMB Cross-Border Investment and Financing. In 2020, the construction of the Shanghai IFC was completed. Shanghai gathered various financial trading platforms and established reliable financial market infrastructures that support the issuance, transaction, and risk management of RMB financial assets, strengthen the RMB's payment and pricing functions and promote RMB investment and financing internationalization. According to World Federation of Exchanges data, Shanghai Stock Exchange became the world's third-largest exchange at the end of 2020.

With the establishment of RQFII, the Shanghai-Hong Kong Stock Connect, Bond Connect, and SGE International, foreign investors are increasingly entering China's financial markets, expanding RMB cross-border investment channels and enhancing RMB internationalization. According to China's National Bureau of Statistics, direct investment in RMB increased significantly following 2014. In 2020, RMB cross-border direct investment reached 2.23 trillion yuan, up to 112.58 percent from 2014 levels, with foreign direct investment increasing to 1.65 trillion yuan and outward direct investment increasing to 0.58 trillion yuan.

In RMB cross-border financing, issuers of Panda Bonds increased their diversification, while foreign entities increased their participation as issuers. Panda Bonds were issued in Shanghai by some countries, most notably

those along the Belt and Road, such as Russia and Poland. By the end of 2020, foreign governments, international development institutions, financial institutions, and non-financial institutions had issued Panda Bonds worth 1 trillion yuan, an increase of 20.24 billion yuan from 2019. The expansion of RMB bonds and its share in the global bond market were facilitated by the continued development of Panda Bonds, which increased the breadth and depth of China's bond market and facilitated the deep interactions between the domestic and global financial markets.

4. Empirical Analysis

4.1. Variables and Data. The scale and activity of the financial markets provide insight into the characteristics of the Shanghai IFC. The greater the financial scale and activity, the more advanced the IFC is and the greater the influence it may have on the global financial market. We chose Shanghai deposits in RMB and foreign currencies (*SDrfc*) as the financial scale indicator because it reflects Shanghai's attractiveness to domestic and foreign capitals. Given that a sizable portion of financial transactions in Shanghai takes place on the Shanghai Stock Exchange, including domestic and foreign investments, it is reasonable to use the Shanghai Stock Exchange's trading volume (*SEtrade*) as a proxy for financial activity.

The proportion of RMB in COFER (Currency Composition of Official Foreign Exchange Reserves) and RMB cross-border settlements of general trade were previously used to quantify the internationalization characteristics of the RMB. Since 2016, RMB reserves have been included in COFER, but their share remains small, limiting the amount of data available for our research. So we chose the scale of RMB cross-border general trade settlements (*CBtrade*) as a proxy for RMB internationalization. We chose the scale of RMB cross-border direct investment (*DInvest*) as the indicator to capture the characteristics of RMB cross-border investment and financing.

We used monthly data from January 2012 to November 2021 for this study. The data mainly comes from China's National Bureau of Statistics, the People's Bank of China, and the CSMAR Database. To obtain a stationary data sample, we took the logarithms of each variable. We used linear interpolation to fill in the missing values. The results of descriptive statistics of the data sample are shown in Table 1.

Table 1: Descriptive statistics.

Variable	Observation	Mean	Std. Dev.	Min	Max
CBtrade	119	8.4051	0.3199	7.1577	8.9848
DInvest	119	7.1795	0.9608	4.7875	8.6634
SDrfc	119	4.6213	0.3198	4.0388	5.1476
SEtrade	119	10.5690	0.7070	9.1133	12.2079

4.2. Regression Model

4.2.1. Structural Change Test. The stability of model coefficients has an effect on the fitting results in time series analysis. If the data sample exhibits obvious structural changes; that is, if the observed values differ significantly across time periods and the corresponding linear regression coefficients differ significantly, the fitting results will have significant errors, reducing the model's accuracy. It is easy to see from the time series lines of each variable that the structure of SDrfc has a noticeable difference around January 2015 (as indicated by the vertical line in Figure 1), implying that the SDrfc data sample may have structural changes. The development of Shanghai IFC entered a new era with the establishment of the Shanghai FTZ in September 2013 and the Shanghai-Hong Kong Stock Connect in November 2014. With policies having a lagged effect, it is reasonable to hypothesize that the data structure may have changed after December 2014.

To assess structural change in the research, we used both the Chow test and a dummy variable. We chose January 2015 as the cut-off point based on the time series line and introduced the dummy variable D and its interaction with *SDrfc*, denoted by *DSDrfc*. D is defined as:

$$D_t = \begin{cases} 1, & \text{after January 2015 (including)}, \\ 0, & \text{others}. \end{cases} \tag{1}$$

We obtained an F-value of 48.91 in the Chow test, an F-value of 69.18, and a P value of 0.00 in the dummy variables test using robust standard errors in the regression of *CBtrade*. The results indicate that at the 1% level of significance, the null hypothesis of "no structural change" can be strongly rejected. The regression results for *DInvest* are consistent with those for *CBtrade*. As a result, we believe that the *SDrfc* data sample's structure changed after January 2015.

4.2.2. Lagged Variables. As indicated by the time series lines, the trend of *SEtrade* lagged behind that of *CBtrade* and *DInvest*. Because stock trading on the Shanghai Stock Exchange is unlikely to have a significant effect on RMB cross-border settlement or direct investment in the near future, it is reasonable to incorporate lagged variables into economic models.

To determine the optimal lags for *SEtrade*, we used the AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion). We calculated AIC and BIC separately for first to sixth order lags and discovered that the third-order lagged variable is optimal for *CBtrade* regressions, and the fifth-order lagged variable is optimal for *DInvest* regressions. As a result, we obtained the following regression models:

$$\begin{aligned} CB\text{trade}_t &= \beta_1 SDrfc_t + \beta_2 SE\text{trade}_t + \beta_3 SE\text{trade}_{t-3} \\ &\quad + \beta_4 D_t + \beta_5 D_t \times SDrfc_t + \beta_0 + \varepsilon_t, \\ D\text{Invest}_t &= \beta_1 SDrfc_t + \beta_2 SE\text{trade}_t + \beta_3 SE\text{trade}_{t-5} \\ &\quad + \beta_4 D_t + \beta_5 D_t \times SDrfc_t + \beta_0 + \varepsilon_t, \end{aligned} \tag{2}$$

where β_1, β_2, β_3, β_4, and β_5 are the coefficients, β_0 is the intercept, and ε_t is the residual error.

Figure 1: Time-series line of data sample.

Table 2: Summary of results.

Panel A: RMB cross-border settlement of trade				
	OLS	HAC	CO	PW
$SDrfc_t$	3.9084*** (0.4288)	3.9084*** (0.4623)	3.5475*** (0.7358)	3.8380*** (0.6429)
$SEtrade_t$	0.1397*** (0.0343)	0.1397*** (0.0358)	0.1697*** (0.0388)	0.1669*** (0.0386)
$SEtrade_{t\text{-}3}$	0.1377*** (0.0362)	0.1377*** (0.0363)	0.0626 (0.0392)	0.0650* (0.0390)
D_t	14.2158*** (1.8478)	14.2158*** (1.8896)	13.0964*** (3.2133)	14.3384*** (2.8250)
$Dt \times SDrfc_t$	−3.4645*** (0.4345)	−3.4645*** (0.4471)	−3.1703*** (0.7539)	−3.4624*** (0.6623)
Constant	−10.8777*** (1.7380	−10.8777*** (1.8770)	−8.9371*** (3.0040)	−10.1673*** (2.5946)
F-value	55.96	71.84	18.68	67.48
R-square	0.7178	0.7178	0.4615	0.7541
Observation	116	116	115	116
Panel B: RMB cross-border direct investment				
	OLS	HAC	CO	PW
$SDrfc_t$	8.9337*** (1.0550)	8.9337*** (0.7466)	9.6198*** (1.5065)	9.4082*** (1.4021)
$SEtrade_t$	0.0203 (0.0723)	0.0203 (0.0806)	0.1212 (0.0859)	0.1211 (0.0854)
$SEtrade_{t\text{-}5}$	0.2577*** (0.0774)	0.2577** (0.1069)	0.1692* (0.0894)	0.1663* (0.0884)
D_t	29.25841*** (4.5196	29.25841*** (3.3460)	32.2873*** (6.5053)	31.3810*** (6.0610)
$Dt \times SDrfc_t$	−6.9411*** (1.0634)	−6.9411*** (0.7671)	−7.6572*** (1.5293)	−7.4437*** (1.4246)
Constant	−34.1685*** (4.3076)	−34.1685*** (2.9672)	−37.1947*** (6.2092)	−36.2667*** (5.7262)
F-value	131.58	131.58	61.80	62.89
R-square	0.8590	0.8590	0.7428	0.7443
Observation	114	114	113	114

*Note.****,**, and * denote significance at 1%, 5%, and 10%, respectively, and the standard errors of each coefficient are enclosed in parentheses.

4.2.3. Research Method. To test the significance of the effects, we primarily used regression models. We tested the economic model's heteroskedasticity and autocorrelation. The heteroskedasticity test was conducted using the White and Breusch–Pagan tests. In the regression of *CBtrade*, we obtained a *P* value of 24.83 percent in the White test and 83.74 percent in the Breusch–Pagan test, indicating that no evidence of heteroskedasticity in the regression model. To test the autocorrelation of the error term, we used the Breusch–Godfrey LM test and the Durbin–Watson test. We obtained a *P* value of 0.00 for the Breusch–Godfrey LM test and a d-statistic of 1.22 for the *CBtrade* regression, indicating significant autocorrelation. The regression results for *DInvest* are consistent with the results mentioned previously, so we will not display the details of these results.

To address the autocorrelation of the error term in the regression model, we performed regressions separately using Newey–West standard errors (HAC), Cochrane–Orcutt estimation (CO), and Prais–Winsten estimation (PW). Standard error estimations are revised in the HAC

Table 3: Summary of robustness test results.

	(1)			(2)		
	HAC	CO	PW	HAC	CO	PW
$SDrfc_t$	4.32*** (0.65)	4.21*** (0.91)	4.37*** (0.80)	8.22*** (0.84)	8.43*** (1.30)	8.45*** (1.22)
$SEtrade_t$	0.26*** (0.05)	0.25*** (0.05)	0.25*** (0.05)	0.03 (0.08)	0.08 (0.08)	0.08 (0.08)
$SEtrade_{t\text{-}3,5}$	0.13** (0.06)	0.06 (0.05)	0.06 (0.05)	0.20* (0.11)	0.15* (0.08)	0.15* (0.08)
F-value	47.02	17.08	33.37	166.52	71.05	72.23
R-square	0.67	0.44	0.60	0.84	0.77	0.77
Observation	116	115	116	114	113	114

*Note.****,**, and * denote significance at 1%, 5%, and 10%, respectively, and the standard errors of each coefficient are enclosed in parentheses.

regression to account for autocorrelation effects while leaving the regression coefficients unchanged. The feasible generalized least squares (FGLS) regressions, including CO and PW estimations, employ an iterative procedure to eliminate autocorrelation and obtain robust results.

4.3. Results. The regression results (Table 2) indicate that the independent variables have a significant positive correlation with the dependent variables *SDrfc* and *SEtrade*, indicating that Shanghai's deposits in RMB and foreign currencies and the trading volume of the Shanghai Stock Exchange both have a positive effect on RMB internationalization. As illustrated in panel A of Table 2, the Shanghai IFC's financial scale (as measured by *SDrfc*) and financial activity (as measured by *SEtrade*) significantly boost RMB cross-border trade settlement. These effects are also reflected in RMB cross-border direct investment (as illustrated in panel B of Table 2). However, the difference is that financial activity exhibits a clear hysteresis effect on RMB cross-border direct investment, as only the coefficients of the lagged *SEtrade* are significant.

The results suggest that the expansion of financial scale and activity in Shanghai has benefited both RMB cross-border settlements in general trade and direct investment, implying that the Shanghai IFC promoted RMB internationalization.

4.4. Robustness Test. Under the current account, cross-border trades include trades in goods and services. Given that RMB cross-border settlement of goods trade accounts for approximately 75% of total RMB cross-border settlement in trade, we used the indicator in place of *CBtrade*. The regression results (see column (1) of Table 3) indicate that *SDrfc* and *SEtrade* are positively correlated with the independent variable.

Under the capital account, the direct investment includes ODI (Outward Direct Investment) and FDI (Foreign Direct Investment). Because FDI accounts for 75% of RMB cross-border direct investment, we chose FDI to replace *DInvest*. According to the regression results (see column (2) of Table 3), we discovered that *SDrfc* and lagged *SEtrade* have a significant positive correlation with FDI. The robustness test results are consistent with the main findings, demonstrating the robustness of our empirical results.

5. Concluding Remarks

Based on the theoretical analysis of the effect of Shanghai IFC on RMB internationalization, we conducted an empirical analysis to determine whether the construction of Shanghai IFC benefits the process of RMB internationalization. We found that Shanghai IFC's financial size, scale, and activity can effectively boost RMB cross-border trade settlement and RMB cross-border direct investment, implying that Shanghai IFC has a sizable impact on RMB internationalization.

Our research addressed a critical question that remained unresolved in previous studies and provided reasonable empirical evidence for related theoretical findings. The theoretical analysis established a more precise framework for subsequent research, and the methods and indicators employed in the study serve as a helpful reference for subsequent empirical analysis on related topics. Our findings established the efficiency of the Shanghai IFC in the process of RMB internationalization, implying that it would be prudent to replicate the policies and practices of the Shanghai IFC in additional cities throughout China. Additionally, the suggestions we make below may aid in the development of policy and practice at the Shanghai IFC.

Based on our findings, we believe that further development of the Shanghai IFC is necessary and beneficial for RMB internationalization. We propose that in the future, policymakers and supervisors should prioritize accelerating the development of Shanghai's offshore RMB market, enhancing the multilayered capital market, and strengthening financial regulation in order to avert systemic financial risk.

An RMB offshore market in Shanghai could contribute to the further opening of China's financial market by enhancing the RMB's two-way circulation mechanism between onshore and offshore markets, providing a more active market for RMB securities, and increasing the currency's international use. Shanghai's offshore market will be well connected to the onshore market, which could help Shanghai establish itself as a global center for RMB foreign exchange transactions, cross-border settlements, and cross-border investment.

Shanghai has established a fully functional IFC and a multitiered capital market. However, compared with some mature international financial centers, such as London and Hong Kong, the Shanghai IFC still requires improvement.

A sophisticated registration-based initial public offering (IPO) system should be adequately implemented on the Shanghai Stock Exchange to optimize capital market functions. Appropriate financial innovations should be encouraged to upgrade the financial market's activity, and capital liberalization should be enhanced to attract more foreign investors.

Increased financial scale and activity also expose the market to increased systemic financial risk. Thus, as the RMB internationalizes, the supervisor should take more effective measures to avoid systemic financial risk, such as strengthening the macro prudential regulatory system, enhancing the monitoring and supervision of cross-border capital flows, and implementing countercyclical financial market adjustment.

Additionally, there are some obvious limitations to this research. Due to the data sample's limitations, we did not use the RMB internationalization index or create a development index for the Shanghai IFC. To obtain more precise empirical results, we intend to collect additional data in the future and select appropriate methods for developing sophisticated indexes to assess the degree of RMB internationalization and the Shanghai International Financial Center. Besides that, the mechanism by which the Shanghai IFC influences RMB internationalization is still unknown in theory. With the establishment of an offshore market in Shanghai, the issue will become more complex. Thus, additional theoretical research is required to elucidate this issue.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was financially funded by the project of the Beijing Philosophy and Social Science Foundation (21JJC024).

References

[1] B. J. Cohen, "Toward a leaderless currency system," *The Future of Global Currency: The Euro versus the Dollar*, pp. 148–166, Routledge, Oxfordshire, UK, 2011.

[2] B. Eichengreen, "Managing a multiple reserve currency world," *The Future Global Reserve System*, An Asian Perspective, Baltimore, Maryland, 2010.

[3] T. Ito, "Changing international financial architecture: growing Chinese influence?" *Asian Economic Policy Review*, vol. 13, no. 2, pp. 192–214, 2018.

[4] F. Wu, R. Pan, and D. Wang, "Renminbi's potential to become a global currency," *China and World Economy*, vol. 18, no. 1, pp. 63–81, 2010.

[5] H. Chen and W. Peng, "The potential of the renminbi as an international currency," *Currency Internationalization: Global Experiences and Implications for the Renminbi*, Palgrave Macmillan, London, UK, pp. 115–138, 2010.

[6] J.-W. Lee, "Will the renminbi emerge as an international reserve currency?" *The World Economy*, vol. 37, no. 1, pp. 42–62, 2014.

[7] B. Eichengreen and M. Kawai, "Issues for renminbi internationalization: an overview," *ADBI Working Paper*, Asian Development Bank Institute, vol. 454, 2014.

[8] T. Ito, "A new financial order in Asia: will a RMB bloc emerge?" *Journal of International Money and Finance*, vol. 74, pp. 232–257, 2017.

[9] C. A. McNally and J. Gruin, "A novel pathway to power? Contestation and adaptation in China's internationalization of the RMB," *Review of International Political Economy*, vol. 24, no. 4, pp. 599–628, 2017.

[10] Y. Cui, L. Liu, and K. Peng, "International competitiveness and currency internationalization: an application to RMB internationalization," *Journal of the Asia Pacific Economy*, pp. 1–24, 2022.

[11] Y. Huang, D. Wang, and G. Fan, "Paths to a reserve currency: internationalization of the renminbi and its implications," *ADBI Working Paper*, Asian Development Bank Institute, vol. 482, 2014.

[12] Q. Zhao and Y. Wang, "How far is RMB from global currency: an analysis based on the effect of Shanghai pilot FTZ on RMB internationalization," 2015, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2558922.

[13] F. Pan, Z. He, T. Sigler, K. Martinus, and B. Derudder, "How Chinese financial centers integrate into global financial center networks: an empirical study based on overseas expansion of Chinese financial service firms," *Chinese Geographical Science*, vol. 28, no. 2, pp. 217–230, 2018.

[14] S. Strange and B. J. Cohen, "The future of sterling as an international currency," *International Affairs*, vol. 48, no. 1, pp. 90–92, 1972.

[15] P. Krugman, "The international role of the dollar: theory and prospect," *Exchange rate theory and practice*, vol. 1, pp. 261–278, 1984.

[16] P. Bacchetta and E. Van Wincoop, "A theory of the currency denomination of international trade," *Journal of International Economics*, vol. 67, no. 2, pp. 295–319, 2005.

[17] M. Chinn and J. Frankel, "Why the euro will rival the dollar," *International Finance*, vol. 11, no. 1, pp. 49–73, 2008.

[18] L. S. Goldberg and C. Tille, "Micro, macro, and strategic forces in international trade invoicing: synthesis and novel patterns," *Journal of International Economics*, vol. 102, pp. 173–187, 2016.

[19] Q. He, I. Korhonen, J. Guo, and F. Liu, "The geographic distribution of international currencies and RMB internationalization," *International Review of Economics & Finance*, vol. 42, pp. 442–458, 2016.

[20] J. A. Batten and P. G. Szilagyi, "The internationalisation of the RMB: new starts, jumps and tipping points," *Emerging Markets Review*, vol. 28, pp. 221–238, 2016.

[21] W. Chung, "Imported inputs and invoicing currency choice: theory and evidence from UK transaction data," *Journal of International Economics*, vol. 99, pp. 237–250, 2016.

[22] M. Li, F. Qin, and Z. Zhang, "Short-term capital flows, exchange rate expectation and currency internationalization: evidence from China," *Journal of Risk and Financial Management*, vol. 14, no. 5, pp. 223–315, 2021.

[23] H. Chey, "The concepts, consequences, and determinants of currency internationalization," GRIPS Discussion

Paper03 pages, GRIPS Discussion Paper, 2013, https://ideas.repec.org/p/ngi/dpaper/13-03.html.

[24] B. Eichengreen, "The renminbi as an international currency," *Journal of Policy Modeling*, vol. 33, no. 5, pp. 723–730, 2011.

[25] D. He and R. N. McCauley, "Offshore markets for the domestic currency: monetary and financial stability issues," *BIS Working Papers*, Monetary and Economic Department, Bank for International Settlement, vol. 301, 2010.

[26] Y. Cheung, "The role of offshore financial centers in the process of renminbi internationalization," *BOFIT Policy Brief, Institute for Economies in Transition*, Bank of Finland, vol. 11, 2014.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8292991, 14 pages
https://doi.org/10.1155/2022/8292991

Research Article

Intelligent Gamification Mechanics Using Fuzzy-AHP and K-Means to Provide Matched Partner Reference

Fitri Marisa,[1] **Sharifah Sakinah Syed Ahmad**,[2] **Nasreen Kausar**,[3] **Sajida Kousar**,[4] **Dragan Pamucar**,[5] **and Nasr Al Din Ide**[6]

[1]*Informatics Engineering, Widyagama University of Malang, Malang 65125, Indonesia*
[2]*Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka, Melaka 76100, Malaysia*
[3]*Department of Mathematics, Faculty of Arts and Sciences, Yildiz Technical University, Esenler 34210, Istanbul, Turkey*
[4]*Department of Mathematics and Statistics, International Islamic University Islamabad, Islamabad, Pakistan*
[5]*Department of Logistics, University of Defence in Belgrade, Belgrade, Serbia*
[6]*Department of Mathematics, University of Aleppo, Aleppo, Syria*

Correspondence should be addressed to Nasr Al Din Ide; ide1112002@yahoo.ca

Received 23 March 2022; Accepted 22 April 2022; Published 31 May 2022

Academic Editor: Lele Qin

Players in the Small and Medium System (SME) collaboration gamification system need suitable partner references to support the goals of their activities. This study aims to build an intelligent system gamification mechanics model to provide the proper partner reference for players. The following steps are carried out sequentially in carrying out this research. First, analyze needs for a recommendation model that supports partner reference. Second, design an intelligent system formula using the Fuzzy-Analytical Hierarchy Process (Fuzzy-AHP) and K-Means algorithms to obtain partner reference recommendation patterns and segmentation of similarity of interests between partners. Third, compile the scenario of recommendation model mechanics which involves actors and activities involved in the model. Fourth, design use cases and activity diagrams to translate scenarios in the form of program flow. Fifth, code programs related to use cases and activity diagrams. The sixth is to conduct experiment with the prototype results to test all the functions of the proposed model. Fuzzy-AHP produces a weight for each tested data which can be claimed as a ranking, with the highest weight value being 9,980. K-Means produces 3 clusters in which, based on this experimental data, the third cluster has the most members. Both models are realized in the dashboard, and referring to experiments from 63 respondents, the model shows its performance by displaying SME rankings and clusters according to the data and criteria being tested. Intelligent system algorithms are to develop models of gamification mechanics, primarily to support player decisions in determining more effective game steps. This model can work well if sufficient data requirements support it. Therefore, the proposed mechanics depends on game activities, and more data are available to be extracted and produce more precise recommendations.

1. Introduction

Small and Medium Enterprise (SME) is one of the essential components of the country's economy because its existence contributes to the absorption of labour and an increase in per capita income. However, there are many challenges faced [1–3]. Some of the challenges include weak information exchange and low activity and retention and motivation to collaborate [2, 4–7]. Several studies reported that SMEs are reluctant to collaborate because of the lack of information regarding appropriate partner references in collaborating [1, 2] and the lack of effective exchange of information and good knowledge extraction between SMEs [4, 8].

Meanwhile, partner reference recommendations are an important part of collaborating activities [1, 8]. The accuracy of partner references determines the success of the collaboration between SMEs [1, 8]. Appropriate partner references are coming from aspects of similarity of interest,

mutual need, and interdependence [1, 1, 2, 4, 8]. The results of the review study found nine (9) studies that proposed matters relating to extracting data on SME [1, 2, 4, 8–11]. Most of these studies are at the conceptual level (8 studies), where the topics are mostly by the proposed concept of data extraction models for information exchange. It can indicate that SME data extraction research development is mostly still at the conceptual level, which is still broad to be developed, and subsequent research needs to develop further to create more concrete and specific models. Meanwhile, one study proposes extracting data related to collaboration partner references and has become a partner reference model. However, it still has weaknesses in only single criteria and is generated from data that are difficult to calculate, so it is prone to bias [11]. Related to the literature review, there are still few appropriate approaches for presenting references for suitable SME partners in collaborating, and there are not many appropriate mechanisms for collecting and extracting information into new knowledge in exchanging information within the SME network [1, 2, 4, 8].

Concerning collaboration problems that collaboration retention is small, so the collaboration framework approach can be chosen out from how attractive or acceptable the characteristics of the approach are. There is a gamification approach that is currently being developed and has become part of the lifestyle of today's society and aims to increase user participation and motivation and try to influence user behavior [12–14]. Gamification is the process of imitating a fun and even addictive gameplay atmosphere while players complete nongame tasks [14–16]. Gamification seeks to bring together functionality and engagement to increase functionality, productivity, and satisfaction, create more experiences, drive behavior, and generate positive business impact [17]. Showing the principles of the MDE framework model, the essential components of gamification consist of mechanics, dynamics, and emotional where each of these components cannot be separated because the mechanical element (M) will create the dynamics of the game and create its emotional atmosphere for the players [17–19]. The success of the gamified system lies in the application of game mechanics according to the characters of players [19]. Gamification is suitable as an SME collaboration framework platform regarding its characteristics. We expect to make collaboration more exciting and increase retention. So, going from the two problems, a solution is needed by building an intelligent system in a collaborative gamification mechanics model that can provide knowledge extraction to produce a suitable reference partner for SME actors.

Several intelligent systems approaches can be applied in this research. Among them is the fuzzy-analytical hierarchy process (Fuzzy-AHP) which has the potential to provide a more precise weight value in completing the weighting of data with several criteria [20, 21]. Fuzzy-AHP has the advantage of being able to weigh more precisely than data criteria that have more subjective characteristics and are uncertain so that the resulting reference is claimed to be more precise [21–23]. While the K-Means clustering approach has the potential to group objects based on their characteristics [24] so that objects with the same characteristics are grouped in the same cluster and objects with different characteristics are grouped into other clusters [25, 26]. This condition fits the mapping needs and position of each SME to make it easier for them to identify partners who have the same interests.

This study introduces the proposed "Intelligent Gamification Mechanics (IGM)" model. This model embodies gamification mechanics made from an intelligent system to provide knowledgeable recommendations to players. The IGM formula uses the fuzzy-AHP algorithm [24] and K-Means [25] to provide two knowledge recommendations that support each other in providing a suitable partner reference. The fuzzy-AHP formula produces recommendations for ranking suitable SME partners [27]. The K-Means formula produces SME segmentation mapping that provides information on the position of players in groups who have the same interests and potential to collaborate. The model is built in the gamification platform to make the model more attractive and interactive. This model can be included in a collaboration framework to provide recommendations for suitable partner references for collaborators.

This study reports the results of our research on the performance of the IGM model. The experiment used 63 respondent data according to the criteria used in the algorithm. The prototype demonstrates the model's ability to present a suitable ranking of SME partners while at the same time presenting the mapping/positioning of SMEs in groups that have the exact needs and great potential for collaboration. This research resulted in 3 contributions: first, an intelligent system formula in gamification mechanics; second, a leader board prototype that displays suitable partner ranking and SME segmentation mapping. Future research can apply or develop this model to improve collaboration partner references in various fields. The model can be developed by adding criteria and the number of clusters as needed, and the results can be compared and analyzed.

2. Materials and Methods

There are five method steps (Figure 1). First, analyze the need for a recommendation model that supports the provision of appropriate partner reference information. Second, design an intelligent system formula using the fuzzy-AHP and K-Means algorithms to obtain partner reference recommendation patterns and segmentation of similarity of interests between partners. Third, develop a scenario of recommendation model mechanics by involving the actors and activities involved in the model. Fourth, design use cases and activity diagrams to translate scenarios in the form of program flow. Fifth, code programs containing use cases and activity diagrams. The sixth is to experiment with the prototype results to test all the functions of the proposed model.

The first stage is to build an intelligent system formula to produce two recommendation models.

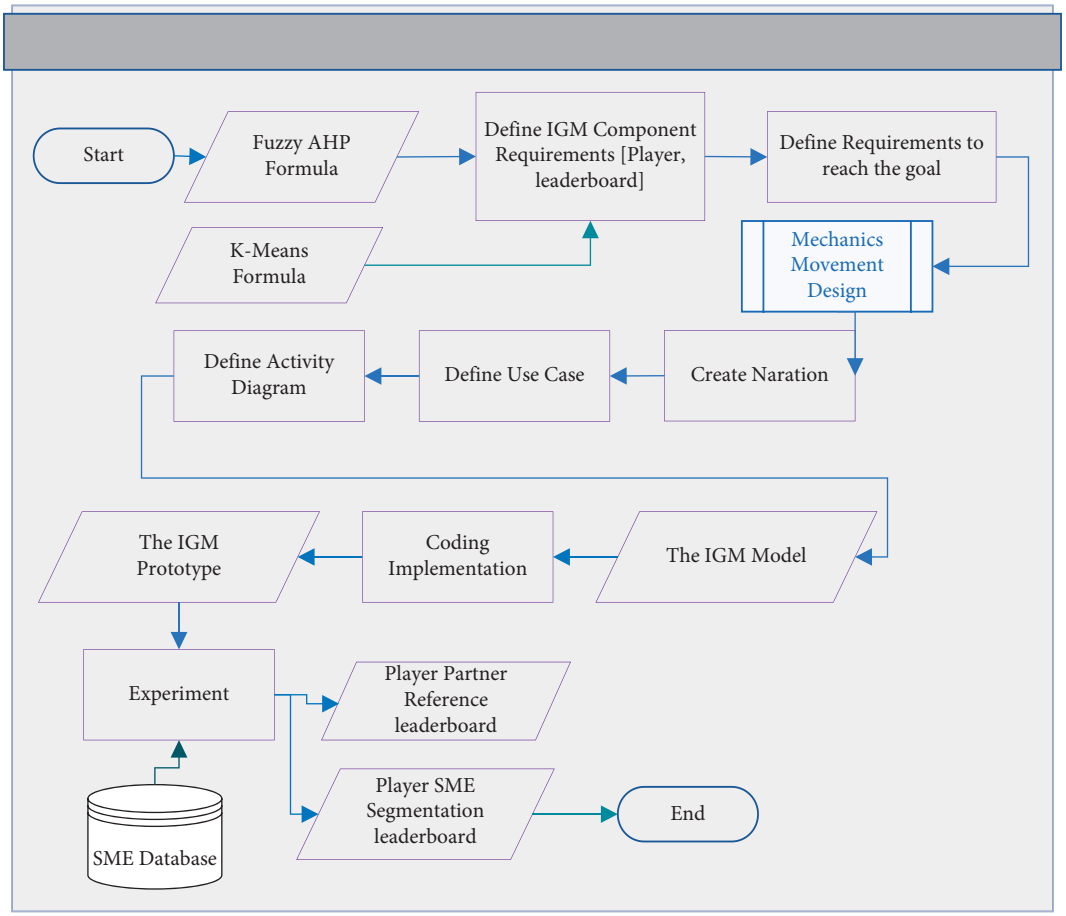


Figure 1: Research method.

2.1. Fuzzy-AHP Algorithm. Fuzzy-AHP was first proposed by Chang which is a direct development of the AHP method which consists of matrix elements represented by fuzzy numbers [20, 21]. Fuzzy-AHP is a combination of the AHP method with fuzzy concept approach. Fuzzy-AHP covers the weaknesses found in AHP, namely, problems with criteria that have more subjective characteristics [20, 21, 26]. A scale order represents the uncertainty of numbers. The Fuzzy-AHP method uses a fuzzy ratio called triangular fuzzy number (TFN) and is used in the fuzzification process. TFN consists of three functions. The membership consists of the lowest score (l), the middle grade (m), and the highest grade (u) [21, 26].

The steps of the FAHP method are as follows [20, 21]:

(1) Arrange problems in a hierarchical form

(2) Compile a comparison matrix between all elements/criteria

(3) Calculating the value of the consistency ratio from the results of the comparison matrix, calculation with the condition that the CR value is 0.1

(4) Change the weighted results into fuzzy numbers using the TFN scale

(5) Calculate the fuzzy geometric mean and fuzzy weight

(6) Determine the fuzzy priority for each alternative using linguistic variables

In this study, SME partner ranking recommendations apply the fuzzy-AHP algorithm with four criteria: scope, market, product, and marketplace. All fFuzzy-AHP steps and formulas are compiled and tested with dummy data to ensure correct calculations.

2.2. K-Means Algorithm. The K-Means algorithm is unsupervised machine learning algorithm. In the data analysis process, K-Means clustering is a method that performs data grouping with a partition system [24–26]. K-means clustering is also a non-hierarchical cluster analysis method that seeks to partition existing objects into one or more clusters or group objects in regard to their characteristics. Objects with the same characteristics are grouped in the same cluster. Objects that have different characteristics are grouped into other clusters [26, 28]. K-Means steps are as follows [28–30]:

(1) Perform data preprocessing followed by data transformation; then, determine the number of clusters (Number of K)

(2) Choose a centroid at random as many as the specified number of K

(3) Calculates the rarity of the centroid to the object and grouping connected with the minimum distance

(4) Check if the object moves; then, the iteration process continues

(5) If the object does not move, the last cluster is recorded as the result of the cluster formed

In this study, recommendations SME segmentation applies the K-Means clustering algorithm by determining three clusters and the centroid at random. K-Means calculates data containing four criteria (scope, market, product, and marketplace). After the K-Means step is declared, the formula is tested with dummy data to ensure the correctness of the formula calculation.

The second stage is to define the mechanical components, including the player and the leader board. The player is defined by definition, status, and access rights, while the leader board is defined by description, user interface, and access pattern. Then, the third step is to define the rules and requirements to reach the goal, namely, player rankings and segmentation are displayed on the leader board accurately. Then, the second and third steps produce a mechanics movement module. The fourth step is to compose a mechanics narrative according to the mechanics movement module completed. In this stage, the mechanics are equipped with detailed steps of each path from actor to system or vice versa and from system to system or actor to actor. This narrative also explains the origin of the data processed in the intelligent system.

The fifth stage is to complete the mechanics with use cases and activity diagrams that serve to translate the program flow and all activities in mechanics. After this stage is complete, the model is ready to be implemented in the coding program at the next stage. The fifth stage is coding this program using a web programming language with the coding flow following what has been described in the use case and activity diagram. Then, the completion of the fifth stage means the IGM prototype is ready to be tested. The last stage is to experiment by entering data from 63 respondents with the condition that the data have been preprocessed and transformed. Respondent data include general identity and four criteria used in the intelligent system formula. Experiments were carried out to observe all prototype functions and the performance results of the IGM model.

3. The Proposed Model

This section reports the details of the proposed model related to the method steps described in Figure 1. Figure 2 describes the general flow of the IGM model. The model is built on a gamified platform that adopts a leader board and dashboard to showcase the mechanics of the intelligent system.

From Figure 2, the model is detailed to the following steps to describe the flow of the proposed model.

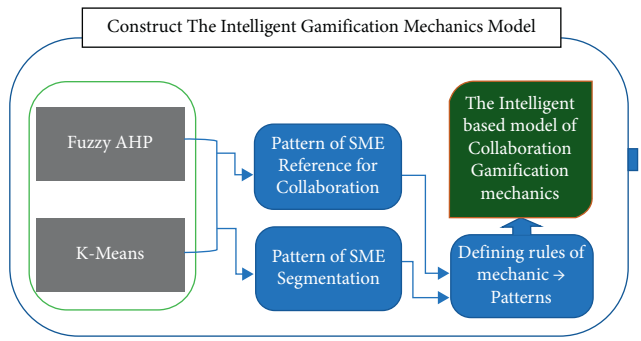


Figure 2: IGM model.

3.1. SME Reference Formula with Fuzzy-AHP. This section describes the flow of the player reference formula with fuzzy-AHP using dummy data. The first step in the fuzzy-AHP process is to tabulate the data using dummy data (Table 1) as an experiment to ensure the model works correctly. In Table 1, dummy data are presented in the form of 4 data on SME players who will be ranked as reference partners along with four criteria possessed by players, namely, SME, scope, market, product, and marketplace. These four criteria were chosen by considering the analysis of the needs and availability of SME data, which of course can change if applied to data in different situations and fields.

Triangular fuzzy number (TFN) is used in the fuzzification process which consists of three membership functions, namely, the lowest value (l), the middle value (m), and the highest value (u) [20, 26]. Determination of TFN is guided by linguistic variable and triangular fuzzy number (Table 2).

Step 1: define a priority comparison of criteria using the TFN scale (Table 2). Previously, the following were the guidelines for determining the TFN scale out from the weight of each criterion in reference to expert opinion and literature review [2, 3] in the SME sector by adjusting the TFN value guidelines (Table 3). Then, determining the priority value between criteria (Table 4) is to determine the value of 1 for two criteria that have the same value and find the difference for the two criteria that have different values.

Step 2: determine the comparison of paired matrices between criteria with the TFN scale in the decimal value (Table 5).

Step 3: determine the fuzzy synthesis (S_i) limit value referring to the FAHP calculation step fuzzy formula (S_i):

$$S_i = \sum_{j}^{m} m_i^j X \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^i \right]^{-1}, \tag{1}$$

where

$$\sum_{j=1}^{m} M_{gi}^j = \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j. \tag{2}$$

Table 1: Dummy data of SME identity.

Alternative	Criteria			
	C1	C2	C3	C4
A1-SME Player-1	2	1	1	1
A2-SME Player-2	2	1	3	3
A3-SME Player-3	1	2	3	3
A4-SME Player-4	1	1	2	3

Table 2: TFN table [20, 26].

Intensity	Linguistic variable	TFN number	Reciprocal
1	Equally strong	(1,1,1)	(1,1,1)
2	Intermediate of 1 to 3	(1/2, 1, 3/2)	(2/3, 1, 2)
3	Very strong	(1, 3/2, 2)	(1/2, 2/3, 1)
4	Intermediate of 3 to 5	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
5	Strong	(2, 5/2, 3)	(1/3, 2/5, 1/2)
6	Intermediate of 5 to 7	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
7	Moderately strong	(3, 7/2, 4)	(1/4, 2/7, 1/3)
8	Intermediate of 7 to 9	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)
9	Equally strong	(4, 9/2, 9/2)	(2/9, 2/9, 1/4)

Table 3: Weight of criteria based on expert perspective.

Criteria	Weight
C1-scope of SME	5
C2-market	3
C3-product	9
C4-market place	7

Table 4: Comparison of priorities between criteria with TFN scale.

	C1	C2	C3	C4
C1-scope of SME	1	2	1/4	1/3
C2-market	1/2	1	1/6	1/7
C3-product	4	6	1	2
C4-market place	3	7	1/2	1

Table 5: Determine the comparison of paired matrices between criteria with TFN.

	C1			C2			C3			C4		
	L	M	U	L	M	U	L	M	U	L	M	U
C1	1.00	1.00	1.00	0.50	1.00	1.50	0.40	0.50	1.50	1.00	1.50	2.00
C2	0.67	1.00	2.00	1.00	1.00	1.00	0.29	0.33	0.40	0.25	0.29	0.33
C3	1.50	2.00	0.67	2.50	3.00	3.50	1.00	1.00	1.00	0.50	1.00	1.50
C4	0.50	0.67	1.00	3.00	3.50	4.00	0.67	1.00	2.00	1.00	1.00	1.00

While

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \frac{i}{\sum_{j=1}^{n} u_j \sum_{j=1}^{n} m_j \sum_{j=1}^{n} l_j}, \tag{3}$$

calculates the total lower value in each column, and here is an example of C1:

$$\sum_{j=1}^{n} l_j = 1 + 0.5 + 0.4 + 1 = 2.9. \tag{4}$$

For the total value of lower, $c_2 = 2.20, \cdot c_3 = 5.50$, and $c_4 = 5.17$, using the same method according to the data in Table 5,

$$\sum_{i=1}^{n}\sum_{j=1}^{m} l_j = 2.9 + 2.20 + 5.50 + 5.17 + 15.77. \quad (5)$$

Calculate the total median value in each column and here is an example of C1:

$$\sum_{j=1}^{n} m_j = 1 + 10.50 + 1.50 = 4. \quad (6)$$

For the total value of the median, C2 = 2.62, C3 = 7, and C4 = 6.17, using the same method according to the data in Table 5,

$$\sum_{i=1}^{n}\sum_{j=1}^{m} m_j = 4 + 2.62 + 7 + 6.17 + 19.79. \quad (7)$$

Calculate the total upper value in each column and here is an example of C1:

$$\sum_{j=1}^{n} u_j = 1 + 1.5 + 1.5 + 2 = 6. \quad (8)$$

For the upper total value, C2 = 3.73, C3 = 6.67, and C4 = 8, use the same method according to the data in Table 5:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} u_j = 6 + 3.73 + 7 + 6.67 + 8 = 24.40. \quad (9)$$

Calculating fuzzy synthesis value at lower, we obtain

$$S_i = \sum_{j=1}^{n} l_j X \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} u_j}, \qquad s_1 = 2.90x\frac{1}{24.40} = 0.119. \quad (10)$$

To calculate S_2, S_3, and S_4, use the same formula as the data reference in Table 6.

Calculate the value of Fuzzy synthesis on the median:

Table 6: Total of lower, median, and upper for each criteria.

	$\sum_{j=1}^{n} l_j$	$\sum_{j=1}^{n} m_j$	$\sum_{j=1}^{n} u_j$
C1	2.90	4.00	6.00
C2	2.20	2.62	3.73
C3	5.50	7.00	6.67
C4	5.17	6.17	8.00
Total	15.77	19.79	24.40

$$S_i = \sum_{j=1}^{n} m_j X \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} m_j}, \qquad S_1 = 4x\frac{1}{19.79} = 0.20. \quad (11)$$

To calculate S_2, S_3, and S_4, use the same formula as the data reference in Table 6.

Calculating the value of fuzzy synthesis on upper, we obtain

$$S_i = \sum_{j=1}^{n} u_j X \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} l_j}, \qquad S_1 = 6x\frac{1}{15.77} = 0.38. \quad (12)$$

To calculate S_2, S_3, and S_4, use the same formula as the data reference in Table 6.

Step 5: determine the value of the fuzzy-AHP's priority vector (V) using the FAHP calculation step, specifically in equation (12). Determine the vector's value using the following equation:

$$V(M_2 \geq M_1) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq m_2, \\ \dfrac{l_1 - \mu_2}{(m_2 - \mu_2) - (m_1 - l_1)}, & \text{other}, \end{cases} \quad (13)$$

m_i is triangular fuzzy number of Ci criteria.

Calculating the vector value (C1) containing Table 7 data, we obtain as follows:

$$V(C_1 \geq (C_2, C_3, C_4, C_5, C_6, C_7, C_8)),$$

$$V(C_1 \geq C_1) = 1 \text{ as value } m_1 = m_1 \longrightarrow 1 = 1,$$

$$V(C_1 \geq C_2) = 1 \text{ as value } m_1 \geq m_2 \longrightarrow 0.20 \geq 0.15,$$

$$V(C_1 \geq C_3) = \frac{l_3 - u_1}{(m_1 - u_1) - (m_3 - l_3)} \text{ as value } m_1 \leq m_3 \longrightarrow 0.20 \geq 0.35,$$

Table 7: Synthesis value limit.

	S_i		
	l	m	U
C1	0.119	0.20	0.38
C2	0.090	0.13	0.24
C3	0.225	0.35	0.42
C4	0.212	0.31	0.51

$$
\begin{aligned}
V(c_1 \geq c_3) &= \frac{(0.225 - 0.38)}{((0.20 - 0.38) - (0.35 - 0.225))} = 0.506, \\
V(c_1 \geq c_4) &= \frac{l_4 - u_1}{(m_1 - u_1) - (m_4 - l_4)} \text{ as value } m_1 \leq m_1 \longrightarrow 1 = 1, \\
V(c_1 \geq c_4) &= \frac{(0.012 - 0.38)}{((0.20 - 0.38) - (0.31 - 0.012))} = 1.579, \\
V(c_2 \geq c_1) &= \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \text{ as value } m_1 \geq m_2 \longrightarrow 0.13 \geq 0.20, \\
V(c_2 \geq c_1) &= \frac{(0.119 - 0.24)}{((0.15 - 0.24) - (0.20 - 0.119))} = 0.628, \\
V(C_2 \geq C_2) &= 1 \text{ as value } m_2 \leq m_2 \longrightarrow 1 = 1, \\
V(c_2 \geq c_3) &= \frac{l_3 - u_2}{(m_2 - u_2) - (m_3 - l_3)} \text{ as value } m_2 \leq m_3 \longrightarrow 0.13 \leq 0.35, \\
V(c_2 \geq c_3) &= \frac{(0.225 - 0.24)}{((0.15 - 0.24) - (0.35 - 0.225))} = 0.049, \\
V(c_2 \geq c_4) &= \frac{l_4 - u_2}{(m_2 - u_2) - (m_4 - l_4)} \text{ as value } m_2 \leq m_4 \longrightarrow 0.13 \leq 0.35, \\
V(c_2 \geq c_4) &= \frac{(0.212 - 0.24)}{((0.15 - 0.24) - (0.31 - 0.51))} = 0.122, \\
V(C_3 \geq C_1) &= 1 \text{ as value } m_3 \leq m_1 \longrightarrow 0.35 \geq 0.20, \\
V(C_3 \geq C_2) &= 1 \text{ as value } m_3 \leq m_2 \longrightarrow 0.35 \geq 0.13, \\
V(C_3 \geq C_3) &= 1 \text{ as value } m_3 \leq m_3 \longrightarrow 1 = 1, \\
V(C_3 \geq C_4) &= 1 \text{ as value } m_3 \leq m_4 \longrightarrow 0.35 \geq 0.31, \\
V(C_4 \geq C_1) &= 1 \text{ as value } m_4 \leq m_1 \longrightarrow 0.31 \geq 0.20, \\
1\, V(C_4 \geq C_2) &= 1 \text{ as value } m_4 \leq m_2 \longrightarrow 0.31 \geq 0.13, \\
V(c_4 \geq c_3) &= \frac{l_3 - u_4}{(m_4 - u_4) - (m_3 - l_3)} \text{ as value } m_4 \leq m_3 \longrightarrow 0.31 \leq 0.35, \\
V(C_4 \geq C_3) &\frac{(0.225 - 0.51)}{((0.31 - 0.51) - (0.35 - 0.225))} = 0.870, \\
V(C4 \geq C4) &= 1 \text{ as value } m_4 = m_4 \longrightarrow 1 = 1.
\end{aligned} \tag{14}
$$

To calculate the vector in the next cells, we use the same equation, where all the priority vector results have been presented in Table 8.

Step 6: determine the defuzzification-ordinate (d') value related to the FAHP calculation step equation (5). Determining the value of the defuzzification ordinate is

Table 8: Fuzzy-AHP priority vector (V) value.

	C1	C2	C3	C4
C1	1.000	1.000	0.506	1.579
C2	0.628	1.000	0.049	0.122
C3	1.000	1.000	1.000	1.000
C4	1.000	1.000	0.870	1.000

to find the minimum value of the vector value of each criterion:

$$d' A_i = \min V\left(S_i \geq S_k\right), \tag{15}$$

for $k = 1, 2, \ldots, n$, $k \neq i$; then, this process produces a vector weight.

Then, the application is $d'\left(C_1 = \min\left(C1, C2, C3, C4\right)\right)$ so that it produces data as in Table 9.

Step 7: normalize the value of the fuzzy vector weight (W) going from the FAHP calculation step in equation (6).

Normalization of fuzzy vector weight value (W) is

$$W' = \left(d'\left(A_1\right), d'\left(A_1\right) \ldots, d\left(A_n\right)\right)^T, \tag{16}$$

where $A_1 = 1, 2, \ldots, n$ is the decision element.

After the normalization of the W' equation, the normalized value of the vector weight (see Table 10) is like equation (7):

$$W = \left(d'\left(A_1\right), d'\left(A_1\right) \ldots, d\left(A_n\right)\right)^T, \tag{17}$$

where is W is nonfuzzy number and value of $\sum W = 1$,

$$\begin{aligned} W' &= (0.505,\ 0.049,\ 1.000,\ 0.870)^T, \\ \sum W &= (0.505 + 0.049 + 1.000 + 0.870) = 2.424, \\ W &= \frac{(0.505,\ 0.049,\ 1.000,\ 0.870)}{2.424} = (0.209, 0.020, 0.412, 0.359). \end{aligned} \tag{18}$$

Step 8: determine the vector weight value of each criteria using equation (8):

$$b_{ij} = \frac{a_{ij} - a_j^{\min}}{a_j^{\max} - a_j^{\min}}, \tag{19}$$

where $a_j^{\max} = \max\ (a_{1j}, a_{1j}, a_{1j}, \ldots, a_{mj})$ and $a_j^{\min} = \min\ (a_{1j}, a_{1j}, a_{1j}, \ldots, a_{mj})$, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Then, carry out the process of normalizing the weight vector of each criterion that represents the weight of each alternative with the total number of weight values equal to 1. Then, rank decision results by calculating the total score with equation (9).

$$S_j = \sum\left(S_{ij}\right)\left(W_i\right), \tag{20}$$

where S_j = score, S_{ij} = the weight of each criterion which represents the weight of S_j, and W_i = weight of every criteria. The outputs of these calculations determine which score is the highest. The score with the greatest recommendation is the best. Table 11 contains the maximum and minimum values for each criterion.

Considering the vector weight on the criteria (W) using equation (9), the following procedure is used for C1:

For C2, C3, and C4 using the same equation formula, then the overall result of the weight vector value is shown in Table 12.

Determine the score by multiplying the weight vector (w) (Table 9) by the weight vector (w) for each criterion (Table 12), which represents the weight of each, as shown in equation (9). The overall score in alternative 1 (A1) is calculated as follows:

$$\begin{aligned} A1 &= (1 \times 0.209) + (0 \times 0.020) + (0 \times 0.412) + (0 \times 0.359) = 0.209, \\ A2 &= (1 \times 0.209) + (0 \times 0.020) + (1 \times 0.412) + (1 \times 0.359) = 0.980, \\ A3 &= (0 \times 0.209) + (1 \times 0.020) + (1 \times 0.412) + (1 \times 0.359) = 0.791, \\ A4 &= (0 \times 0.209) + (0 \times 0.020) + (0.5 \times 0.412) + (1 \times 0.359) = 0.565. \end{aligned} \tag{21}$$

Table 9: Defuzzification (d') ordinal value.

	C1	C2	C3	C4	Defuzzification
C1	1.000	1.000	0.506	1.579	0.506
C2	0.628	1.000	0.049	0.122	0.049
C3	1.000	1.000	1.000	1.000	1.000
C4	1.000	1.000	0.870	1.000	0.870

Table 10: Normalization of fuzzy vector weight value (W).

C_i	W
C1	0.209
C2	0.020
C3	0.412
C4	0.359

Table 11: Maximum and minimum value.

Alternative	Criteria			
	C1	C2	C3	C4
A1-SME 1	2	1	1	1
A2-SME 2	2	1	3	3
A3-SME 3	1	2	3	3
A4-SME 4	1	1	2	3
Max	2	2	3	3
Min	1	1	1	1

Table 12: Vector weight value (w) specification criteria.

Alternative	Criteria			
	C1	C2	C3	C4
A1-SME 1	1	0	0	0
A2-SME 2	1	0	1	1
A3-SME 3	0	1	1	1
A4-SME 4	0	0	0.5	1

From the fuzzy-AHP ranking results, the SME ranking is generated according to the criteria set in the fuzzy-AHP calculation (Table 13). The ranking results in this model use dummy data to ensure that the process input and output functions have been running according to the target. The value of the weight score determines the ranking results. The higher the value, the higher the ranking of an alternative. This model is devoted to ranking SME players according to suitable criteria for collaborating with a player. The higher the weight score is, the higher the ranking of SME partners chosen to be suitable partners. From testing with dummy data, the ranking of the data is shown in Table 14.

Table 13: Vector weight value (w) specification criteria.

Alternative	Criteria				Vector weight value	Weight score
	C1	C2	C3	C4		
A1-SME 1	1	0	0	0	0.209	0.209
A2-SME 2	1	0	1	1	0.020	0.980
A3-SME 3	0	1	1	1	0.410	0.791
A4-SME 4	0	0	0.5	1	0.359	0.565

3.2. SME Segmentation Formula with K-Means

Step 1: tabulate the data using dummy data. Then, determine the number of clusters in the first iteration, wherein determining the number of clusters and the position of the cluster (denoted K) in the first iteration is determined randomly [29]. In this model design, 3 ($K = 3$) clusters are determined by choosing randomly from the data with the details of the data centroid in Table 15. Then, it can be notated as C1 (2,1,1,1), C2 (3,3,3,3), and C3 (2,2,4,2).

Step 2: calculate the distance value of the data to the centroid using the Euclidean distance formula (equation (10)):

$$D(a,b) = \sqrt{\sum_{k=1}^{n} (a_k - b_k)^2}. \tag{22}$$

Showing the data in Table 14, the data distance from the centroid of each criterion is as follows

To get (S_n, C_1),

$$\begin{aligned}
D(S_1,C_1) &= \sqrt{(S_{1a}-C_{1a})^2 + (S_{1b}-C_{1b})^2 + (S_{1c}-C_{1c})^2 + (S_{1\,d}-C_{1\,d})^2},\\
D(S_1,C_1) &= \sqrt{(2-2)^2 + (1-1)^2 + (1-1)^2 + (1-1)^2} = 0,\\
D(S_2,C_1) &= \sqrt{(S_{2a}-C_{1a})^2 + (S_{2b}-C_{1b})^2 + (S_{2c}-C_{1c})^2 + (S_{2\,d}-C_{1\,d})^2},\\
D(S_2,C_1) &= \sqrt{(2-2)^2 + (1-1)^2 + (3-1)^2 + (1-3)^2} = 0.828.
\end{aligned} \tag{23}$$

Furthermore, the data $D(S_n, C_1)$ use the same method as the calculation results in Table 11 column Cr1. We use the same formula to get $D(S_n, C_2)$ and $D(S_n, C_3)$, and the result is described in Table 16.

Step 3: group the data according to the centroid by grouping the data according to the shortest distance of each item. This process can be calculated by finding the smallest value among the values, $D(S_n, C_1)$, $D(S_n, C_2)$, and $D(S_n, C_3)$. The cluster is determined containing the smallest value obtained by one of the Euclidean distance values in each item set. The results of determining the cluster can be seen in Table 17.

Table 14: Ranking of SME reference on fuzzy-AHP.

Alternative	Weight score	Ranking
A1-SME 1	0.209	Rank 4
A2-SME 2	0.980	Rank 1
A3-SME 3	0.791	Rank 2
A4-SME 4	0.565	Rank 3

Table 15: Cluster data in the first iteration.

SME player (S)	Cr1	Cr2	Cr3	Cr4	Centroids
SME Player-1	2	1	1	1	C1
SME Player-2	2	1	3	3	
SME Player-3	1	2	3	3	
SME Player-4	1	1	2	3	
SME Player-5	3	3	3	3	C2
SME Player-6	1	2	4	2	
SME Player-7	2	2	4	2	
SME Player-8	1	1	5	1	C3
SME Player-9	1	1	2	1	
SME Player-10	2	2	2	1	

Table 16: Euclidean distance in the first iteration.

SME player (S)	Cr1	Cr2	Cr3	Cr4	$D(S_n, C_1)$	$D(S_n, C_2)$	$D(S_n, C_3)$
SME Player-1	2	1	1	1	0.000	3.606	3.317
SME Player-2	2	1	3	3	2.828	2.236	1.732
SME Player-3	1	2	3	3	3.162	2.236	1.732
SME Player-4	1	1	2	3	2.449	3.000	2.646
SME Player-5	3	3	3	3	3.606	0.000	2.000
SME Player-6	1	2	4	2	3.464	2.646	1.000
SME Player-7	2	2	4	2	3.317	2.000	0.000
SME Player-8	1	1	5	1	4.123	4.000	2.000
SME Player-9	1	1	2	1	1.414	3.606	2.646
SME Player-10	2	2	2	1	1.414	2.646	2.236

Step 4: determine the centroid for iteration 2, by calculating the average of the results of the sum of data for each cluster group (Table 18).

With the results of the average data value for each cluster group (Table 18), the centroid value with the details of the centroid is notation C1 (1.5, 1.25, 1.75, 1.5), C2 (3, 3, 3, 3), and C3 (1.4, 1.6, 3.8, 2.2).

Table 17: Cluster group in first iteration.

SME player (S)	$D(S_n, C_1)$	$D(S_n, C_2)$	$D(S_n, C_3)$	Nearest distance	Cluster
SME Player-1	0.000	3.606	3.317	0.000	C1
SME Player-2	2.828	2.236	1.732	1.732	C3
SME Player-3	3.162	2.236	1.732	1.732	C3
SME Player-4	2.449	3.000	2.646	2.449	C1
SME Player-5	3.606	0.000	2.000	0.000	C2
SME Player-6	3.464	2.646	1.000	1.000	C3
SME Player-7	3.317	2.000	0.000	0.000	C3
SME Player-8	4.123	4.000	2.000	2.000	C3
SME Player-9	1.414	3.606	2.646	1.414	C1
SME Player-10	1.414	2.646	2.236	1.414	C1

Table 18: Centroids in iteration 2.

SME	C1	C2	C3	C4
Cluster 1				
SME Player-1	2	1	1	1
SME Player-4	1	1	2	3
SME Player-9	1	1	2	1
SME Player-10	2	2	2	1
Centroid-1	1.5	1.25	1.75	1.5
Cluster 2				
SME Player-5	3	3	3	3
Centroid-2	3	3	3	3
Cluster 3				
SME Player-2	2	1	3	3
SME Player-3	1	2	3	3
SME Player-6	1	2	4	2
SME Player-7	2	2	4	2
SME Player-8	1	1	5	1
Centroid-3	1.4	1.6	3.8	2.2

Step 5: the process of repeating the iteration as before with different data centroids, namely, calculating the distance value of the data to the centroid, using the Euclidean distance formula (10)

Consisting of the data in Table 13, the data distance from the centroid of each criterion is as follows.

To get $D(S_n, C_1)$,

Table 19: Euclidean distance in the second iteration.

SME player (S)	Cr1	Cr2	Cr3	Cr4	$D(S_n, C_1)$	$D(S_n, C_2)$	$D(S_n, C_3)$
SME Player-1	2	1	1	1	1.061	3.606	3.162
SME Player-2	2	1	3	3	2.031	2.236	1.414
SME Player-3	1	2	3	3	2.151	2.236	1.265
SME Player-4	1	1	2	3	1.620	3.000	2.098
SME Player-5	3	3	3	3	3.021	0.000	2.408
SME Player-6	1	2	4	2	2.475	2.646	0.632
SME Player-7	2	2	4	2	2.475	2.000	0.775
SME Player-8	1	1	5	1	3.335	4.000	1.844
SME Player-9	1	1	2	1	0.791	3.606	2.280
SME Player-10	2	2	2	1	1.061	2.646	2.280

Table 20: Cluster group in second iteration.

SME player (S)	$D(S_n, C_1)$	$D(S_n, C_2)$	$D(S_n, C_3)$	Nearest distance	Cluster
SME Player-1	1.061	3.606	3.162	1.061	C1
SME Player-2	2.031	2.236	1.414	1.414	C3
SME Player-3	2.151	2.236	1.265	1.265	C3
SME Player-4	1.620	3.000	2.098	1.620	C1
SME Player-5	3.021	0.000	2.408	0.000	C2
SME Player-6	2.475	2.646	0.632	0.632	C3
SME Player-7	2.475	2.000	0.775	0.775	C3
SME Player-8	3.335	4.000	1.844	1.844	C3
SME Player-9	0.791	3.606	2.280	0.791	C1
SME Player-10	1.414	2.646	2.236	1.414	C1

$$\begin{aligned}
D(S_1, C_1) &= \sqrt{(S_{1a} - C_{1a})^2 + (S_{1b} - C_{1b})^2 + (S_{1c} - C_{1c})^2 + (S_{1\,d} - C_{1\,d})^2},\\
D(S_1, C_1) &= \sqrt{(2 - 1.5)^2 + (1 - 1.25)^2 + (1 - 1.75)^2 + (1 - 1.5)^2} = 1.061,\\
D(S_2, C_1) &= \sqrt{(S_{2a} - C_{1a})^2 + (S_{2b} - C_{1b})^2 + (S_{2c} - C_{1c})^2 + (S_{2\,d} - C_{1\,d})^2},\\
D(S_2, C_1) &= \sqrt{(2 - 1.5)^2 + (1 - 1.27)^2 + (3 - 1.75)^2 + (3 - 1.5)^2} = 2.031.
\end{aligned} \tag{24}$$

Furthermore, the data $D(S_n, C_1)$ use the same method as the calculation results in Table 19 column Cr1. We use the same formula to get $D(S_n, C_2)$ and $D(S_n, C_3)$.

Step 6: group the data according to the centroid by grouping the data according to the shortest distance of each item. This process can be calculated by finding the smallest value among the values, $D(S_n, C_1)$, $D(S_n, C_2)$, and $D(S_n, C_3)$; the cluster is determined as concerning the smallest value obtained by one of the Euclidean distance values in each itemset. The results of cluster determination can be seen in Table 20.

From the results of the second iteration, there is no change in the position of the cluster, so the iteration process stops until the second iteration, and the resulting cluster is as presented in Table 21.

4. The Experiment Result and Discussion

The experiment uses SME data of 63 respondents' data inputted into the prototype. Figure 3 shows the results of the recommendations generated from the ranking of SME partners with fuzzy-AHP. The results display the identity of the name, email address, and score of the fuzzy-AHP which aims to provide and facilitate information for players to continue their actions after being recommended by the system. These results are constantly changing according to changes in player data in the game. Rankings are displayed in a dashboard accessible to recommended players and partners. The prototype shows its ability to present SME rankings according to the criteria data that have been used as test material.

Figure 4 shows the results of the recommendations generated from SME segmentation with K-Means. Cluster 1 produces four players, cluster 2 produces 41 players, and cluster 3 produces 18. These results constantly change according to changes in player data in the game. The SME segmentation is displayed on the leader board so that all the players involved can see their position in the cluster. They can continue to collaborate in regard to the cluster recommendations generated by the system, considering that they have many characteristics and interests in common.

Experiments show that the model can provide recommendations for SMEs' knowledge for collaboration.

Table 21: Cluster group result of SME segmentation.

SME	C1	C2	C3	C4
Cluster 1				
SME Player-1	2	1	1	1
SME Player-4	1	1	2	3
SME Player-9	1	1	2	1
SME Player-10	2	2	2	1
Cluster 2				
SME Player-5	3	3	3	3
Cluster 3				
SME Player-2	2	1	3	3
SME Player-3	1	2	3	3
SME Player-6	1	2	4	2
SME Player-7	2	2	4	2
SME Player-8	1	1	5	1

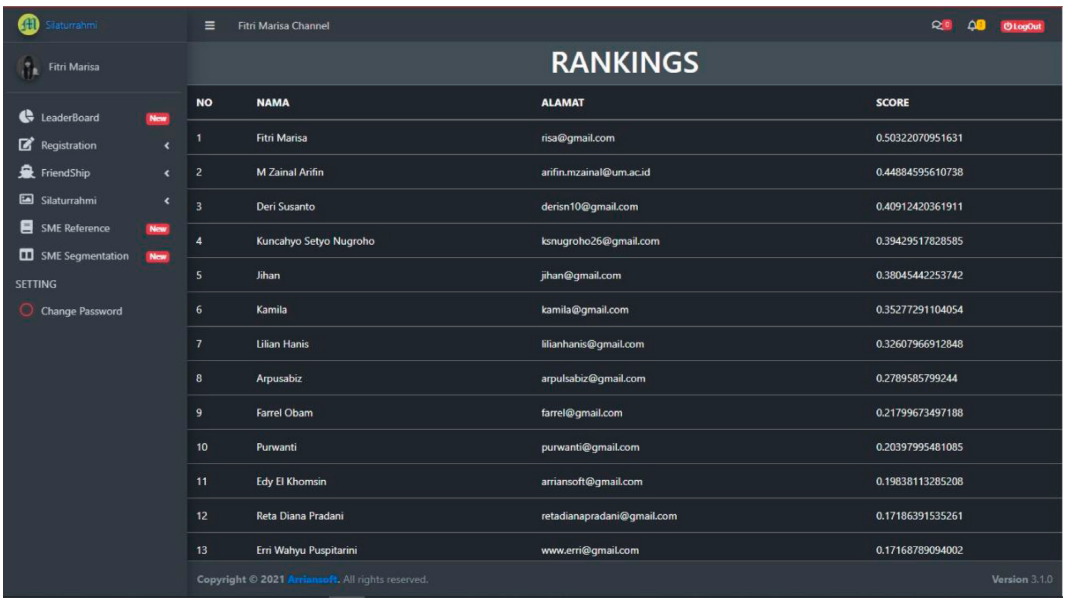


Figure 3: SME ranking using fuzzy-AHP.

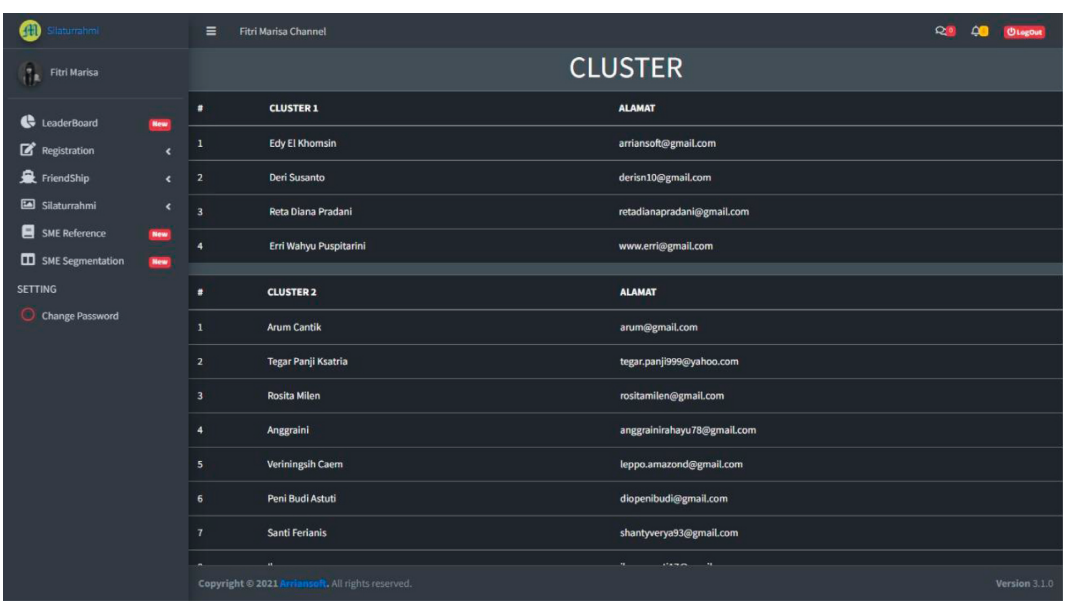


Figure 4: SME segmentation using K-Means.

However, this result depends on the adequacy of the data processing. The extensive and valid data affect the accuracy of this model in the analysis. For this reason, anticipation needs to be considered in the prototype to ensure that the data inputted by players are correct and consistent.

5. Conclusion

The Intelligent Gamification Mechanics (IGM) model makes essential recommendations for SME actors to collaborate to provide the proper reference for SMEs to establish cooperation to make it more useful and on target. SME ranking and SME segmentation work complementarily to support players' decisions in cooperating. The proposed intelligent system mechanics model has demonstrated its proper function using the experimental test of SME actor respondent data. At the same time, the dashboard and leaderboard function well and can present the mechanics of the intelligent system in a gamification-based prototype specification. The availability of data will determine the results of the IGM analysis. In line with that, the characteristics of the data and the expected solution of the problem raised also determine the weighting criteria in the fuzzy-AHP model and also determine the number of clusters in the K-Means. Therefore, further research needs to be developed and anticipated changes in respondent data that are up to data and sustainable so that IGM performance can be optimal. This study can also be the initiation of future research on the development of gamification mechanics based on intelligent systems. Gamification in presenting partner references is needed in other fields, and it is necessary to test the performance of this model in solving these problems. For this reason, the implementation and development of this proposed model is still wide open.

Data Availability

The data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there were no conflicts of interest regarding the publication of this article.

Authors' Contributions

All authors contributed equally to the preparation of this manuscript.

References

[1] A. Oussous, F.-Z. Benjelloun, A. Ait Lahcen, and S. Belfkih, "Big Data technologies: a survey," *Journal of King Saud University-Computer and Information Sciences*, vol. 30, no. 4, pp. 431–448, 2018.

[2] S. D. Bhoganadam, "A study on issues and challenges faced by SMEs: a literature review," *Res. J. SRNMC*, vol. 1, 2017, https://www.researchgate.net/publication/316595283_A_study_on_Issues_and_Challenges_faced_by_SMEs_A_Literature_Review.

[3] N. Yoshino and F. Taghizadeh-hesary, "Major challenges facing small and medium-sized enterprises in Asia and solutions for mitigating them," *ADBI Work. Pap. Ser*, vol. 564, 2016.

[4] P. Ajdari and K. Talebi, "The effect of networking behavior on the reduction of innovation obstacles to small and medium-sized enterprises," *International Journal of Academic Research in Business and Social Sciences*, vol. 5, no. 3, pp. 419–432, 2015.

[5] A. H. Gausdal, "Methods for developing innovative SME networks," *Journal of the Knowledge Economy*, vol. 6, no. 4, pp. 978–1000, 2015.

[6] M. R. Llave, "Business intelligence and analytics in small and medium-sized enterprises: a systematic literature review," *Procedia Computer Science*, vol. 121, pp. 194–205, 2017.

[7] J. Patricio, L. Axelsson, S. Blomé, and L. Rosado, "Enabling industrial symbiosis collaborations between SMEs from a regional perspective," *Journal of Cleaner Production*, vol. 202, pp. 1120–1130, 2018.

[8] F. O. Isinkaye, Y. O. Folajimi, and B. A. Ojokoh, "Recommendation systems : principles , methods and evaluation," *Egyptian Informatics Journal*, vol. 16, no. 3, pp. 261–273, 2015.

[9] K. O'Leary, *Exploring Distributed Collaboration and the Potential of Blockchain as an Enabling Technology*, National University of ireland, Cork, 2019.

[10] E. Lithoxoidou, S. Doumpoulakis, A. Tsakiris et al., "A novel social gamified collaboration platform enriched with shop-floor data and feedback for the improvement of the productivity, safety and engagement in factories," *Computers & Industrial Engineering*, vol. 139, Article ID 105691, 2020.

[11] H. Shambayati, M. S. Nikabadi, S. Mohammad, and A. Khatami, "Partner selection in virtual enterprises using the Interval Neutrosophic fuzzy approach," *An International Journal in Information Science and Engineering*, vol. 35, 2020.

[12] J. Koivisto and J. Hamari, "The rise of motivational information systems: a review of gamification research," *International Journal of Information Management*, vol. 45, pp. 191–210, 2019.

[13] A. M. Toda, R. M. C. Do Carmo, A. P. Da Silva, I. I. Bittencourt, and S. Isotani, "An approach for planning and deploying gamification concepts with social networks within educational contexts," *International Journal of Information Management*, vol. 46, pp. 294–303, 2019.

[14] J. Kasurinen and A. Knutas, "Publication trends in gamification: a systematic mapping study," *Computer Science Review*, vol. 27, pp. 33–44, 2018.

[15] A. M. Toda, R. M. C. D. Carmo, and A. P. D. Silva, "An approach for planning and deploying gamification concepts with social networks within educational contexts," *International Journal*, vol. 46, 2019.

[16] F. Marisa, S. Sakinah, Z. Izzah, A. L, R. David, and A. Aris, "Evaluation of student core drives on e-learning during the covid-19 with octalysis gamification framework," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 11, pp. 104–116, 2020.

[17] G. Baptista and T. Oliveira, "Gamification and serious games: a literature meta-analysis and integrative model," *Computers in Human Behavior*, vol. 92, pp. 306–315, 2019.

[18] J. Landsell and E. Hägglund, *Towards a Gamification Framework: Limitations and Opportunities when Gamifying Business Processes*, Umea Universitet, Umea, Sweden, 2016.

[19] K. Robson, K. Plangger, J. H. Kietzmann, I. McCarthy, and L. Pitt, "Is it all a game? Understanding the principles of gamification," *Business Horizons*, vol. 58, no. 4, pp. 411–420, 2015.

[20] A. Emrouznejad and W. Ho, *Fuzzy Analytic Hierarchy Process*, CRC Press, Boca Raton, 2018.

[21] Y. Liu, C. M. Eckert, and C. Earl, "A review of fuzzy AHP methods for decision-making with subjective judgements," *Expert Systems with Applications*, vol. 161, Article ID 113738, 2020.

[22] D. Pamučar, D. Bo, D. Božanić, A. Puška, and D. Marinković, "Application of neuro-fuzzy system for predicting the success of a company in public procurement," *Decision Making: Applications in Management and Engineering*, vol. 5, no. 1, pp. 135–153, 2022.

[23] S. Mustafa, A. A. Bajwa, and S. Iqbal, "A new fuzzy grach model to forecast stock market technical analysis," *Operational Research in Engineering Sciences: Theory and Applications*, vol. 5, no. 1, pp. 185–204, 2022.

[24] Y. Li, "Text mining research based on intelligent computing in information retrieval system," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 13, no. 4, Article ID 1384, 2015.

[25] A. Jamal, A. Handayani, A. A. Septiandri, E. Ripmiatin, and Y. Effendi, "Dimensionality reduction using PCA and K-means clustering for breast cancer prediction," *Lontar Komputer: Jurnal Ilmiah Teknologi Informasi*, vol. 9, no. 3, p. 192, 2018.

[26] Y. Wang, L. Xu, and Y. A. Solangi, "Strategic renewable energy resources selection for Pakistan: based on SWOT-Fuzzy AHP approach," *Sustainable Cities and Society*, vol. 52, Article ID 101861, 2020.

[27] F. Marisa, S. S. Syed Ahmad, Z. I. Mohd Yusoh et al., "The rank of silaturrahmi-assimilated collaboration parameter based on core drive using octalysis gamification framework and fuzzy AHP," *TEM Journal*, vol. 10, no. 4, pp. 1971–1982, 2021.

[28] A. M. A. Alan Fuad Jahwar, "Meta-heuristic algorithms for K-means clustering: a review," *Pjaee*, vol. 17, no. 7, pp. 1–20, 2021.

[29] F. Marisa, S. Sakinah, S. Ahmad, and Z. I. Mohd, "Analysis of relationship CLV with 8 core drives using clustering K-means and octalysis gamification framework," *Journal of Theoretical and Applied Information Technology*, vol. 98, no. 20, pp. 3151–3164, 2020, http://www.jatit.org/volumes/Vol98No20/6Vol98No20.pdf.

[30] M. Ahmed, R. Seraj, and S. M. S. Islam, "The k-means algorithm: a comprehensive survey and performance evaluation," *Electronics Times*, vol. 9, no. 8, pp. 1295–1312, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 3936122, 8 pages
https://doi.org/10.1155/2022/3936122

Research Article

Long Short-Term Memory Recurrent Neural Network for Predicting the Return of Rate Underframe the Fama-French 5 Factor

Bui Thanh Khoa [1] **and Tran Trong Huynh** [2]

[1] *Finance, Economics, and Management Research Group, Ho Chi Minh City Open University, Ho Chi Minh City, Vietnam*
[2] *FPT University, Hanoi, Vietnam*

Correspondence should be addressed to Bui Thanh Khoa; khoa.bt@ou.edu.vn

Received 22 April 2022; Accepted 19 May 2022; Published 30 May 2022

Academic Editor: Lele Qin

The multifactor approach helps determine the linear connection between a diversified portfolio's return and risk; however, the efficacy of the model models is still limited in the experiment. Algorithms in machine learning have recently grown in popularity to compensate for some of the shortcomings of theoretical models. This study applied a machine learning technique to compare the performance of the Fama-French 5-factor model (FF5). Two approaches are employed in the Fama-French model: Long Short Term Memory Recurrent Neural Network (LSTM-RNN) and Maximum Likelihood Estimation (MLE). From January 1, 2010, through March 3, 2022, the stock market in Ho Chi Minh City was experimentally researched. The rolling window approach is used in combination with the Root Mean Square Error (RMSE), and the results of the FF5 model with the LSTM-RNN algorithm are more efficient in prediction error than the MLE methodology. This contribution encourages investors and hedge fund managers to use the LSTM-RNN algorithm to boost forecasting efficiency.

1. Introduction

Sharpe [1] introduced the proposed capital asset pricing model (CAPM) based on Markowitz's portfolio diversification theory. The CAPM model measures the linear relationship between hazardous assets' return and risk. This concept swiftly became one of the theoretical pillars of modern finance. Because of its simplicity, it is employed by academia, investors, and investment management institutions. CAPM provides a minimum rate of return for risky investment projects for investors to reference. CAPM measures the systematic risk of marketed financial instruments such as stocks and bonds via beta coefficients. However, because CAPM makes too many assumptions that are difficult to meet in practice, its reality has remained a source of contention.

Years later, Banz [2] found the size effect in the US market. Small enterprises, in particular, appear to have larger returns than large firms. This finding shows that the CAPM's explanation for the scale effect is faulty. Basu [3]'s subsequent work produced similar results to Banz's. Fama and French [4] established the value-growth impact of equities in 1992. Value equities (those with high B/M ratios) outperform growth companies (those with low B/M ratios). Fama and French proposed a three-factor model by adding two new components while preserving the market factor (later called the 3-factor Fama-French model). Because the 3-factor model explains better than the CAPM patterns previously utilized, Fama and French conducted research using thousands of random stock certificates to test their pattern and discovered that when the ratings and values are combined with the amount of beta, the model can explain 89 percent profit in a varied stock category. With the ability to explain 89 percent of profits compared to the overall market, the investor can construct a portfolio in which they obtain a high-yield rate of relativity in which they have built-in their investment.

Continuing to develop the 3-factor model, Fama and French [5] expanded the three-factor model by including two elements linked to the company's investment and profit. From 7/1963 through 12/2013, Fama-French tested the 5-factor model in the US market. The model explained roughly 71% to 94% of the volatility in the return series of diverse portfolios. Compared to the 3-factor model, the 5-factor model is more effective in explaining return volatility.

The use of machine learning algorithms to exploit complex correlations between variables is a recent trend. The initial wave of publications used neural networks to forecast derivatives prices [6, 7]. Heaton et al. [8] created a deep learning approach to portfolio selection using neural networks. Shrinkage and selection algorithms were developed to estimate expected returns based on nonlinear connections between variables [9, 10]. Gu et al. [11] offered numerous machine learning algorithms for forecasting market returns, including dimension reduction, boosted regression trees, random forests, and neural networks.

The rapid advancement of the information technology industry, particularly the processing speed of computers, has greatly aided deep learning algorithms. As a result, deep learning algorithms are commonly used to tackle experimental challenges. A recurrent neural network (RNN) predicts future events using time-series data. However, some issues linked to the vanishing gradient problem persist, hurting the prediction model's effectiveness. LSTM-RNN was created to address this issue to address various difficulties that traditional RNN could not [12–15].

Roondiwala et al. [12] examined the accuracy of stock price projections under the LSTM-RNN when the NIFTY50 share price of the National Stock Exchange of India stock was paired with Open data for the study of stock prices. Consequently, the best results are obtained by combining the four input variables. Furthermore, Zhuge et al. [13] predicted the opening share prices of individual equities. It is concluded that the acquired results appear to be superior to the standard RNN application. When used for time series data processing, it is well known that LSTM-RNN has high efficiency. However, depending on the model-building approach, it might be a means of an effective predictive model. In other words, a good model contains both the underlying theory and an algorithm that fully exploits the latent correlations between variables. LSTM-RNN has also been applied successfully in demand forecasting and financial market forecasting [14–16]. Siami-Namini et al. [17] show that the LSTM-RNN model outperforms the ARIMA model in time series forecasting. LSTM-RNN was utilized in the Forex market rate prediction model by Yıldırım et al. [18].

In this work, this study proposed to combine the theoretical framework FF5 and the LSTM-RNN algorithm in the model for predicting the series of returns of investment portfolios. The main contribution of the study consists of two parts:

(i) Application of the LSTM-RNN algorithm in the stock return forecasting model.

(ii) Build a pattern that includes financial theory and AI algorithms.

2. Theoretical Foundation and Empirical Evidence

2.1. Fama-French Five-Factor Model. Fama and French [19] proposed a three-factor model frequently employed in academic and experimental research. The CAPM model explains less well than the 3-factor approach (the CAPM model lacks explanations regarding the size premium and the value premium). Some data suggest that the three-factor Fama-French model is insufficient. Novy-Marx [20], for example, shows that profitability is closely connected to average returns. In addition to this issue, Titman et al. [21] and Anderson and Garcia-Feijoo [22] discovered that investment growth is inversely connected with returns. Fama and French [5] presented a 5-factor model that includes both profit and investment factors to address these issues.

The three-factor model augments CAPM with additional factors to capture the size and value premiums. The time series regression equation has the form:

$$r_{it} - r_{ft} = \alpha_{it} + \beta_1 \mathrm{Mkt}_t + \beta_2 \mathrm{SMB}_t + \beta_3 \mathrm{HML} + \varepsilon_{\mathrm{it}}. \tag{1}$$

means:

(i) r_{it} = Return on asset i at time t.

(ii) r_{ft} = The risk-free rate at time t.

(iii) Mkt_t = The excess return of the market portfolio at time t.

(iv) SMB_t = Scale offset (small-scale minus large scale).

(v) HML_t = Value premium (value stocks minus growth stocks).

(vi) $\beta_{1,2,3}$ = Regression coefficients.

(vii) $\varepsilon_{\mathrm{it}}$ = Random error.

The five-factor model adds profitability and investment factors to the three-factor model. The regression equation has the form:

$$r_{\mathrm{it}} - r_{ft} = \alpha_{\mathrm{it}} + \beta_1 \mathrm{Mkt}_t + \beta_2 \mathrm{SMB}_t + \beta_3 \mathrm{HML}_t + \beta_4 \mathrm{RMW}_t + \beta_5 \mathrm{CMA}_t + \varepsilon_{\mathrm{it}}. \tag{2}$$

Means:

(i) r_{it} = Return on asset i at time t.

(ii) r_{ft} = The risk-free rate at time t.

(iii) Mkt_t = The excess return of the market portfolio at time t.

(iv) SMB_t = Scale offset (small-scale minus large scale).

(v) HML_t = Value premium (value stocks minus growth stocks).

(vi) RMW_t = Return factor (high-return portfolio minus low-return portfolio).

(vii) CMA_t = Investment-related factor (small portfolio minus high portfolio).

(viii) $\beta_{1,2,3,4,5}$ = Regression coefficients.

(ix) ε_{it} = Random error.

Some tests are based on the standard five-factor Fama-French model. Cakici [23] investigated the stock market in 23 developed nations between 7/1992 and 12/2014. The study's findings are as follows: the five-factor model is more effective than the 3-factor model in North America, Europe, and International markets, as most of the initial components are present. In other cases, the HML factor is not statistically significant. The two newly added variables of the five-factor model have no statistical significance or have a very low level in the Japanese and Asia Pacific markets. Gruodis [24] investigated the Swedish stock market on 600 firms between 1991 and 2014. The same result is that a 5-factor factor is more effective than a 3-factor, and more than an HML factor does not mean statistical. Zheng [25] studied the Australian stock market from 2001 to 2012 and collected the results of the most influential factor with the number of $R^2 = 0.7539$. Foye [26] tests the five-factor model utilizing a large sample of 18 countries from three different regions; this is the first work to examine the performance of the aforementioned five-factor model. As a diverse set of emerging markets in Eastern Europe and Latin America, the five-factor model routinely beats the three-factor model. However, in Asia, returns or investment premiums are not statistically significant.

2.2. LSTM-RNN Algorithm. A recurrent neural network (RNN) is a neural network. The output o_t at each node of the RNN depends not only on the input x_t at that node but also on the output o_{t-1} of the previous node in the network. The function can represent in (3)

$$o_t = f\left(W_{\text{input}} x_t + W_{\text{output}} o_{t-1} + b\right), \tag{3}$$

where f is the cell's activation function, x_t, o_t are the input and output of the RNN at time t, W_{input}, W_{ouput} is the matrix of parameters to be searched for in the model, and b is the bias vector of the model. One of the disadvantages of the RNN model is that it does not solve problems related to long-term memory well. The long short-term memory (LSTM) model introduced by Hochreiter and Schmidhuber [27] is an enhanced/advanced version of RNN that overcomes the inherent weakness of the RNN model.

In a typical architecture of an LSTM, the input of each cell at time t and the input value x_t have the state C_{t-1} and the output value o_{t-1} of the previous step. The cell's output and the output value o_t also have long-term information carried in the cell state C_t. This improves the RNN model and helps LSTM learn more effectively when learning depends on long-term memory.

Mathematically, the model uses the following functions:

$$f_t = \sigma\left(W_f \cdot \left[o_{t-1}, x_t\right] + b_f\right). \tag{4}$$

$$i_t = \sigma\left(W_i \cdot \left[o_{t-1}, x_t\right] + b_i\right). \tag{5}$$

$$\widetilde{C}_t = \tanh\left(W_C \cdot \left[o_{t-1}, x_t\right] + b_C\right). \tag{6}$$

$$C_t = f_t * C_{t-1} + i_t * \widetilde{C}_t. \tag{7}$$

$$o_t = \sigma\left(W_o \cdot \left[o_{t-1}, x_t\right] + b_o\right). \tag{8}$$

LSTM uses a forget gate to decide which input information should be kept or ignored through the logistic function sigmoid σ as shown in (4). The number of information f_t calculated by this function will be used to calculate the output o_t, C_t in (7) and (8). In addition, the functions in (5) and (6) say that new information should be combined with the retained data to create the new state and update it to the cell state C_t.

Recently, deep learning has been gaining more attention in financial forecasting tasks. Ding and Qin [28] implemented a convolution neural network (CNN) to process events collected from news websites to predict the S&P index. Chen et al. [29] deployed a recurrent neural network to analyze news content posted on social media. Ko and Chang [30] used LSTM-RNN to forecast stock prices; input variables include opening price, closing price, highest price, lowest price, volume, news, and forum.

3. Methodology

Research data include all companies listed on the Ho Chi Minh City Stock Exchange (HoSE) from January 2012 to January 2022. We will exclude companies with a listing period of less than one year and nonstock codes (such as fund certificates and bonds). The collected information includes adjusted closing prices of stocks, VN-Index, and a 1-year bond yield. Price data and VN-Index are collected from the stock exchange, and bond yields are collected from the website of the Ministry of Finance, which can be accessed from the URL: https://vst.mof.gov.vn/webcenter/portal/btc/r/m/trangchu?_afrLoop=597429615077068.

We arrange the stocks alphabetically and divide them into ten diversified portfolios. By the end of 2021, on HoSE, there are 404 stocks, which will be classified into ten lists, each of 40 stocks; the 10th list alone will have 44 stocks. The return rate will be calculated with equal weight on stocks. The factors are built and calculated as described in Fama and French [5]. Details are shown in Table 1.

Consider the general linear regression model of the form as

$$y = x^T \beta + \varepsilon. \tag{9}$$

In which,

(i) x is the matrix of inputs

(ii) y is the output matrix

(iii) β is the matrix of regression coefficients

(iv) $\varepsilon \sim N(0, \sigma^2)$ is the random error with the unknown parameter.

Suppose a training set is obtained from a random sample of k inputs $x_i \in R^n$ and $y_i \in R$. The likelihood function is determined by

Table 1: Variable description.

Variable name	Description
Mkt	Outstanding return on market portfolio
HML	The difference between returns on diversified portfolios of high and low B/M stocks
RMW	The difference between returns on diversified portfolios of high and weak profitability stocks
SMB	Profit from a diversified portfolio of small stocks minus profit from a diversified portfolio of large stocks
CMA	The difference between returns on diversified portfolios of low and high investment companies' stocks can be conservative and aggressive.
$P1, P2, \ldots, P10$	Returns of equal-weighted portfolios

$$p\left(y|x,\beta,\sigma^2\right) = p\left(y_1, y_2, \ldots, y_n|x_1, x_{2,}, \ldots, x_n, \beta, \sigma^2\right) = \prod_{i=1}^{n} p\left(y_i|x_i,\beta,\sigma^2\right) = \prod_{i=1}^{n} N\left(y_i|x_i^T\beta,\sigma^2\right). \tag{10}$$

The MLE method is to find β_{MLE} to maximize the likelihood function. This can be done using gradient ascent or gradient descent for the negative likelihood function. However, we often use log-transformation to minimize the log-likelihood function for the likelihood function.

Using log-likelihood for the normality assumption, we have

$$\log\ p\left(y_i|x_i,\beta,\sigma^2\right) = -\frac{1}{2\sigma^2}\left(y_i - x_i^T\beta\right) + \text{const.} \tag{11}$$

Ignoring the constant, we define a loose function as

$$L\left(\beta,\sigma^2\right) = \frac{1}{2\sigma^2}\sum_{i=1}^{n}\left(y_i - x_i^T\beta\right)^2. \tag{12}$$

Using the partial derivative method, we get the following result as

$$\beta_{\text{MLE}} = \left(x^T x\right)^{-1} x^T y. \tag{13}$$

The processing process is carried out according to the following steps as shown in Figure 1: (1) collecting and cleaning data, (2) calculating variables and factors, (3) estimating parameters, and (4) compute errors. The study used two estimation methods. The quantities are MLE and LSTM-RNN. We use past data of 5 consecutive years (60 months) to estimate the parameters, as shown in Figure 2. For the LSTM-RNN algorithm, we use batch_size = 20, deep network = 6, and layers = 6.

We chose the root mean square error (RMSE) evaluation criteria to evaluate the error like in previous studies [17, 31]. The root-mean-square error (RMSE) is a measure frequently used for assessing the accuracy of prediction obtained by a model. It measures the differences or residuals between actual and predicted values. The metric compares prediction errors of different models for a particular data and not between data sets. The formula for computing RMSE is as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - \hat{y}_i\right)^2}{N}}. \tag{14}$$

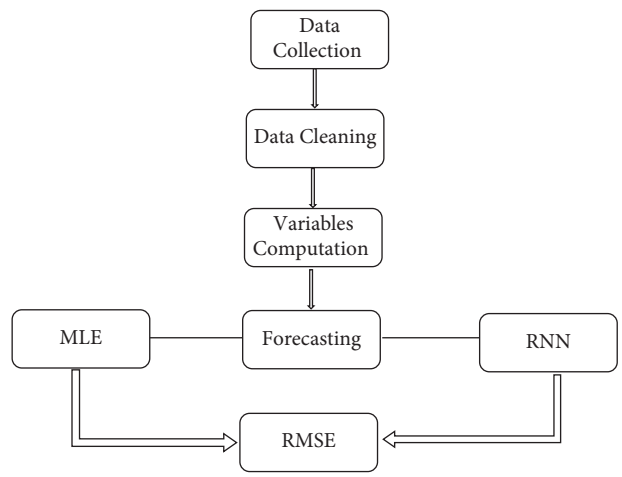


Figure 1: Research process.

where N is the total number of observations, y_i is the actual value, and $\hat{y}_i$ and is the predicted value. The main benefit of using RMSE is that it penalizes large errors. It also scales the scores in the same units as the forecast values (i.e., per month for this study).

4. Results

4.1. Descriptive Statistics. The factors are built from diversified portfolios, according to Fama-French (2015). Specifically, in June each year, stocks will be ranked by market capitalization, B/M (Book to Market Ratio), profitability, and investment. Combining sorting by size and B/M ratio creates six similar for-profit and investment portfolios, yielding 18. Then calculate the factors HML, SMB, RMW, and CMA. The Mkt factor will be represented by the market index (VN-index), specifically the difference between the VN-index return and the 1-year government bond yield. Stocks traded on HoSE will be grouped into ten categories in alphabetical order. The descriptive statistics are summarized in Table 2.

There are 147 observations, each with 1 month, from 1/2010 to 3/2022. The rate of return in various volatile portfolios ranges from 0.176%/month to 0.694%/month. The portfolios $p8$ and $p9$ concentrate most of the codes related to technology and real estate, so they have relatively higher outstanding returns but are characterized by high supply risk and standard deviations are 10,034 and 10,151. In the $p3$

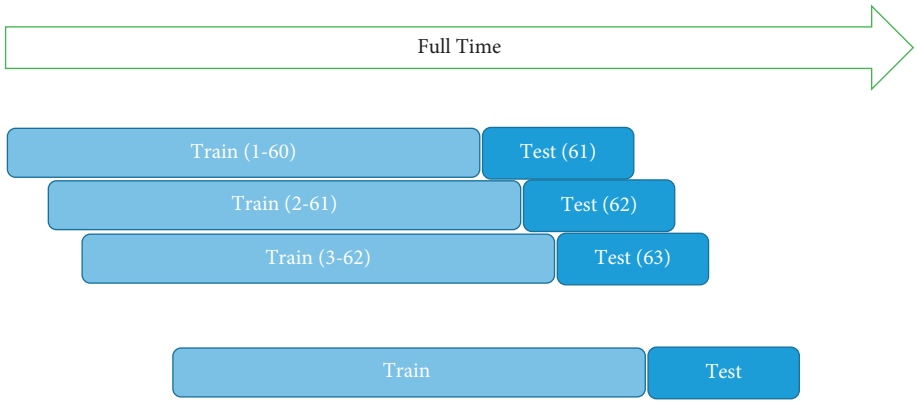


Figure 2: Rolling windows.

Table 2: Descriptive statistics.

Statistic	N	Mean	St. Dev	Min	$Q1$	$Q3$	Max
Mkt	147	0.315	5.913	−28.853	−2.632	3.397	14.761
HML	147	0.237	12.604	−24.628	−7.184	7.004	40.792
SMB	147	0.49	10.639	−23.729	−6.1	6.798	28.775
RMW	147	0.133	11.157	−34.914	−6.977	6.173	44.486
CMA	147	0.188	11.865	−30.31	−8.56	8.29	32.898
r_f	147	0.438	0.302	0.022	0.239	0.659	1.128
$p1$	147	0.183	6.907	−33.516	−2.933	4.47	17.337
$p2$	147	0.18	7.441	−33.03	−4.294	4.696	18.535
$p3$	147	0.284	11.919	−55.68	−6.756	6.735	28.591
$p4$	147	0.484	7.334	−33.039	−3.995	5.012	18.398
$p5$	147	0.22	8.771	−39.636	−4.467	5.291	24.025
$p6$	147	0.276	9.228	−41.607	−5.441	6.052	20.999
$p7$	147	0.58	9.657	−47.985	−4.207	5.683	25.935
$p8$	147	0.598	10.034	−43.716	−4.632	5.903	25.657
$p9$	147	0.694	10.151	−44.273	−5.004	6.706	25.957
$p10$	147	0.176	9.948	−44.007	−5.152	5.399	27.323

category, the standard deviation is the highest compared to the other portfolio, has a value of 11,919, and has the widest range of values, from −55.68 to 28,591. In this portfolio, most stocks related to imports and export are concentrated. During the COVID-19 pandemic, most import-export companies faced cross-border production and trade difficulties. Opposite, stocks in the $p2$ portfolio were quite stable because most were related to banks and financial institutions. As a result, returns and standard deviations are low.

The mean returns of the factors ranged from 0.133 to 0.315, with standard deviations from 5,913 to 12,604. The average return of the Mkt factor is 0.315, implying that the market's excess return (which is equal to return minus the risk-free rate) is 0.315%/month. During this period, the risk-free rate averaged 0.438, so the average market rate of return was 0.744%/month or 8.928%/year. The movements of the factors and the risk-free rate are depicted in Figure 3, which shows that the risk-free rate is almost unchanged compared to the factors. Two periods of strong market volatility were 2012–2013, when the government implemented a tight monetary policy after the global financial crisis, and 2019–2020 during the COVID-19 pandemic.

4.2. Correlation between Explanatory Variables. Considering the correlation between independent variables plays an important role in predictive modeling. The high correlation between the variables will increase the prediction error. If this phenomenon is detected early, there will be treatment methods to increase the model's predictability. Table 3 describes the correlation between the independent variables.

Table 3 shows that the variables have a low correlation (absolute value less than 0.7), in which all variables are statistically significant with Mkt. The market factor is positively correlated with the value factor and negatively correlated with the HML, RMW, and CMA factors. The negative relationship between Mkt and HML shows that investors expect more in growth stocks when the market is upbeat (bullish). Conversely, when the market is down, investors prefer value stocks. The positive relationship between Mkt and SMB shows that, when the market is

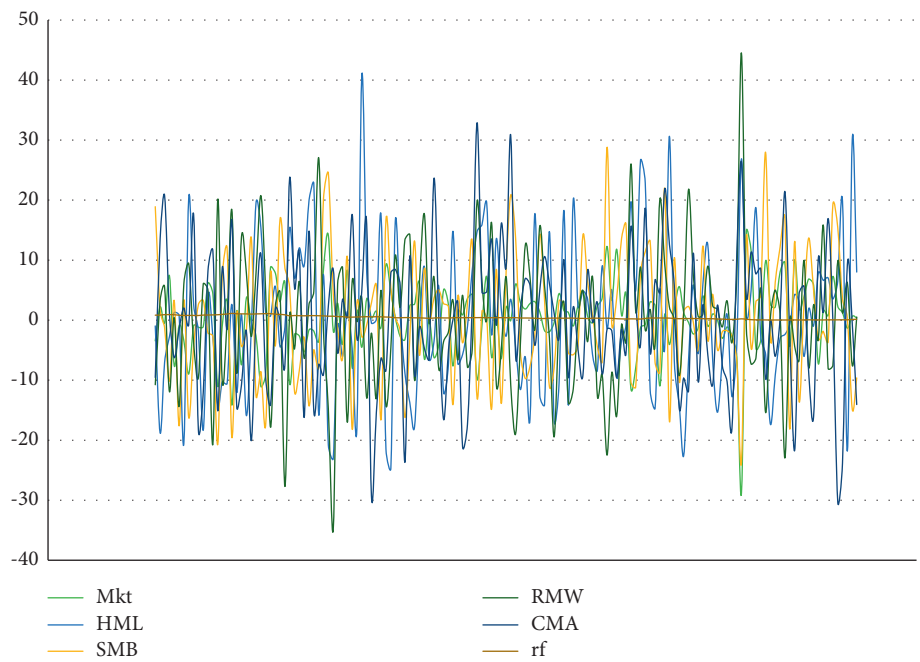


Figure 3: Movements of factors and risk-free rate over time.

Table 3: Correlation between variables.

	Mkt	HML	SMB	RMW	CMA
Mkt	1	−0.297*	0.584*	−0.582*	−0.276*
HML	−0.297*	1	−0.227*	0.183*	0.177*
SMB	0.584*	−0.227*	1	−0.378*	−0.148
RMW	−0.582*	0.183*	−0.378*	1	0.157
CMA	−0.276*	0.177*	−0.148	0.157	1

The sign "*" stands for significance level 0.05.

Table 4: RMSE error for 10 categories.

Portfolio	MLE	RNN
1	3.024	2.144
2	2.530	1.921
3	2.283	2.000
4	2.412	1.982
5	2.327	2.163
6	2.847	1.990
7	2.244	1.738
8	2.650	1.772
9	2.892	1.930
10	2.702	1.878
Average	2.591	1.952

growing, investors prefer small-cap stocks, which leads to a corresponding increase in the value of SMB.

4.3. Forecast Results. This study uses the rolling windows method with a time series of 60 months to evaluate the effectiveness of the two forecasting models. As a result, the RMSE calculation is summarized in Table 4.

The results of Table 4 show that the RMSE error in the model using the LSTM-RNN algorithm is superior to that of the regression model using the maximum likelihood method with an average RMSE error of 1,952 2,591, respectively. The MLE method is most effective in category $p7$ with an RMSE error of 2,244 and least effective in category $p1$, RMSE error ranges from 2,244 to 3,024. The prediction model using LSTM-RNN also gives similar results as MLE, most effective in the $p7$ portfolio and the worst in the $p5$ and $p1$ portfolio; RMSE ranges from 1,738 to 2,163.

To show that LSTM-RNN is more effective than MLE, we perform a T-Test for the series of distances between the predicted value and the actual value of the two models with the following hypothesis and hypothesis:

H_0: There is no difference between the two algorithms

H_1: The LSTM-RNN algorithm is more efficient

The test results obtained t-stat $= -7.63$, and the corresponding p-value is less than 0.0001, so reject H_0. Thus, the LSTM-RNN algorithm is more efficient than the RNN algorithm.

5. Conclusion

The MLE algorithm is considered a more general parameter estimation method than the ordinary least squares (OLS)

method in the case of normally distributed random errors. However, the assumption of a normal distribution is sometimes unrealistic; moreover, the relationship between the variables is not simply linear. Some machine learning algorithms are superior to classical econometric algorithms to exploit latent relationships between variables. For data related to time series, the LSTM-RNN algorithm is considered one of the very effective algorithms in future forecasting.

A signal prediction model requires a combination of two factors: the supporting background theory and an efficient parameter estimation algorithm. For portfolio return forecasting, the FF5 model is one of the most effective explanatory models [23–25, 32]. However, these studies compare with a few other models, such as the CAPM model, 3-factor model, and 4-factor model. Moreover, these studies only stop at the interpretation of statistical significance and R^2 value without considering the perspective of machine learning, that is, evaluating the prediction error.

The T-Test results have shown that the MLE or OLS method is not the best method of estimating beta coefficients in the FF5 model in the specific case of the HoSE market. The LSTM-RNN method is more efficient, with the average RMSE error of 10 categories only 1,952. This result is more consistent with some previous studies, such as Zhuge et al. [13], Borovkova and Tsiamas [15], Minami [16], Ko and Chang [30].

Compared with some previous studies, we have overcome some limitations in them. More specifically, the forecasting model that we use is completely based on the theoretical foundation of finance, which has been proven to be effective experimentally. Furthermore, the algorithm we use has proven effective for time series forecasting. The new point of this study is to propose a method to estimate the parameters in the FF5 model to produce a more effective predictive model. Furthermore, our study overcomes some limitations from previous studies; for example, in the study of Ko and Chang [30], the authors exploit the LSTM-RNN algorithm and rely on past information to predict the future. Unfortunately, if the markets are effective [33], all past information fully reflects the stock price. So, it is hard to predict; in other words, a price model is a random b.

The main objective of this study is to apply the LSTM-RNN algorithm in the 5-factor Fama-French model experimentally in the HoSE market. We compare the model using the LSTM-RNN algorithm and the model using the MLE method. The MLE method is considered a more general method than the OLS method. As a result, the model uses LSTM-RNN more efficiently than MLE. From that, we propose to use the estimation method using the LSTM-RNN algorithm in the 5-factor model to increase the accuracy of the forecast. We emphasize that an effective predictive model must combine the underlying theory and a suitable estimation method. Hence, this study proposes some recommendations based on the result.

With the theoretical contributions, first, the five-factor Fama-French model is a good predictive framework for changing the expected returns of diversified portfolios. The model quantifies the linear relationship between risk and expected return. From a Machine Learning perspective, when estimating the optimal input parameters, we can forecast the returns of the portfolios with controlled errors. Therefore, Machine Learning should be considered an alternative to traditional econometric methods. Second, for time series where the characteristic parameters change over time, the rolling window method should be considered instead of other methods such as k-fold cross-validation to increase the model's reliability. Shape and limit the phenomenon of overfitting. Moreover, the LSTM-RNN algorithm is one of the candidates for estimating the parameters in the predictive model. Deep learning algorithms can "learn" data in-depth, thus having better predictive capabilities than conventional algorithms like MLE or algorithms in economics basis quantity such as OLS regression. Therefore, researchers should consider them in actual forecasting.

In managerial implications for investors and fund managers, the 5-factor model is considered one of the best models to estimate the expected return of the investment portfolio. We can increase accuracy by using algorithms in deep learning, such as LSTM-RNN, to exploit latent relationships between variables.

The scope of research is still narrow, only considering the HoSE market. Furthermore, we have not considered the uncertain events affecting the market, such as the COVID-19 pandemic or crises, special fiscal policies, etc., market distortions that the Fama-French model is difficult to explain. We propose that the next research direction is to combine behavioral finance, multifactor models, and some algorithms in deep learning to build a more effective predictive model.

Data Availability

The data are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] W. F. Sharpe, "Capital asset prices: a theory of market equilibrium under conditions of risk," *The Journal of Finance*, vol. 19, no. 3, pp. 425–442, 1964.

[2] R. W. Banz, "The relationship between return and market value of common stocks," *Journal of Financial Economics*, vol. 9, no. 1, pp. 3–18, 1981.

[3] S. Basu, "The relationship between earnings' yield, market value and return for NYSE common stocks," *Journal of Financial Economics*, vol. 12, no. 1, pp. 129–156, 1983.

[4] E. F. Fama and K. R. French, "The cross-section of expected stock returns," *The Journal of Finance*, vol. 47, no. 2, pp. 427–465, 1992.

[5] E. F. Fama and K. R. French, "A five-factor asset pricing model," *Journal of Financial Economics*, vol. 116, no. 1, pp. 1–22, 2015.

[6] J. M. Hutchinson, A. W. Lo, and T. Poggio, "A nonparametric approach to pricing and hedging derivative securities via learning networks," *The Journal of Finance*, vol. 49, no. 3, pp. 851–889, 1994.

[7] J. Yao, Y. Li, and C. L. Tan, "Option price forecasting using neural networks," *Omega*, vol. 28, no. 4, pp. 455–466, 2000.
[8] J. B. Heaton, N. G. Polson, and J. H. Witte, "Deep learning for finance: deep portfolios," *Applied Stochastic Models in Business and Industry*, vol. 33, no. 1, pp. 3–12, 2017.
[9] S. Kozak, S. Nagel, and S. Santosh, "Shrinking the cross-section," *Journal of Financial Economics*, vol. 135, no. 2, pp. 271–292, 2020.
[10] J. Freyberger, A. Neuhierl, and M. Weber, "Dissecting characteristics nonparametrically," *Review of Financial Studies*, vol. 33, no. 5, pp. 2326–2377, 2020.
[11] S. Gu, B. Kelly, and D. Xiu, "Empirical asset pricing via machine learning," *Review of Financial Studies*, vol. 33, no. 5, pp. 2223–2273, 2020.
[12] M. Roondiwala, H. Patel, and S. Varma, "Predicting stock prices using LSTM," *International Journal of Science and Research*, vol. 6, no. 4, pp. 1754–1756, 2017.
[13] Q. Zhuge, L. Xu, and G. Zhang, "LSTM neural network with emotional analysis for prediction of stock price," *Engineering Letters*, vol. 252 pages, 2017.
[14] T. Fischer and C. Krauss, "Deep learning with long short-term memory networks for financial market predictions," *European Journal of Operational Research*, vol. 270, no. 2, pp. 654–669, 2018.
[15] S. Borovkova and I. Tsiamas, "An ensemble of LSTM neural networks for high-frequency stock market classification," *Journal of Forecasting*, vol. 38, no. 6, pp. 600–619, 2019.
[16] S. Minami, "Predicting equity price with corporate action events using LSTM-RNN," *Journal of Mathematical Finance*, vol. 08, no. 01, pp. 58–63, 2018.
[17] S. Siami-Namini, N. Tavakoli, and A. S. Namin, "A comparison of ARIMA and LSTM in forecasting time series," in *Proceedings of the 17th IEEE International Conference on Machine Learning and Applications (ICMLA)*, pp. 1394–1401, IEEE, Orlando, FL, USA, December 2018.
[18] D. C. Yıldırım, I. H. Toroslu, and U. Fiore, "Forecasting directional movement of Forex data using LSTM with technical and macroeconomic indicators," *Financial Innovation*, vol. 7, no. 1, pp. 1–36, 2021.
[19] E. F. Fama and K. R. French, "Common risk factors in the returns on stocks and bonds," *Journal of Financial Economics*, vol. 33, no. 1, pp. 3–56, 1993.
[20] R. Novy-Marx, "The other side of value: the gross profitability premium," *Journal of Financial Economics*, vol. 108, no. 1, pp. 1–28, 2013.
[21] S. Titman, K. C. J. Wei, and F. Xie, "Capital investments and stock returns," *Journal of Financial and Quantitative Analysis*, vol. 39, no. 4, pp. 677–700, 2004.
[22] C. W. Anderson and L. Garcia-feijóo, "Empirical evidence on capital investment, growth options, and security returns," *The Journal of Finance*, vol. 61, no. 1, pp. 171–194, 2006.
[23] N. Cakici, *The Five-Factor Fama-French Model: International Evidence*, Fordham University, Bronx, NY, USA, 2015.
[24] D. Gruodis, *The Fama-French Five-Factor Asset Pricing Model for the Swedish Stock Market*, Stockholm School of Economics, Stockholm, Sweden, 2015.
[25] X. Zheng, *An Empirical Analysis of Asset Pricing Models in Australia*, Auckland University of Technology, New Zealand, 2015.
[26] J. Foye, "A comprehensive test of the Fama-French five-factor model in emerging markets," *Emerging Markets Review*, vol. 37, pp. 199–222, 2018.
[27] S. Hochreiter and J. Schmidhuber, "Long short-term memory," *Neural Computation*, vol. 9, no. 8, pp. 1735–1780, 1997.
[28] G. Ding and L. Qin, "Study on the prediction of stock price based on the associated network model of LSTM," *International Journal of Machine Learning and Cybernetics*, vol. 11, no. 6, pp. 1307–1317, 2020.
[29] H. Chen, K. Xiao, J. Sun, and S. Wu, "A double-layer neural network framework for high-frequency forecasting," *ACM Transactions on Management Information Systems*, vol. 7, no. 4, pp. 1–17, 2017.
[30] C.-R. Ko and H.-T. Chang, "LSTM-based sentiment analysis for stock price forecast," *PeerJ Computer Science*, vol. 7, Article ID e408, 2021.
[31] B. T. Khoa and T. T. Huynh, "Is it possible to earn abnormal return in an inefficient market? An approach based on machine learning in stock trading," *Computational Intelligence and Neuroscience*, vol. 2021, Article ID 2917577, 14 pages, 2021.
[32] E. F. Fama and K. R. French, "International tests of a five-factor asset pricing model," *Journal of Financial Economics*, vol. 123, no. 3, pp. 441–463, 2017.
[33] E. F. Fama, "Efficient capital markets: a review of theory and empirical work," *The Journal of Finance*, vol. 25, no. 2, pp. 383–417, 1970.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1427913, 12 pages
https://doi.org/10.1155/2022/1427913

Research Article

Influence Factors and Policy Analysis of Small and Microenterprises' Sustainable Development: Empirical from Zhejiang

Pengyue Wu and Huijie Zhou

College of Science and Technology, Ningbo University, Ningbo 315300, China

Correspondence should be addressed to Huijie Zhou; zhouhuijie@nbu.edu.cn

Received 31 March 2022; Revised 7 May 2022; Accepted 13 May 2022; Published 27 May 2022

Academic Editor: Lele Qin

The sustainable development of enterprises is the driving force of national economic growth. The main objectives of this paper are to find what are all the influencing factors of enterprise sustainable development, how to produce the influence, and how to carry out effective strategy combination. This paper investigates 321 enterprises and analyzes their financial data from the aspects of market, internal management, industry, scale, products, and innovation ability. We find that fixed assets, information management level, and the overall quality of employees have the best driving force, reaching 0.132, 0.195, and 0.874, respectively. Enterprises also put more efforts on the improvement of internal management level and the expansion of industrial chain, which were 0.3778 and 0.2138, respectively. As far as the government's strategy of supporting and promoting tax policy is concerned, tax policy has a good independent impact, but when combined with other indicators, the impact effect is not significant. This shows that the promotion efficiency of the policy is low, and the applicability and pertinence need to be optimized. In addition, the promotion effect of innovation investment on sustainable development is poor, which shows that the innovation efficiency of small and microenterprises in Zhejiang Province is not high, and the ability to transform innovation resources into innovation output is insufficient.

1. Introduction

In Zhejiang, small and microenterprises, all of which refer to industrial manufacturing enterprises in this paper, continue to flourish, and they have made great contributions to the growth of national economy, the promotion of employment, and the increase of tax revenue. However, small and microenterprises rely on resource input for a long time, and the economic leading model characterized by "high consumption, low quality, and low efficiency" will not be sustainable. The Chinese government has been actively promoting the sustainable development of small and microenterprises and encouraging them to make use of new technologies. However, small and microenterprises have small-scale and poor antirisk ability. They need effective self-growth and appropriate government support to achieve sustainable development. Combined with the data of internal and external factors of small and microenterprises, this paper analyzes the impact on sustainable development. Our main objective is to establish evaluation indicators for the sustainable development of small and microenterprises, find the influence differences of different factor combinations through data demonstration, and find out the effective ways for the sustainable development of small and microenterprises.

Sustainable development has been a reform actively promoted by the Chinese government in recent years. In terms of industrial policy, the Chinese government not only gives great concessions in taxes and fees but also continues to strengthen subsidies for some R&D investment. However, some characteristics of small and microenterprises make the implementation of relevant policies inconsistent with expectations. For example, in fixed assets, foreign trade, R&D, and training support policies, its results show significant

differences. How to assess the effectiveness of these measures requires adequate investigation and analysis.

Sustainable development is a macro concept, including rich and diverse content. In different research, its concept also has a big difference. Looking at the research in recent years, it is found that sustainable development takes enterprise transformation and upgrading as the connotation, and the discussion includes two levels: enterprise transformation and enterprise upgrading [1]. There are also differences in the sensitivity of transformation and upgrading to practical factors. Therefore, we should classify and analyze the influencing factors of the transformation and upgrading of small and microenterprises.

In the research on the strategy of promoting sustainable development, the existing relevant research results are mostly based on the empirical analysis with the potential factors of transformation and upgrading as variables, such as the number of innovative products and patents, which is difficult to cover the connotation of sustainable development and the design of effective promotion means of sustainable development from a systematic perspective, which is one-sided. Therefore, when analyzing the promotion strategy of sustainable development of small and microenterprises, we need to solve the problem of evaluation system of sustainable development first. Starting from the connotation system of sustainable development, we need to build evaluation indicators including transformation and upgrading and then classify the data for demonstration. Through in-depth data analysis, explore the relationship between different promotion and incentive methods and transformation and upgrading system, so as to design more effective strategies to promote the sustainable development of small and microenterprises.

The contribution of this paper may lie in constructing the evaluation system of sustainable development by using qualitative and quantitative analysis methods, studying the influencing factors of sustainable development of enterprises from the perspective of enterprise transformation and upgrading, and providing reference for sustainable development for enterprises and governments in combination with the influence of policy incentives.

Enterprise sustainable development is a new concept put forward in the 1980s with the extensive discussion of global environment and development. It is the crystallization of people's long-term and profound reflection on the traditional development model. Enterprise sustainable development means that in the process of pursuing self-survival and sustainable development, enterprises should not only consider the realization of enterprise business objectives and improve their market position, but also maintain the continuous profit growth and ability improvement in the leading competitive field and the business environment of future expansion. Transformation and upgrading is an important means for enterprises to achieve sustainable development. Transformation can improve the problem-solving ability of enterprises to deal with complex market environment, and upgrading can improve the stability of enterprise business performance.

Many scholars analyze the connotation, strategic choice, system construction, dynamic mechanism, and influencing factors of enterprise sustainable development. These results explain the sustainable development from the endogenous growth model. However, the continuous innovation of enterprises is influenced not only by the wage level and scale within the organization, the company's liquidity management, technical leadership, technological diversification, the control of the general manager, and the heterogeneity between the chairman and the general manager [2] but also by the fierce market competition outside the organization, environmental uncertainty, and government subsidy investment [3, 4].

The sustainable development of enterprises needs to be connected with the outside world. One is the market in which the enterprise is located, and the other is the policy environment in which the enterprise is located [5]. The sustainable development of enterprises needs to adapt to the changes of market environment through the absorption of connected resources and policy texts, and make corresponding strategies [6, 7]. The sustainable development of enterprises needs to break the organizational boundary and obtain the driving force of sustainable development through the external market, so it is embedded in a certain industry [8]. The integration of internal and external resources in the process of sustainable development of enterprises needs to design corresponding policy incentives and establish information communication and resource trading mechanism through the connection between enterprise subjects. Enterprises can deal with the complexity of knowledge in sustainable development [9], reduce transaction costs, including information search, communication and negotiation, and improve the strength of knowledge and technology connection between enterprises [10]. This reflects the transformation and upgrading performance of enterprises in sustainable development.

From the perspective of resource-based theory, the motivation of transformation and upgrading comes from within the enterprise. Enterprises could gain competitive advantage by allocating its valuable, scarce, and imitative resources. The possession of key resources and acquisition of key capabilities laid a foundation for enterprise transformation and upgrading. Key resources include capital accumulation and human resources [11]. The key capabilities of enterprises include independent innovation capability and marketing service capability [12].

From the perspective of contingency theory, the motivation source of enterprise transformation and upgrading is its external. On one hand, the market prospect is broad, the consumption psychology is maturing day by day, and the market competition order is becoming more and more standardized, which provides a broad external space for the enterprise to upgrade. The government vigorously creates a good external environment for technological innovation, which is conducive to promoting the rapid upgrading of enterprises [13]. On the other hand, entrepreneurship and brand awareness can accelerate the process of establishing independent brands. Enterprise ambition is an important factor affecting the transformation and upgrading of enterprises, while enterprise ambition is an external manifestation of entrepreneurship and corporate culture [14]. It

also includes innovative, aggressive, passionate, and persistent entrepreneurship; strong sense of responsibility to people and employees; strong independent intellectual property rights and brand awareness; and different influence on enterprises to choose different transformation and upgrading paths [15].

Policy incentive can guide the enthusiasm and initiative of enterprise transformation and upgrading [16, 17]; tax preferential policy can better induce technological innovation [18, 19]; and policy incentive intensity is not linearly related to enterprise performance [20]. Tax and government R&D policy fluctuations will have a certain negative inhibitory effect [21]. A variety of strategic combinations of policy incentives [22, 23], with better pertinence and balance [24–26].

Based on this, this paper believes that the factors that promote the transformation and upgrading of the manufacturing industry are composed of internal and external factors, including the size of the enterprise itself, R&D investment, the management level of entrepreneurs, and the support of government fiscal and taxation policies.

To sum up, the transformation and upgrading of enterprises are highly matched with sustainable development, and the indicators can be designed from the two aspects of internal management and external competition. However, at present, there is a lack of design of observation indicators at the specific microlevel, and the weight of indicators is not calculated, so it is difficult to quantitatively analyze the influencing factors of sustainable development of manufacturing industry. In the research of policy analysis, most literature are based on the effect evaluation of a one-way policy, and lack the analysis of the combination effect under the combination of internal and external factors. Therefore, by establishing the micromeasurement index system of transformation and upgrading and through the coordinated combination analysis of internal and external factors, this paper has good research value for the sustainable development of enterprises.

2. Materials and Methods

2.1. Data Sample Collection. This paper took manufacturing small and microenterprises as the research object, selected Zhejiang Province as the sample area, and did the investigation from 2018 to 2019. In accordance with the criteria for the classification of enterprises in the Law of the People's Republic of China on the Promotion of Small and Medium-sized Enterprises and the Opinions of the State Council on Further Promoting the Development of Small and Medium-sized Enterprises, this paper selected enterprises with less than 100 employees or operating income of less than 40 million yuan as the research object. Using the multistage sampling method, we selected 3 from 10 prefecture-level cities in Zhejiang, then selected 2 typical counties or districts from each of the 3 prefecture-level cities, and then selected 3 typical industries in each county or district. A total of 321 samples were obtained.

Based on the transformation and upgrading indicators of enterprise sustainable development, this paper uses AHP to construct the evaluation system and design a quantitative evaluation index. The article then selects variables from the internal and external factors that affect the sustainable development of enterprises, and empirically analyzes the impact of the factors of sustainable development of enterprises using multiple regression method. This paper analyzes the influencing factors of enterprise sustainable development from the microlevel, combined with the effect of policy incentives, and puts forward a practical mathematical analysis model, with the framework shown in Figure 1.

2.2. Sustainable Development Index System. According to the aforementioned hypothesis, the sustainable development of small and micromanufacturing enterprises should be evaluated comprehensively from the two aspects of transformation and upgrading. Transformation is the ability of an enterprise to respond to the competitive environment in terms of market, management, and industrial energy. Upgrading is the static result of the sustainable development of enterprises, which is characterized by enterprise scale, industrial competitiveness, and innovation level. Based on this, the paper designs a questionnaire, and the results are as follows.

In terms of upgrading, enterprises consider scale, product, and innovation ability to be the most reflected indicators, accounting for 33%, 31%, and 29%, respectively. In terms of transformation, enterprises believe that the most visible indicators are market, management, and industry, accounting for 28%, 26%, and 23%, respectively. Accordingly, an overall evaluation system for the transformation and upgrading of small and micromanufacturing enterprises was constructed. Considering the needs of subsequent data analysis, 17 measurement points were designed for each of the 6 indicators to provide data support for quantitative analysis. The details are shown in Figure 2.

The scale of small and microenterprises is the main embodiment of enterprise upgrading. The scale of small and microenterprises is the main bottleneck of its development, and the scale of cost allocation, R&D investment and so on is the main influencing factor. To this end, the state and provinces and cities issued a series of measures to promote the upgrading of small and microenterprises. The evaluation index of enterprise scale mainly includes total fixed assets, total industrial output value, and number of employees.

Products are the foundation of the development of small and microenterprises. The brand, technology content and quality of the product are the main influencing factors of its market competitiveness, the guarantee of enterprise upgrading, and the important link of differential competition of small and microenterprises. Product evaluation indicators mainly include enterprise brand, product technology content, and total finished product.

Innovation ability is the key link of small and microenterprise transformation and upgrading. Small and microenterprises in the market competition product competitiveness mainly rely on its innovation ability to promote. In order to promote the upgrading of its products, this is also

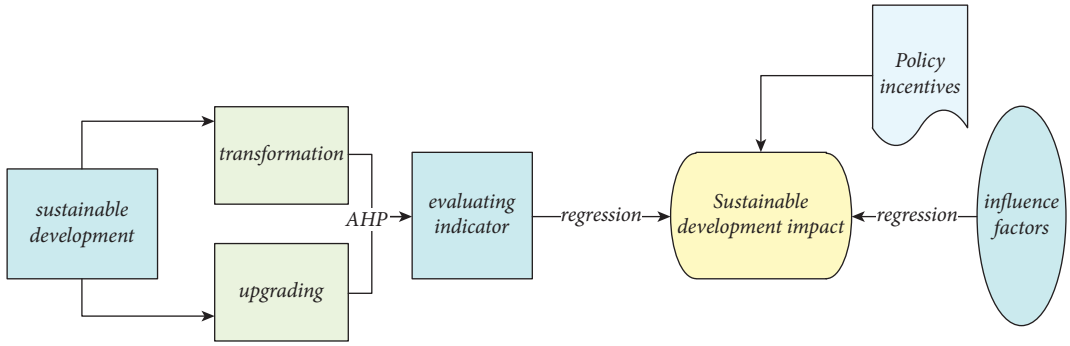


Figure 1: Overall design model framework.

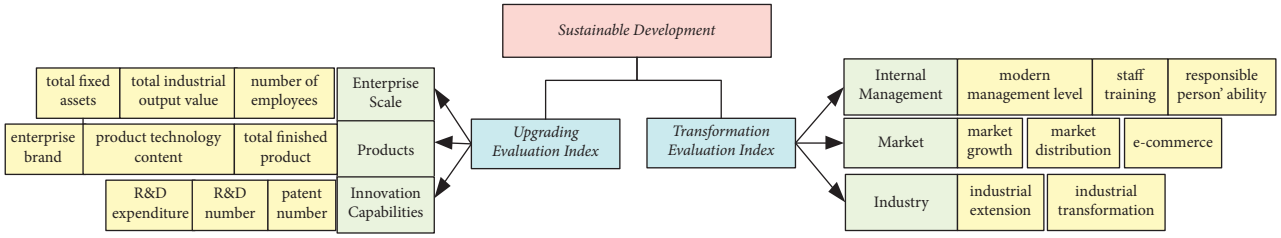


Figure 2: Evaluation index system for transformation and upgrade.

a key bottleneck for small and microenterprises. The evaluation index of innovation ability mainly includes R&D expenditure, R&D number, and patent number.

Market is the reflection of the level of small and microenterprise value chain. The market occupied by small and microenterprise products is the comprehensive embodiment of its product brand, technology, and quality, and also the direct influence factor of small and microenterprise profits. In addition, the market development mainly lies in the domestic market, the international market and the electronic commerce market. Market evaluation indicators are market growth, market distribution, and e-commerce.

Internal management is the source of the transformation of small and microenterprises. Most of the management of small and microenterprises is loose and random, so it is necessary to highlight the application of new technology, new tools, and new ideas. At the same time, the overall quality of small and microenterprises is low, and management is mainly responsible for subjective decisions. The main evaluation indexes of modern management level are staff training and management ability of responsible person.

Industry is one of the important ways to transform small and microenterprises. Through the development of the original industry, small and microenterprises extend to upstream or downstream industries, or infiltrate into other emerging characteristic industries, and then enhance the maximization of the overall value chain effect of enterprises, which is the highest requirement for the transformation of small and microenterprises. The evaluation index of industry mainly includes industrial extension and industrial transformation.

2.3. Weight Measurement of the Sustainable Development Evaluation System. In Section 2.2, we constructed an evaluation system and specific indicators of sustainable development. However, the degree of reflection of each index in the enterprise transformation and upgrading system is different. The importance of different indicators in the transformation and upgrading system is also different. The transformation and upgrading index obtained through the questionnaire can only express a general tendency of the enterprise. However, the importance of relationship between indicators cannot be determined, so it is necessary to further analyze the weight value of each index in the transformation and upgrading, which can reflect the scientific nature of the evaluation system.

Analytic hierarchy process is to decompose complex problems step by step to form a multilevel structure. The weight coefficient of each index is an important analysis tool of decision theory. Hierarchical analysis method can present the relationship of importance between multiple factors in numerical form and has the advantage of quantifying qualitative problems. Therefore, it is necessary to construct a three-tier evaluation system. The first level is the overall goal of small and microenterprise transformation and upgrading "A". The second level consists of six criterion layers, Enterprise size "B1", product "B2", innovation capability "B3", market "B4", internal management "B5", and industry "B6". The third layer contains 17 indicators in the 6 criteria layer. The details are shown in Figure 1.

Building judgement matrices: The relative importance of each factor at each level is expressed in numerical form. For example, u_{ij} expression of u_i and u_j (i, $j = 1, 2, 3, \ldots$). The relative importance, take 1, 2, 3,. . .. If u, then u_j percent t_i important, then expressed by countdown, as shown in Table 1.

Table 1: Numerical description of the judgement matrix.

Value	Note
1	Representation of two indicators is equally important
3	The former factor is slightly more important than the latter
5	The former is more important than the latter
7	The former is more important than the latter
9	The former is more important than the latter
2, 4, 6, 8	Median value between 1, 3, 5, 7, 9
Countdown	The former is important

According to the aforementioned instructions, the following judgment U is constructed as follows:

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{ij} \\ u_{12} & u_{22} & \cdots & u_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ u_{i1} & u_{i2} & \cdots & u_{ij} \end{bmatrix}.$$

The values in the matrix are scored by expert Delphi method. In order to ensure the scientific and accurate scoring, the author has visited 12 experts from government, enterprises, and other institutions. Through the proposed questionnaire, this paper quantifies the experience of managers and consults with expert group members in accordance with established procedures. Members of the Group submitted their comments anonymously. After two rounds of consultation and feedback, the opinions of the members of the expert group gradually tend to be stable, and the questions are not objective, and the logical questions are removed. Finally, 5 bits of collective judgment with high accuracy are obtained, and the judgment matrix is constructed.

The analysis model is as follows. M experts are set to evaluate n decision-making schemes. The expert decision-making group is expressed as $e = \{E1, E2, \ldots EM\}$, and the candidate decision-making evaluation scheme is $s = \{S1, S2, \ldots, Sn\}$. Then the evaluation judgment matrix of the k expert is $E_k = [a(k)_{ij}]n * n$.

Based on the expert judgment matrix, the geometric average method is used to construct the comprehensive judgment matrix of the criterion layer for the overall goal, calculate the maximum value of each comprehensive judgment matrix, sort the vector, and test their consistency. Similarly, calculate the comprehensive judgment matrix of each index layer to the criterion layer. The calculation method is $m_{ij} = \sqrt[n]{\prod_{n=1}^{n} A^n a_{ij}}$.

Single-layer weight ranking and consistency test. The weight of each layer is calculated according to the judgment matrix. The importance of the related indexes at this level can be transformed into the calculation of the corresponding matrix eigenvalues and eigenvectors, and the normalized eigenvectors are taken as the weights of the indexes in this layer relative to the upper layer. Owing to the uncertainty, the judgment matrix needs to be checked for consistency. When the consistency index of the judgment matrix is less than 0.1, it shows that the matrix has satisfactory consistency, otherwise it is necessary to adjust the matrix index.

2.4. Policy Incentives for Sustainable Development. Governments tend to use financial subsidies and tax incentives to support the development of small and microenterprises. Financial subsidy is a kind of subsidy established by the government for innovative enterprises and a kind of monetary compensation. The enterprise needs to pass the declaration and qualification review before obtaining the qualification Tax preference is an inclusive policy, not for specific enterprise groups. Through the questionnaire design, we designed and assigned the financial subsidies and tax preferences obtained by enterprises as virtual variables, combined with multiple regression model and enterprise sustainable development factors to analyze the policy effect. We hope to obtain the promotion effect of policy incentives on sustainable development under different combinations.

3. Results and Discussion

3.1. Performance Evaluation of Sustainable Development. First, for the overall target of small and microenterprise transformation and upgrading, the relative importance of the six criteria is calculated in Table 2.

$\lambda_{\max} = 6.0481$, $C \bullet I = 0.00962$, $C \bullet R = 0.0076 < 0.1$

Second, the index weights of the six criteria of the first-level, enterprise-scale, industry, innovation, market, internal management, and industry, are calculated, respectively. The index weights of each criterion level are calculated as shown in Table 3.

According to the calculation results of the aforementioned judgment matrix, all matrices pass the consistency test, which shows that each weight index has satisfactory consistency.

Total ranking of final weights: The total ranking needs to be carried out from top to bottom. First, the vector values of 6 criterion layers, product, innovation ability, market, internal management, and industry are calculated. Then the weight value relative to the total target is obtained by multiplying the vector value of the fixed assets, the total industrial output value and the number of employees. The weight value of product, innovation ability, market, internal management, and industry index relative to the total target is calculated. The results are shown in Table 4.

Table 4 shows the influencing factors and weights of the sustainable development system of small and microenterprises. The influencing factors are in order of importance: employee training, responsible person's education level, industry transformation, patent number, industry extension, information level, product technology content, enterprise brand, e-commerce, R&D number, export destination, fixed assets, total finished product value, R&D expenditure, number of employees, total industrial output value, and export delivery value.

For the overall goal of enterprise sustainable development, most enterprises, and experts think that we should pay more attention to internal management, followed by the expansion and extension of industry, and third, innovation ability and products. It may be that the internal management of small and microenterprises is the primary problem of their survival and development, as well as the guarantee of

Table 2: Ranking weights B the target layer A in the criterion layer.

Evaluation indicators for sustainable development	Enterprise scale	Products	Innovation capacity	Market	Internal management	Industry	Weight
Enterprise size	1.0000	0.3674	0.2508	0.6084	0.1581	0.2682	0.0493
Products	2.7216	1.0000	0.7248	2.0626	0.3749	0.5818	0.1313
Innovative capacity	3.9874	1.3797	1.0000	1.9744	0.3081	0.6646	0.1546
Market	1.6438	0.4848	0.5065	1.0000	0.2088	0.3155	0.0732
Internal management	6.3253	2.6673	3.2453	4.7894	1.0000	1.8384	0.3778
Industry	3.7279	1.7188	1.5047	3.1698	0.5439	1.0000	0.2138

Table 3: Ranking weights of index layer B1 criterion layer.

Enterprise scale B1	Fixed assets	Industrial GDP	Number of employees	Weight	
Fixed assets	1.0000	0.8219	0.5957	0.2538	$\lambda\max = 3.0060$, $C\bullet R = 0.0058 < 0.1$
Industrial GDP	1.2167	1.0000	0.5743	0.2858	
Number of employees	1.6788	1.7411	1.0000	0.4604	
Products B2	Corporate brand	Technical content	Number of finished products	Weight	
Corporate brand	1.0000	0.6310	1.9855	0.3180	$\lambda\max = 3.0024$, $C\bullet R = 0.0024 < 0.1$
Technical content	1.5849	1.0000	3.6502	0.5296	
Number of finished products	0.5037	0.2740	1.0000	0.1524	
Innovative capacity B3	R&D expenditure	R&D	Patent	Weight	
R&D expenditure	1.0000	0.6683	0.1616	0.1214	$\lambda\max = 3.0109$, $C\bullet R = 0.0105 < 0.1$
R&D	3.1777	1.0000	0.3309	0.2017	
Patent	6.1879	3.0219	1.0000	0.6768	
Market B4	Market growth	Market distribution	E-commerce	Weight	
Market growth	1.0000	0.3147	0.2881	0.1298	$\lambda\max = 3.0081$, $C\bullet R = 0.0078 < 0.1$
Market distribution	3.1777	1.0000	0.6988	0.3771	
E-commerce	3.4713	1.4310	1.0000	0.4931	
Management B5	Modern management	Staff training	Management ability of responsible person	Weight	
Modern management	1.0000	0.5000	0.8415	0.2433	
Staff training	2.0000	1.0000	1.1404	0.4274	$\lambda\max = 3.0169$, $C\bullet R = 0.0162 < 0.1$
Management ability of responsible person	1.1884	0.8769	1.0000	0.3292	
Industry B6	Industrial extension	Industrial transformation		Weight	
Industrial extension	1.0000	0.8027		0.4453	$\lambda\max = 2.0000$, $C\bullet R = 0.0000 < 0.1$
Industrial transformation	1.2457	1.0000		0.5547	

Table 4: Summary table.

General	Level 1	Weight	Level 2	DS_i	Weight	Relative weight
DS evaluation index system for sustainable development	B1: Enterprise size	0.0493	Fixed assets	488	0.4604	0.0227
			Industrial GDP	480	0.5957	0.0125
			Number of employees	511	0.5743	0.0141
	B2: Products	0.1313	Corporate brand	73	0.3180	0.0418
			Product technical	155	0.5296	0.0696
			Gross product	409	0.1524	0.0200
	B3: Innovative capacity	0.1546	R&D expenditure	147	0.1214	0.0188
			R&D number	25	0.2017	0.0312
			Number of patents	122	0.6768	0.1047
	B4: Market	0.0732	Market growth	233	0.1298	0.0095
			Market distribution	127	0.3771	0.0276
			E-commerce	35	0.4931	0.0361
	B5: Internal management	0.3778	Modern management	501	0.2433	0.0919
			Staff training	156	0.4274	0.1615
			Management ability of responsible person	307	0.3292	0.1244
	B6: Industry	0.2138	Industrial extension	60	0.4453	0.0952
			Industrial transformation	40	0.5547	0.1186

innovation and products. There are many cases of decision-making errors, which is one of the most important evaluation factors for enterprises and experts.

The first three are employee training, responsible person level, and industry transformation, and the results are consistent with those of the criterion level. The results show that small and microenterprises need to solve the talent problem first. Talent is the core element of enterprise internal management. The transformation and upgrading of small and microenterprises can only be promoted by talents. Therefore, strengthening staff training and improving the education level of enterprise leaders is the key to enhance the transformation and upgrading of small and microenterprises.

3.2. Analysis of Policy Effect of Sustainable Development. Through AHP analysis, internal management has become the most important link of enterprise sustainable development. However, the impact of enterprises' contribution to sustainable development in the actual operation process needs to be further tested by quantitative methods. Therefore, by collecting 321 small and microenterprise survey data and combining 2018 to 2019 statistical panel data, this paper uses multiple regression method to analyze the impact of transformation and upgrading.

Measurement of transformation and upgrading of dependent variables: Based on the hierarchical analysis method to obtain the weight of each index of transformation and upgrading, this paper quantitatively calculates the transformation and upgrading, and sets each observation index of transformation and upgrading as the DS_i. The weight value of each index calculated by AHP. W_i and then through the weighted average method summary calculation of the overall transformation and upgrading value DS. Obtained for each transformation or upgrade, the enterprise can get 1 point and 0 point. For the transformation or upgrading of non-divariate variables, this paper will score the average value of variables in stages. Each microindex sustainable development value DS calculation formula is as follows:

$$DS = \sum_{i=1}^{n} W_i DS_i. \tag{1}$$

We select 12 industry experts to score, including 6 government departments and 6 enterprise experts. There are 6 production managers, technical supervisors, and business operations managers. At the same time, this paper combines the two aspects of enterprise transformation and upgrading, set up three groups: enterprise transformation, enterprise upgrading, and enterprise transformation and upgrading.

In order to reduce the error caused by the data unit, the qualitative evaluation method of grade division is selected. Among them, electronic commerce adopts qualitative index (dummy variable) brings directly into calculation. Staff training is calculated by hierarchical weighted average. The responsible person management ability, modern management, industry extension, industry transformation, enterprise brand, and product technology content are assigned according to questionnaire enterprise self-evaluation opinions. The remaining indicators are divided by 6 grades and assigned by 0~6 points. The scoring basis of experts is shown in Table 5.

Independent variable setting: The selection of independent variables in this paper starts from the enterprise sustainable development performance evaluation system. We select the strategic factors that pay more attention to the performance evaluation of enterprise sustainable development. Considering the independence of independent variables and dependent variables, we try to select objective indicators. In the enterprise internal input, the enterprise mainly tries to asset investment and science & technology investment. The enterprise management ability, the information application level, the employee quality and the enterprise responsible person degree of education are the important influence factors which affect the management efficiency. In the external influence strategy, the dual influence of the market and the government is the main. The export-oriented economic characteristics of small and microenterprises in Zhejiang are remarkable, so export trade and export market are regarded as market factors. The government chooses the tax reduction and fee reduction policy which the Chinese government actively implements at present and takes the financial support and the preferential enjoyment of taxes and fees as the influencing factors.

Based on the aforementioned analysis, we propose the following assumptions:

H1: Enterprise asset investment can promote sustainable development.

H2: Science and technology investment can promote sustainable development.

H3: Enterprise internal management can promote sustainable development.

H4: Foreign trade of enterprises can promote sustainable development.

H5: Government policy support can promote sustainable development.

Model selection and analysis. In this paper, the metrological model is set as a multivariate linear regression model. The models are as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k. \tag{2}$$

The β is a fixed value, and x represents the selected independent variables. We select export delivery value (JH), export destination (CK), fixed assets (ZC), information management level (GL), the overall quality of employees (SZ), education background of enterprise leader (XL), science & technology investment (TF), tax concessions (SF), and financial support (CZ) as independent variables. We take transformation value *DS_A*, upgrade value *DS_B*, transformation upgrade value as dependent variables. The regression test coefficient is tested in Table 6.

4. Discussion of Results

Based on the hypothesis of H1, we find that, whether it is enterprise transformation grouping or enterprise upgrading grouping, the regression coefficients of fixed assets are

Table 5: Expert scoring basis.

Level 1	Level 2	Basis
B1: Enterprise size	Fixed assets	Divide 6 grades and scored according to 0 ~ 6
	Industrial GDP	Divide 6 grades and scored according to 0 ~ 6
	Number of employees	Divide 6 grades and scored according to 0 ~ 6
B2: Products	Corporate brand	Assign 0 or 1 by presence or absence
	Product technical	Divide 6 grades and scored according to 0 ~ 6
	Gross product	Divide 6 grades and scored according to 0 ~ 6
B3: Innovative capacity	R&D expenditure	Divide 6 grades and scored according to 0 ~ 6
	R&D number	Divide 6 grades and scored according to 0 ~ 6
	Number of patents	Divide 6 grades and scored according to 0 ~ 6
B4: Market	Market growth	Divide 6 grades and scored according to 0 ~ 6
	Market distribution	Assign 0 or 1 by presence or absence
	E-commerce	Assign 0 or 1 by presence or absence
B5: Internal management	Modern management	Assign 0 or 1 by presence or absence
	Staff training	Assign 0 or 1 by presence or absence
	Management ability of responsible person	Divide 6 grades and scored according to 0 ~ 6
B6: Industry	Industrial extension	Assign 0 or 1 by presence or absence
	Industrial transformation	Assign 0 or 1 by presence or absence

significantly positive in all grouping models. This shows that the investment in fixed assets of enterprises has a significant role in promoting transformation and upgrading. This further illustrates the importance of corporate fixed assets in promoting transformation and upgrading.

Based on the hypothesis of H2, we find that, corporate R&D expenditures have positive and negative variables in the model of corporate transformation and transformation and upgrading, and they are not significant. This shows that the innovation investment effect of enterprises is not very good, which may be due to the speculative behavior of enterprises under the influence of government financial support. However, it is significant in Model 10 and Model 12 for enterprise upgrading, which shows that enterprise innovation has certain help to enterprise upgrading.

Based on the hypothesis of H3, we find that, the level of information management, the overall quality of employees and the educational background of enterprise leaders are consistent, regardless of the enterprise transformation group or the enterprise upgrading group. The regression coefficients are significantly positive in all the grouping models, which reflects that the internal management of enterprises has a significant positive effect on enterprise transformation or enterprise upgrading. This further illustrates the importance of internal management in the sustainable development of enterprises. Only the better the internal management, the better the transformation and upgrading of enterprises can be realized, and internal management is the fundamental of enterprise sustainable development.

Based on the hypothesis of H4, we find that, export destinations play a significant role in the transformation and upgrading of small and microenterprises. Model 13 undoubtedly confirms this point, but the effect of export delivery value similar to the previous results on enterprise transformation and upgrading is not clear. Enterprises rely solely on export quantity expansion is not conducive to the transformation and upgrading of enterprises, and may even have negative effects. However, export-developed areas are conducive to promoting the transformation and upgrading of enterprises. Owing to the technical and quality requirements of developed regions, targeted assistance will be given to enterprise product technology, so as to realize the reverse promotion of enterprise products. So small and microenterprises should pay more attention to the export of high-tech and high-content products.

Based on the hypothesis of H5, we find that, government financial support has positive and negative variables in the model of enterprise transformation, upgrading, and transformation and upgrading, and they are not significant. Tax reduction and exemption have positive and negative variables in the model of enterprise transformation and transformation and upgrading, and they are both insignificant, while in the model 11 of enterprise upgrading, the tax concessions are significant. This implies that when tax acts alone, it can retain more profits for enterprises, help enterprises grow and reduce operating costs. Tax incentives generally take the form of laws and regulations. The implementation cost is low and the effect is wide. This can reasonably reduce the cost of technological innovation and other aspects, enhance the initiative of enterprises in transformation and upgrading, and thus affect the sustainable development. Although the impact coefficient of SF on *DS-A*, *DS-B*, and *DS* is 0.078, 0.076, 0.106, 0.100, and 0.147, the tax impact is not significant, but it still has a weak driving force for sustainable development.

Policy Analysis: From the perspective of the classification model, at the two levels of transformation and upgrading, the combination of fixed assets, information management level and the overall quality of employees is the best effect of promoting transformation and upgrading. As an independent variable, R&D expenditure has a significant effect on upgrading, but the combined effect with other strategies is not significant. This indicates that R&D expenditure is highly sensitive and lacks robustness. The efficiency of R&D investment of enterprises is not high.

Although the strategic combination of government support and preferential tax and fee promotion has no significant effect, independent variables of tax and fee

Table 6: Multimultiple linear regression coefficient table.

Model	1	2	3	4	5	6	7	8	9	10	11	12	13
Dependent variables	DS_A	DS_A	DS_A	DS_A	DS_A	DS_A	*DS_B*	*DS_B*	*DS_B*	*DS_B*	*DS_B*	*DS_B*	*DS*
Constant term	0.122***	0.221***	0.290***	0.186***	0.104***	0.358***	0.165	0.301***	0.386**	0.253***	0.139***	0.468*	0.690***
JH	0.085					0.082	0.114					0.108	0.159
CK	0.181					0.177	0.244					0.231	0.341**
ZC		0.063**				0.06**		0.086**				0.080**	0.118**
GL			0.060***			0.063**			0.080***			0.083***	0.062***
SZ			0.103***			0.106***			0.137***			0.139***	0.204***
XL			0.095*			0.099*			0.127**			0.130*	0.191*
TF					0.150	0.148					0.200***	0.194*	0.286
SF				0.078		0.076				0.106*		0.100	0.147
CZ				0.087		0.084				0.118		0.110	0.162
R2	0.009	0.000	0.121	−0.002	−0.001	0.106	0.250	0.400	0.358	0.442	0.410	0.270	0.243
F	2.014	1.006	10.989	0.821	0.769	3.862	3.749	0.120	14.634	1.487	10.224	5.944	5.944

Note. The data in brackets in the table are standard deviation of regression coefficients; ***, **, and * represent significant levels of 1%, 5%, and 10%, respectively.

incentives are significant to the upgrading of enterprises. It shows that the tax and fee policy is being upgraded in the enterprise, which has a good impetus for the increase of R&D expenditure.

In order to improve the level of transformation and upgrading of small and microenterprises, the government needs to coordinate with the endogenous factors of transformation and upgrading of small and microenterprises in the policy mix, so as to make the policy focus on the power point of transformation and upgrading. The government should avoid publishing too many policies and reduce the institutional transaction costs of enterprises. The government needs to design an overall tax and fee preferential system that takes into account fixed assets, information technology and staff training, such as the tax discount for the purchase of fixed assets, the value-added tax deduction for the purchase of information technology services and staff training services. The tax policy of R&D expenditure needs an independent framework design, which is exclusive to the government's financial subsidy policy, so as to avoid the inhibitory effect of the government's direct financial support. At present, the Chinese government is increasing the policy of R&D expense deduction, and our research conclusion is consistent with it. The government also should design positive competition policies, establish a fair and neutral policy environment, avoid huge differences in policies among different industries, reduce system costs and improve market efficiency.

5. Conclusion

5.1. Modern Management Is the Key to the Sustainable Development of Small and Microenterprises. From the research results, internal management has become the primary factor affecting the transformation and upgrading of small and microenterprises. Most of the small and microenterprises are in the initial stage of enterprise development and tend to pay more attention to the development of products and markets. Under the background of mass entrepreneurship and innovation, internal management is the foundation and guarantee of continuous product innovation and market development.

The promotion of internal management needs to start from the awareness of enterprise leaders and cultivate entrepreneurs with modern entrepreneurship. Small and microenterprises need to establish a management environment with modern enterprise system on the whole, and constantly standardize the behavior rules from the aspects of product production process, employee management, market customer relationship, and supplier relationship management. Small and microenterprises should actively adopt advanced management technology tools, enhance the advanced nature of management tools, and establish a good foundation for enterprise operation.

5.2. Innovation Ability Is the Key Driving Force for the Sustainable Development. This study found that only 70 small and microenterprises have R&D expenditures, accounting for 18.51% of the surveyed enterprises. This shows that small and microenterprises are extremely deficient in investment in innovation and insufficient in taking innovation risks. Innovation is a link that requires high investment, uncertain returns, and high risks. For small and microenterprises in the early stages of development, survival is the top priority.

The competition neutral policy should be used to release the innovation vitality of enterprises. The government should establish a universal preferential tax system to stimulate the innovation willingness of small and microenterprises. The government should draw a clear market boundary, reduce direct financial subsidies, and direct intervention in the market. The government should establish a more perfect market mechanism and a fair competition environment. The government should establish a unified tax system, reduce the industry access control, and promote the flow of enterprise innovation resources.

5.3. Fixed Investment Is the Important Means of Sustainable Development. The investment of fixed assets is remarkable for the transformation and upgrading of small and microenterprises. The increase of advanced equipment investment will inevitably bring about the process and the improvement of production efficiency, thus improving the economic benefit. However, after a certain amount of investment, the effect of transformation and upgrading will be reduced, which indicates that the endogenous innovation power of small and microenterprises is insufficient, and the development of new equipment and new technology needs to be absorbed and innovated in order to maintain sustainable development.

The investment of fixed assets requires enterprises to have good future expectations, and the government needs to build a stable and sustainable policy system, such as extending the policy time. In addition, the government should develop the fixed assets leasing market and give more tax incentives to leasing services, so as to make full use of equipment resources among enterprises.

5.4. Open Trade Is the Driving Force of Sustainable Development. The data analysis shows that the more the number of export regions is in Europe, America, or developed countries, the better the sustainable development of enterprises than those without export or export developing countries. However, the insufficient contribution of export delivery value indicates that most of the products from developed regions are at the bottom of the value chain. Although foreign trade has promoted the upgrading of products in a certain sense, the added value of the overall products is low, the technological content is not high, and the main benefits are absorbed by importers.

Products in developed areas often have higher quality standards, which require small and microenterprises to have better production technology to match. The government needs to set more preferential tariffs to promote the growth of orders in developed regions. The Chinese government has established free trade zones in Shanghai, Hainan, Zhejiang, and other regions, which will help small and

microenterprises to obtain high value-added products in international trade and improve the production level of small and microenterprises' products.

Based on the aforementioned research, among the factors affecting the sustainable development of small and microenterprises, internal management and innovation have the strongest impact. This paper makes an empirical analysis from the internal and external influencing factors of enterprise sustainable development, breaks through the analysis of single factors in theory, and gives the explanation of enterprise sustainable development from the combination of different dimensions. In practice, it provides an optional combination for the development of small and microenterprises and the design of government policies. The main difference from previous studies is that it does not analyze the impact of a certain factor in isolation, and comprehensively considers the impact of the enterprise's own conditions and external environment. Then, the factors affecting the sustainable development of small and microenterprises are complex and numerous. I cannot bring some random and unobservable factors into the analysis category, and these may produce some important roles, which is the limitation of this paper. How to add some random interference factors to the analysis needs to be further studied.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] Y. Mao, W. Zhang, and W. Weiyu, "Enterprise transformation and upgrading: the frontier area of management research in China - literature research based on SSCI and CSCI (2002-2013)," *Academic research*, vol. 1, pp. 72–82, 2015.

[2] F. Roberto and V. Andrea, "Technological leadership and persistence in product innovation in the local area network industry 1990-1999," *Research Policy*, vol. 45, no. 8, pp. 1604–1619, 2016.

[3] C. Antonelli, F. Crespi, and G. Scellato, "Internal and external factors in innovation persistence," *Economics of Innovation and New Technology*, vol. 22, no. 3, pp. 256–280, 2013.

[4] D. Suárez, "Persistence of innovation in unstable environments: continuity and change in the firm's innovative behavior," *Research Policy*, vol. 43, no. 4, pp. 726–736, 2014.

[5] Y. Kim and S. S. Lui, "The impacts of external network and business group on innovation: do the types of innovation matter?" *Journal of Business Research*, vol. 68, no. 9, pp. 1964–1973, 2015.

[6] A. I. N. I. G. O. Edurne and A. L. B. A. R. E. D. A. Laura, "Sustainability oriented innovation dynamics: levels of dynamic capabilities and their path-dependent and self-reinforcing logics," *Technological Forecasting and Social Change*, vol. 139, pp. 334–351, 2019.

[7] O. Schilke, S. Hu, C. E. Helfat, and V. Quo, "Dynamic capabilities: a content-analytic review of the current state of knowledge and recommendations for future research," *Social Science Electronic Publishing*, vol. 12, no. 1, pp. 390–439, 2017.

[8] Z. Ann-Kristin, B. Lokshin, and J. Hagedoorn, "Formal and informal appropriation mechanisms: the role of openness and innovativeness," *Technovation*, vol. 59, pp. 44–54, 2017.

[9] X. Cao and M. A. Hui, "Simulation analysis of formation of emerging technology "multi-core" innovation network," *Studies in Science of Science*, vol. 37, no. 1, pp. 165–174, 2019.

[10] X. Cao and M. A. Hui, "Simulation analysis on innovation behavior mechanism of multi-core enterprises under emerging technological innovation network," *China Soft Science*, vol. 6, pp. 138–149, 2019.

[11] Y. Wang and J. Wang, "Several questions about improving the independent innovation ability of enterprises," *China's soft science*, vol. 7, pp. 10–14, 2005.

[12] Z. Liu, "The path and brand strategy of China's manufacturing upgrading under the background of globalization," *Study of financial issues*, vol. 5, pp. 25–31, 2005.

[13] J. S. Gans and S. Stern, "The product market and the market for "ideas": commercialization strategies for technology entrepreneurs," *Research Policy*, vol. 32, no. 2, pp. 333–350, 2003.

[14] R. M. Cyert and J. G. March, "A behavioral theory of the firm," *Social Science Electronic Publishing*, vol. 4, no. 2, pp. 81–95, 2003.

[15] S. G. Winter, "The satisficing principle in capability learning," *Strategic Management Journal*, vol. 21, no. 11, pp. 981–996, 2000.

[16] K. Zhao and S. Xie, "The impact of Government R&D subsidies on R&D investment of enterprises," *An Empirical Study Based on Chinese Listed Companies, World Economic Papers*, vol. 237, no. 2, pp. 91–108, 2017.

[17] H. Zhang, "Opportunity or new poverty trap: rural-urban education disparity and internal migration in China," *China Economic Review*, vol. 44, pp. 112–124, 2017.

[18] G. Liu, Y. Yang, and P. Cao, "Comparative study of tax incentives and financial subsidy incentive effects from the perspective of industrial development - panel data analysis based on the operating performance of listed companies in information technology and new energy industries," *Finance and trade economy*, vol. 36, no. 8, pp. 38–47, 2015.

[19] S. Shi, G. Zhou, and L. Qin, "The incentive effect of tax incentives on the research and development input and output of Chinese enterprises," *Tax research*, vol. 3, pp. 43–47, 2017.

[20] M. P. Brown, M. C. Sturman, and M. J. Simmering, "Compensation policy and organizational performance: the efficiency, operational, and financial implications of pay levels and pay structure," *Academy of Management Journal*, vol. 46, no. 6, pp. 752–762, 2003.

[21] X. Li and D. F. Zhu, "Impact of fiscal and taxation policy fluctuations on transformation and upgrading of China's manufacturing industry: on information asymmetry and goal conflict perspectives," *Finance and Trade Research*, vol. 29, no. 11, pp. 15–30, 2018.

[22] V. Costantini, F. Crespi, C. Martini, and L. Pennacchio, "Demand-pull and technology-push public support for eco-innovation: the case of the biofuels sector," *Research Policy*, vol. 44, no. 3, pp. 577–595, 2015.

[23] A. Zhao and H. Guan, "Simulation and analysis of optimal policy combination for incentive of enterprise environmental technology innovation," *Journal of Management Science*, vol. 31, no. 6, pp. 104–116, 2018.

[24] M. Station, *Research on the Impact of Science and Technology Policy on the Efficiency of High-Tech Industry in China*, Doctoral dissertation, Northeast Normal University, Changchun, China, 2019.

[25] Z. Hu, J. Zhang, H. Ma, J. Xiong, and S. Zhao, "Coordinated analysis of manufacturing transformation and upgrading policy - take Guangdong Su-Oliao as an example," *Scientific and technological progress and countermeasures*, vol. 37, no. 1, pp. 122–128, 2020.

[26] B. Xu, W. Song, X. Gao, and Y. Zhang, "Research on the science and technology policy coordination of China' s yangtze river delta," *American Journal of Industrial and Business Management*, vol. 9, no. 4, pp. 875–885, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1453889, 13 pages
https://doi.org/10.1155/2022/1453889

Research Article

The Application of Web-Based Scientific Computing System in Innovation and Entrepreneurship

Tingli Cheng

School of Foreign Languages, Jiangxi Science and Technology Normal University, Nanchang 330038, Jiangxi, China

Correspondence should be addressed to Tingli Cheng; 1020110915@jxstnu.edu.cn

Received 2 March 2022; Accepted 7 May 2022; Published 24 May 2022

Academic Editor: Lele Qin

In the past ten years, the number of newly added labor forces in China has continued to grow. At the same time, with the increase in the number of university candidates, the number of university employments is also increasing. Due to employment pressure from society and alumni, the government promotes innovation and entrepreneurship and promotes innovative slogans through entrepreneurship. Universities have become the people who are concerned about this slogan. As an important tool for solving large-scale computer problems, scientific computing is increasingly used in various fields of science and engineering. With the development of high-performance computing technology, various parallel computers have appeared and are widely used. This article uses a scientific computing system to conduct research on innovation and entrepreneurship. The entire scientific computing system is a typical three-tier architecture, and the small service program is responsible for analyzing the scientific computing request in the request and generating related calculation expressions. Get the comprehensive evaluation level of innovation and entrepreneurship risk: excellent score is 3.45, good score is 2.56, general score is 1.68, and difference is 0.68.

1. Introduction

As China's economic development gradually stabilizes, the number of university graduates has exceeded one year, and the supply of labor far exceeds demand. Therefore, for contemporary college students, in addition to choosing their own life direction in employment, further education, and examination of civil servants, entrepreneurship is naturally also chosen by a group of quick-thinking and positive students. Entrepreneurship is a great career. However, looking at past entrepreneurial achievements, there are very few successful entrepreneurial cases.

Undergraduate entrepreneurship is a process of discovering and capturing opportunities and therefore developing products and services that are more adapted to social progress and better tap their potential to adapt to the development of the market economy. To put it simply, college students' entrepreneurship is an activity to seize opportunities and gain room for profit. The innovation of science and technology and the relief of employment pressure will be driven by these active and creative entrepreneurial activities of college students.

The innovation of this paper is the introduction of Web services and scientific computing systems and the use of the parallel matrix multiplication FOX algorithm to analyze the scalability of MMP machines. It optimizes the scalability of the scientific computing system and obtains the data comparison of the scientific computing system before and after optimization. The risk of innovation and entrepreneurship of college students is calculated through the scientific computing system, the index weight is determined by the analytic hierarchy process, and the comprehensive risk evaluation of innovation and entrepreneurship is obtained.

2. Related Work

Regarding scientific computing, relevant scientists have done the following research. Kumar R proposed that scientific computing involves the construction of mathematical models and quantitative analysis techniques and the use of

computers to analyze and solve scientific problems. In actual use, it is basically the application of computer simulation and other forms of calculation from numerical analysis and theoretical computer science to problems in different scientific disciplines. The scientific calculation method is to gain understanding, basically through the analysis of the mathematical model implemented on the computer. Python is often used for high-performance scientific applications and is widely used in academia and scientific projects because it is easy to write and performs well [1]. West is investigating the distribution of SARS-CoV-2 among different populations, the biology and structure of the virus and its transmission mechanism, and the development of prophylactic vaccines and effective antiviral therapy. While West J research is still in the early stages of developing effective therapeutic responses, the rapid mobilization of the national research network infrastructure immediately reminds people of the strategic importance of strong and sustainable investments in large-scale computer science [2]. Regarding innovation and entrepreneurship, relevant scientists have done the following research. Barroso-Tanoira F G proposed a plan to increase the motivation of students to become creative, innovative, and entrepreneurial. Based on the intervention of commercial companies, use critical and creative thinking to improve employee performance. The results show that the plan is effective for both workers and students and that the most important factor to improve creativity, innovation, and entrepreneurship is intrinsic motivation [3]. Kumar et al. believe that in the long run, promoting social innovation and entrepreneurship is omnipotent, which will provide impetus to the country's development agenda and solve the country's social problems. A stimulating ecosystem is needed that prioritizes basic skills and innovation and adopts new, sustainable resource and technological perspectives. The research is based on practice, with special reference to contemporary social issues, and explores the prospects of social innovation and entrepreneurship in the state [4]. Sukhariyat analyzed and demonstrated the impact of innovation and entrepreneurship on the competitiveness of small, medium, and micro-enterprises. The results obtained for all indicators of all variables in this study satisfy the approach. The importance of the relationship between innovation and entrepreneurship is positive, and innovation has a significant impact on competitiveness. The importance of the relationship between entrepreneurship and competition is positive, and entrepreneurship has a significant impact on competition. Thus, innovation and entrepreneurship development directly affect the competitiveness of small, medium, and very small enterprises [5]. Presently, education is highly valued and widely developed for innovation and entrepreneurship in the colleges and universities of our country. NIU B proposes an effective and comprehensive assessment system to assess business learning in colleges and universities, monitor the implementation of business learning and provide valuable insights to ensure the integrity of bilateral business learning. According to the study, Nieu Bei made a number of analyzes and recommendations in hopes of accelerating the development of education through "dual innovation" [6]. These methods have provided some references for our research, but due to the short time and small sample size of the relevant research, the research has not been recognized by the public.

3. Methods of Scientific Computing System in Innovation and Entrepreneurship

3.1. Web. The Internet is also called the World Wide Web. It is a global, dynamic, and cross-platform graphic information system distributed on hypertext and HTTP. This is a Web service installed on the Internet. Provide a convenient and intuitive graphical user interface for the browser for searching and finding information on the Internet. Among them, documents and hyperlinks form a single network structure of information nodes on the Internet.

The main function of the Web server in operation and maintenance platform system is to respond to the request of the Web front-end page, and the request and response form are built on Http. Its workflow can be divided into four stages: link processing, request processing, response processing, and close communication. The connection process handles the connection between the web server and the previous web browser. Creating a host file indicates that the connection is successful. Search mode means that the user is sending requests and information to the web server through the web browser. The response process is related to the browser request sent to the Internet server via HTTP. After the server has processed the request, it will send the result back to the browser via HTTP, showing the whole process of searching for browser results. Disconnecting means disconnecting the connection between the web server and the browser [7].

Weaknesses in web applications are often referred to as vulnerabilities. It refers to the vulnerabilities that exist on the website, whether it is code level or logic level. This may be due to web developers controlling the development process or exploiting vulnerabilities in network components. Table 1 shows web application security risks.

The overall scanner structure is basically divided into three parts: the main scanner unit, the additional scanner unit, and the system database. The basic scanning module includes functions such as collecting data and exporting scan reports. The attached scanner mainly performs functions such as attachment detection, attachment detection, and attachment dialing. Incorporating additional modules can make it easier for testers to make phone calls, update, and add plugins; the system database is responsible for the storage and export of various data in the scanner [8]. Figure 1 shows the basic structure of a web application vulnerability scanner.

The main module of the web application vulnerability scanner has two submodules: information collection and report export. When performing a vulnerability scanning task, the first thing to work is the information collection module, which collects basic information on the target website; before the vulnerability scanning task ends, the report export module is called to make a web page vulnerability scanning report.

Table 1: Web application security risks.

Risk name	Difficulty of attack	Vulnerability universality	Difficulty of detection	Technology impact
Injection	3	2	3	3
Invalid authentica	3	2	2	3
Leakage of sensitive data	2	3	2	3
XML external entities	2	2	3	3
Invalid access control	3	2	2	2
Security configuration error	2	3	3	3
Cross-site scripting	2	3	3	2
Unsafe deserialization	3	3	2	3
Use components with known vulnerabilities	3	3	2	2
Insufficient logging and monitoring	3	3	1	2

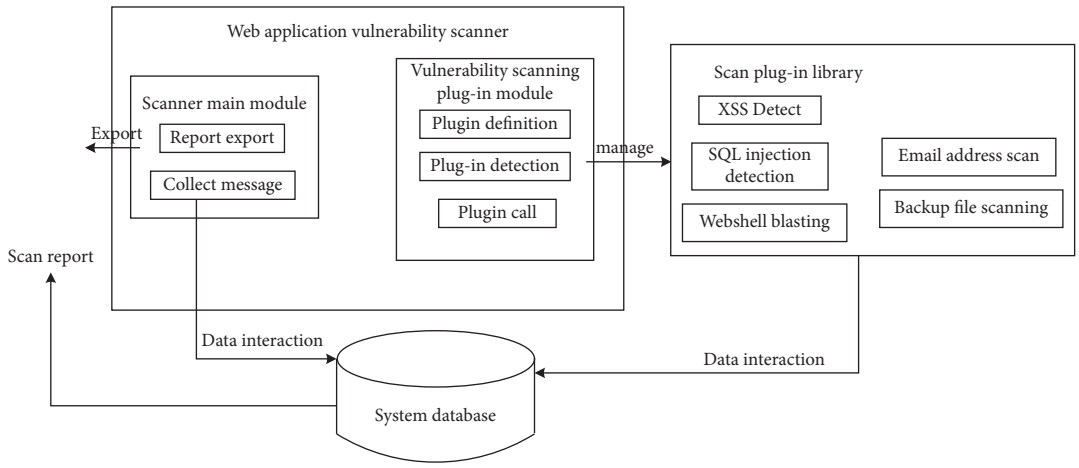


Figure 1: Basic structure of web application vulnerability scanner.

The traditional Web database system generally can adopt two methods to realize the connection and application of the Web database system. One is to provide middleware on the Web server to connect the Web server and the database server, and the other is to download the application to the client and directly access the database on the client. Middleware is responsible for managing the communication between the Web server and the database server and providing application services. It can directly call external programs or script codes to access the database. Therefore, dynamic HTML pages related to the database can be provided, or user queries can be executed, and the query results can be formatted into HTML pages. Return to the web browser through the web server. The most basic middleware technology has two kinds of gateway interface CGI and application program interface API.

Web service is any service published on the Internet that does not depend on the underlying programming language or operating system platform and uses standard XML as the message system. Generally, Web services are self-describing; that is, for every service released, the service provider needs to provide the application interface of the service. The XML file for service call contains service description information such as the function of the service, related interface methods, parameters, and attributes. Web services are also discoverable. After the service is released, it needs to be registered in the third-party service library so that users of the service system can query and call the service through a certain mechanism [9].

The service agreement involved in the Web service mainly includes the following four layers. (1) Service discovery layer. The service discovery layer is responsible for the centralized registration and management of services and provides simple service publishing and search functions. (2) The service description layer describes the public interface of the service, and WSDL language is commonly used to describe the interface of the service. (3) The message layer is responsible for encoding the message into a common XML format, making the service publisher and invoking easier to parse. (4) The service transport layer is responsible for transferring messages between applications.

The manifestations of the Web include the following:

(1) Hypertext. Hypertext is a user interface method used to display text and text-related content. At present, hypertext generally exists in the form of electronic documents. The text in it contains hypertext links that can be linked to other fields or documents, allowing direct switching from the current reading position to the text pointed to by the hypertext link.

(2) Hypermedia. Hypermedia is the abbreviation of hypermedia, which is the combination of hypertext and multimedia in the information browsing environment. Not only can users jump from one text to

another, but they can also activate a sound, display a graphic, and even play an animation.

(3) Hypertext Transfer Protocol is the most widely used network protocol on the Internet.

This structure and operation mode of Web service, on the one hand, makes it fully decouple the form of service from the content provided by the service. For example, a web service-based site only needs to set various content containers on the page by encapsulating relevant parameters in SOAP messages, passing them to the background logic module to obtain relevant content, and filling the corresponding content in its container. On the other hand, the shielding of the underlying details of Web services makes the construction of software and applications based on Web services easier and faster. Figure 2 shows the Web service architecture.

Features of the Web include the following:

(1) Graphicalization. A very important reason why the Web is very popular is its ability to display colorful graphics and text on one page at the same time. Before the Web, information on the Internet was only in text form. The Web can provide features that integrate graphics, audio, and video information.

(2) Distributed. A large amount of graphics, audio, and video information will take up a considerable amount of disk space, and we cannot even predict the amount of information. For the Web, it is not necessary to put all the information together. The information can be placed on different sites. You only need to indicate this site in the browser. Physically, the information on a site is not necessarily logically integrated. From the user's point of view, the information is integrated.

(3) Dynamic. Since the information of each website contains the information of the site itself, the information provider can frequently update the information on the site, such as the development status of a certain agreement, the company's advertising, and so on. Generally, all information sites try to ensure the timeliness of the information. Therefore, the information on the website is dynamic and frequently updated, which is guaranteed by the information provider.

3.2. Scientific Computing. Scientific computing refers to calculations that analyze and solve natural science, social science, and engineering problems through the establishment of mathematical models and numerical solutions and the use of computer technology.

Scientific calculations are usually expressed by various mathematical equations, and the purpose of scientific calculations is to find the numerical solutions to these equations. Such calculations involve large-scale calculations and are difficult to operate with simple computer tools. Before the advent of computers, scientific research and mechanical design relied heavily on experiments to represent data, and computers were only an auxiliary state. The rapid development of computers has made it possible to perform more and more complex calculations. The use of computers for scientific calculations has brought huge economic benefits, as well as fundamental changes in science and technology itself: traditional science and technology have only two parts: theory and experience. After using computers, computing has become an equally important third-party raw material [10].

The calculation process mainly includes three stages: establishing a mathematical model, establishing a solution calculation method, and computer realization. The establishment of a mathematical model is to establish a series of quantitative relationships, namely, a set of mathematical formulas or equations, based on the relevant subject theories. Reasonable simplification of complex models is an important measure to avoid excessive calculations. Mathematical models generally contain continuous variables, such as differential equations and integral equations, which cannot be directly processed on digital computers. To this end, the problem is discretized first. That is, the problem is converted into a discrete form containing a finite number of unknowns (such as a finite algebraic equation system), and then a solution is found. Computer realization includes a series of steps such as programming, debugging, calculation, and analysis results. The development of software technology provides suitable programming languages (such as Fortran and ALGOL) and other software tools for scientific computing, greatly improving work efficiency and reliability.

There are generally two development directions for the improvement of computing performance. One is to improve the computing performance by increasing the clock frequency of a single processor. The other direction is to improve computing performance by increasing the number of computing cores on the processor chip. However, a series of problems, such as the power consumption wall caused by the increase of the core frequency, make the improvement of the computing performance brought about by the increase of the clock frequency to an end. Since the power consumption of a single-core processor is roughly proportional to the third power of its main frequency, when the computing performance is improved by increasing the number of cores, the power consumption increases linearly. Therefore, multicore platforms have become the mainstream direction to improve computing performance.

The number of processors in the Cannon algorithm in the parallel system is just right, and the desired effect can be obtained. The problem of multiplying two matrices can be expressed as $P = M \times N$, that is, the elements of the P matrix are as follows:

$$p_{ij} = \sum_{l=1}^{n} m_{il} n_{lj},$$

$$N_1^I = \sum_{k=0}^{n-1} [(l-k) l_c], \tag{1}$$

$$N^{II} = \sum_{k=0}^{n-1} \left[(l-1-k) l_d + l_{\text{actv}}^H + l_{\text{merg}}^H + \frac{(l-1-k)^* (l-k)}{n} l_f \right],$$

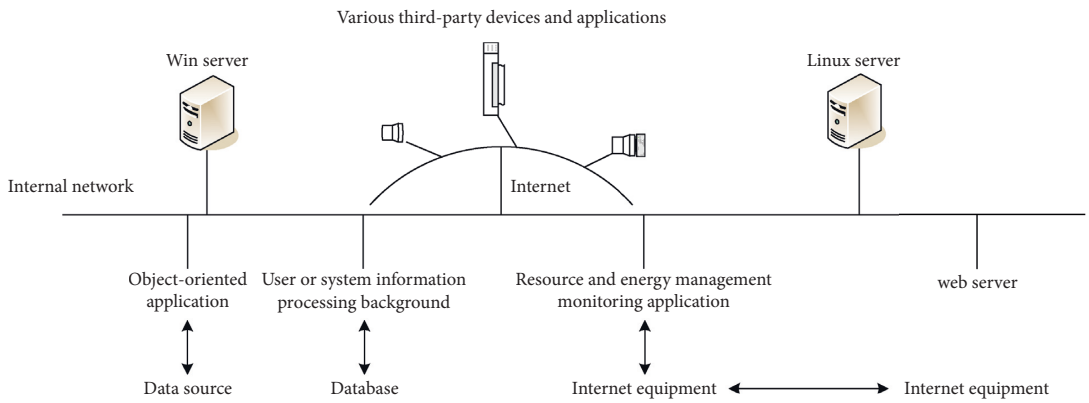


Figure 2: Web service architecture.

l_c-One comparison operation time.

In each super step, the execution time of each slave core is approximately as follows:

$$H_{\text{para}} = \left(h \times \frac{M}{P} \times \frac{K}{h} \times \left(\frac{N}{S} y\right)\right) h_f,$$

$$N_1^H = \sum_{k=0}^{n-1} \left[(l-1-k)h_d + (l-1-k)^* (l-k)h_f\right], \tag{2}$$

$$N_n^I = Y_c \frac{l_2 - l}{2p} h_f + N_{\text{merge}}^I + Y_c p h_f,$$

h_f is the time required for a floating-point calculation. p is the number of elements.

In the first superstep, the result calculation stage only needs to rearrange the calculation results of each slave core without any floating-point operations. Therefore, the calculation time is constant, which can be approximated to 0.

The total execution time of g super step is as follows:

$$\begin{aligned} H_{\text{total}} &= g \times \left(H_{\text{actv}} + H_{\text{para}}\right) + H_{\text{merge}} \\ &= gH_{\text{actv}} + \frac{\text{our}}{p} Y h_f + H_{\text{merge}}, \\ N_1^I &= Y_c \left(\frac{l^2 - l}{2}\right) h_f, \\ N_{\text{para}}^{II} &= \frac{6lY_2}{p} h_f + \frac{l_2 - l}{4p} Y_2 h_f, \end{aligned} \tag{3}$$

H_{total}-Total execution time of super step.

The time required for execution with a single processor is approximately as follows:

$$\begin{aligned} H_1 &= \text{our}\, Y h_f, \\ N_1^2 &= Y h_f + 6lY_2 h_f + \frac{l^2 - l}{4} Y_2 h_f, \\ N_n &= Y_c \frac{l^2 - l}{2p} h_f + N_{\text{merge}}^I + Y_c p h_f + Y h_f, \end{aligned} \tag{4}$$

N_1^2-Sequence execution time.

The speedup ratio is as follows:

$$\begin{aligned} B &= \frac{H_1}{H_{total}} = \frac{o}{1 + \text{obH}_{\text{actv}}/\text{mknYh}_f + oT_{\text{merge}}/\text{mknYh}_f}, \\ W &= \frac{N_1}{N_n} = \left(\frac{1}{1 + f_1(p)/f_2(n)}\right) p, \\ X[k] &= \sum_{n=0}^{N-1} x[n] Q_N^{kn}, \quad 0 \le k \le N-1, \end{aligned} \tag{5}$$

B-Acceleration ratio.

The time complexity of serial implementation is as follows:

$$\begin{aligned} \sum_{i}^{l} (i-1)i &= \frac{\left(l^3 - l\right)}{3} \\ &= U\left(l^3 - 3\right), \\ N_1 &= \left(\frac{T}{2} \log T\right) Y h_f, \end{aligned} \tag{6}$$

N_1-T point sequence required execution time.

The total calculation time of each slave core should be as follows:

$$\begin{aligned} 3 \sum_{1}^{n-1} i^2 &= \frac{1}{2}(n-1)n(2n-1), \\ N_{\text{para}} &= \left(\frac{T}{2p} \log \frac{T}{p}\right) Y h_f + \frac{T}{p^2}\left(\frac{p}{2} \log p\right) Y h_f. \end{aligned} \tag{7}$$

The speedup of parallel implementation is as follows:

$$T = \frac{\left(l^3 - l\right)/3}{l(n+p-1) + 1/2(n-1)n(2n-1)}. \tag{8}$$

The time required for overstepping is as follows:

$$N^1 = \sum_{k=0}^{n-1} \left[\frac{m-k}{p} l_c + l_{\text{actv}}^1 + l_{\text{merg}}^1 + p l_c\right], \tag{9}$$

where l_c is one comparison operation time.

What is scientific computing? Roughly speaking, scientific computing refers to the entire process of using computers to reproduce, predict, and discover the laws of motion and evolution of the objective world. It includes processes such as establishing physical models, researching calculation methods, designing parallel algorithms, developing application programs, carrying out simulation calculations, and analyzing calculation results. With the research object, the focus must be on its main characteristics, grasping the main contradiction and establishing a physical model. The so-called physical model is a set of equations describing the research object and the initial boundary value conditions of the constraint equation set and the corresponding physical parameters. With a physical model, it is necessary to adopt calculation methods and algorithms that are compatible with the physical model to develop application programs. The so-called application program is, in a visual sense, a novel written in a computer language. For scientific computing, the commonly used computer languages are FORTRAN language and C language.

Visualization is a digital method. It is a tool for understanding and analyzing images and interpreting image information and creating images from complex parts. Transform information and symbols into geometric shapes or images so that researchers can view the symbols or digital results. Computer graphics represent the scientific principles, methods, and techniques of transforming information, transforming the results into images and using image processing techniques. The visualization of scientific computing enriches scientific research tools and helps to understand complex and profound problems. It has completely changed the way most people engage in scientific research and use technology [11].

Scientific computer visualization mainly involves the conversion of scientific data-digital values and images to graphics and visual images, that is, the conversion of scientific data to understandable data. On the other hand, research the application of imaging equipment in various physical and mechanical sciences. The visualization of scientific computing subjects mainly includes experience fields such as computer graphics, image processing, and computer projection. As shown in Figure 3, it is a classification diagram of visual chemistry subjects in scientific computing.

Compared with early computer visualization systems, the main feature of scientific computing visualization technology is three-dimensional visualization technology [12]. Table 2 shows the typical technology to realize the visualization system.

Traditional theoretical research is based on analytical methods, which play an important role in the establishment of scientific principles and systems, and can solve relatively simple problems, for example, linear problems, and balance problems. However, as the complexity of the problem increases, the limitations of theoretical research become more and more obvious. For many problems, such as strong nonlinear problems, nonequilibrium problems, and problems that occur in practical applications, traditional theoretical research has been powerless. Compared with

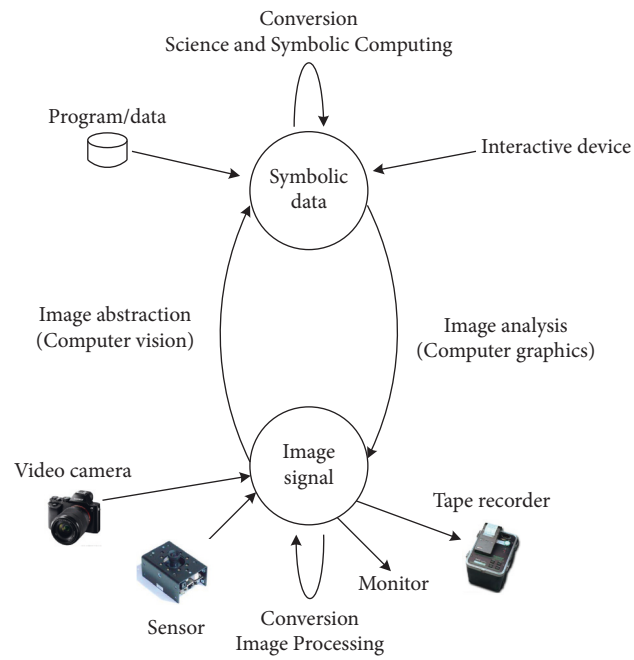


Figure 3: Scientific computing visual chemistry division classification map.

theoretical research, scientific computing can not only deal with linear problems and equilibrium problems, but more importantly, it can deal with strong nonlinear problems and nonequilibrium problems. It can apply scientific principles to solve more and more complex practical problems. Scientific computing is often referred to as a computer virtual experiment. Compared with experimental research, scientific computing has at least the following three characteristics: One is nondestructive, that is, scientific computing will not have a big impact on the environment, etc. This advantage enables scientific computing to undertake things that cannot be done in real experiments. For example, to study the destruction of tsunamis, earthquakes, and nuclear explosions, it is impossible for humans to carry out real experiments, but they can carry out scientific calculations and computer virtual experiments. The second is the whole process, the whole time and space diagnosis. In real experiments, no matter how many methods and instruments are used, the information about system evolution obtained is very limited. It is difficult to diagnose the whole process and the whole time and space. The information of the whole process and the whole time and space is very crucial for people to recognize, understand, and control the research object. Different from real experiments, scientific calculations can complete the whole process and the whole time and space diagnosis. As long as the relevant output program is added to the application, the researcher can obtain all the information about the development and evolution of the research object at any time and at any place when performing scientific calculations. This allows researchers to fully understand and meticulously understand the development and evolution of research objects. The third is that scientific calculations can be performed in a relatively low-cost manner, repeatedly and meticulously in a short period

Table 2: Typical technology of visualization system.

Dimension	Scalar	Loss	Tensor	Multidimensional variables
1D	Straight line drawing, histogram, bar graph	—	—	Combining scalar, loss, and tensor method
2D	Contour line, curved surface view, image display	Two-dimensional arrow	—	
3D	Isosurface, volume rendering, point cloud surface	3D arrows, particle systems, streamlines	Tensor ellipse	
nD	Use multiple 1D, 2D or 3D views			

of time, to obtain comprehensive and systematic information about the research object under various conditions.

3.3. Innovation and Entrepreneurship. Innovation and Entrepreneurship-innovative business activity based on specific points in the field of technological innovation and product innovation. Innovation is the epitome of innovation and entrepreneurship and entrepreneurship is the goal of innovation and entrepreneurship. Innovation and Entrepreneurship is a business based on innovation, which is different from Pure Innovation and Pure Entrepreneurship. Innovation emphasizes the spirit of innovation and innovation, whereas entrepreneurship emphasizes the pursuit of value through action. Thus, in the sense of innovation and entrepreneurship, innovation is the basis and condition of entrepreneurship, and entrepreneurship is the main part and continuation of innovation [13].

The essential difference between new ventures and traditional enterprises is that there are factors of innovation. Here, innovation includes not only technological innovation but also management innovation, knowledge innovation, technological innovation, and market innovation. In short, any activity that can add value to resources is innovation [14].

Innovative entrepreneurship is a new or partly innovative business created by entrepreneurs with individualized, unique thinking and business methods, combined with business models and methods in different fields of production, or new industries, new fields, or different characteristics of the same industry. Conceptually, innovation and entrepreneurship are not purely entrepreneurial activities or innovative work [15].

According to the relationship between the stage of undergraduate entrepreneurship and school work, undergraduate entrepreneurship can be divided into the following four forms: campus entrepreneurship, suspension of school entrepreneurship, graduation-based entrepreneurship, and postgraduation entrepreneurship. The first three types of undergraduate entrepreneurship are undergraduates who started their own businesses while studying at school, undergraduates who started their own businesses while studying abroad, and undergraduates who chose to start their own businesses without looking for a job when they graduated.

College students' innovation and entrepreneurship projects are widely distributed and have high knowledge content. Students have received higher education and have reached a certain level in terms of innovative thinking and knowledge. Some even obtained their own patents or started developing projects during their college years. After entering society, they can start and master their own Professional-related companies and will avoid detours on the path of entrepreneurship. The advantage of college students lies in their years of the learning experience at school, which can be turned into a direct source of capital. Investors are very concerned about the knowledge and technology mastered by college students, which can create huge profits, which is also one of the factors that they are willing to invest in college students' entrepreneurship. In addition, many entrepreneurial projects adapted to the market are available for reference. For example, some college students take their own areas of expertise and proficiency, individually or in partnership, to set up boutiques, daily necessities sales, etc., which all belong to the category of entrepreneurship [16].

College students' start-ups are helpful to the digestion and absorption of book knowledge. The weak sense of practice has caused college students who start their own businesses to stay in the initial stage of "talking on paper." College students at home and abroad have essential differences in entrepreneurial models. Because Chinese students have lived and studied on campus for a long time, their initial knowledge and understanding of society, especially market operations, business operations, entrepreneurial industries, and other fields, were not deep, and Chinese universities also lacked entrepreneurship and business management. However, training related to system theory and practice can acquire formal and commercial skills that can be mainly applied in practice. Secondly, due to the lack of social experience and information in the local student market, they do not have the ability to think carefully. They cannot foresee the dynamic changes that will occur during the entrepreneurial process and lack the ability to actively discover and solve problems [17].

The form of knowledge service enterprise is one of the main forms of college students' innovation and entrepreneurship. The biggest capital for college students is the knowledge system endowed by education for more than ten years. College students can flexibly use the knowledge they have mastered to start a business. For example, going to university as a tutor can not only work-study, experience life, but also increase social practice. This can not only make full use of their own knowledge reserves, but also accumulate an "intangible asset" for them to enter the society and play a role as a bridge for the future entrepreneurship in the home education industry. Therefore, the family education industry

is very suitable as one of the forms of undergraduate entrepreneurship. Easy to get started, quick to get started, and low cost make the tutoring industry the first choice for some college students to start a business.

The main form of innovation and entrepreneurship for college students also includes the form of taking the student route. College students open some stores that mainly rely on students as their customer resources. Because of the same age and similarities in living habits and thoughts, it is easier to start a business, and it can attract the attention of student customers by relying on economic benefits. However, because students have fewer funds, you should fully consider your own costs when you start a business. Therefore, you should choose a place where the rent is slightly cheaper than you choose a store. Therefore, it needs to have strong social skills for promotion. In addition to posting advertisements on campus, you can also organize joint activities with school clubs to achieve the purpose of promoting yourself.

The increase in the number of graduates year by year leads to the risk of employment pressure. The employment project is the first project graduated. The steady increase in the number of university graduates in recent years has led to a sharp increase in employment. Assembling a large and much-needed education management team is a major challenge. The main leader of the college is responsible for employment projects, and it is obliged to refer to labor law issues. However, in the specific implementation process, key executives are often too busy at work and do not pay enough attention to employment and entrepreneurship. Other departments regard employment issues as career guidance and student management issues, and it is simply ignored. Figure 4 shows the distribution of undergraduate graduates in recent years.

The actual number of college students involved in entrepreneurship is relatively small. Although the data survey shows that college students have a very high expectation rate of owning entrepreneurship, in fact, very few are truly invested in the entrepreneurial process. The entrepreneurial ideals they understand are like dream bubbles, and there is a big gap between them and reality.

College students have insufficient entrepreneurial awareness. If college students want to start their own businesses and be successful, they must be distinguished from those of social workers. Because compared with social workers, they have weaknesses in a series of issues such as work experience, connections, funds, etc. Only by using their strengths and rich knowledge reserves can they take a path of entrepreneurship that belongs to their own technological innovation. But facts have proved that the entrepreneurial and innovative consciousness of our college students is relatively insufficient. Traditional industries such as catering and retail are still the first choice for most college student entrepreneurs to start their own businesses. Competitors in these industries are often social workers with decades of operating experience, so the result is predictable, and the success rate is very low.

The entrepreneurial project selected by the college student's new venture is a key indicator. Choosing a suitable entrepreneurial project can be said to be equivalent to half of the success. Because college students have a less social experience, people often choose projects and choose entrepreneurial projects without goals, and the final result can be imagined. Therefore, you must choose a project that suits you so that you can have a direction and goal for entrepreneurship and stimulate your entrepreneurial potential and entrepreneurial enthusiasm. There are many problems and challenges in the process of starting a business, and good management methods play a very important role. It can help start-ups to succeed and mature, and it can do more with less.

Figure 4: Distribution of undergraduate graduates in recent years. Ine: innovation and entrepreneurship. Dgs: domestic postgraduate. Pa: postgraduate study abroad. Pfpec: prepare for postgraduate entrance examination. Wfe: to be employed.

4. Experiments of Scientific Computing System in Innovation and Entrepreneurship

Developing a WEB-based scientific computing system and specifically providing scientific computing services to apply the system. Users do not need to install any software, nor do they need to conduct special learning. They only need to use the WEB browser to log in to the system and complete the scientific computing tasks through the web page. The overall model of the system is shown in Figure 5.

The entire system is a typical three-tier architecture: the first layer is the client browser, through which users submit scientific calculation requests and display calculation results. The second layer is the WEB server, which is responsible for providing WEB services. After receiving the request, the HTTP connector of the WEB server analyzes the WEB program and resource corresponding to the request. The servlet is responsible for analyzing the scientific calculation request in the request and generating related calculation expressions. Passing the expression to be responsible for communicating with the calculation program, including starting and closing related calculation programs; pass the calculation expression to the mathematical software for calculation, obtain the calculation result of the mathematical software and return it to the service program. The service program is finally responsible for generating an HTML page

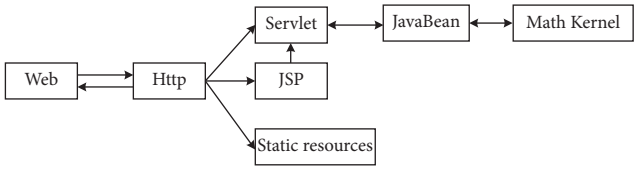


Figure 5: The overall model of the system.

containing the calculation result and returning it to the user. The third layer is mathematical software, responsible for scientific calculations [18].

High-performance scientific computers are a very important class of scientific computers. These applications mainly include nuclear explosion simulation, weather forecasting, and biological data processing. In a parallel high-performance system, the efficiency of the application is mainly determined by two factors: the degree of parallelism between nodes and the performance of a single node. The performance on a single node mainly depends on access to the optimized program memory and parallel deployment. This paper optimizes the single-machine performance of the scientific computing system, uses the optimized scientific and technological system to obtain data through Web services, and calculates the benefits and risks of innovation and entrepreneurship [19].

According to the different measured parameters, the parallel scalability model can be roughly divided into two categories: fixed performance and fixed resources.

The analysis of scalability is very important. Algorithm designers can use it to analyze the algorithm and select the optimal parallel algorithm to make full use of the increased processor resources. At the same time, it can also be used to estimate the best number of processors for the best speedup or other performance parameters. Manufacturers of parallel machines can use it to study the impact of hardware technology on performance. In addition, scalability also plays an important role in performance evaluation. A good scalability measurement method can reflect the matching degree of the algorithm and the machine combination.

The equal efficiency, equal speed, equal time, and equal average cost models all have fixed properties. This type of model is to fix a certain performance index and then study the scale of the problem scale randomizer's ability to scale so as to measure the scalability of the parallel system. At the same time, it can best reflect the changing law of the actual performance indicators of the system. Table 3 shows the measurement method of a fixed-performance scalable model.

The parallel matrix multiplication FOX algorithm is used to analyze the scalability on the MMP machine. Divide A, B, and C into $l \times l$ submatrices of the same size.

A-$m \times k$ matrix.

B-$k \times n$ matrix.

C-$m \times n$ matrix.

Taking $A_{4\times4}$, $B_{4\times4}$, and $l = 4$ as examples, the algorithm process is shown in Figures 6 and 7.

It can be seen from the above that the algorithm process can be divided into three parts: "broadcast, product, and move up." The product is the calculation part, and the other two are the communication part, so it is easy to measure the communication time of the algorithm [1]. Figure 8 shows the scalability test result of the FOX algorithm on the MPP machine used.

In the experiment, if the number of threads on each node is fixed at 1, then the calculation using commonly used nodes is equivalent to a normal cluster. The FOX algorithm adopts a mixed programming method to achieve higher performance than when MPI programming is used alone [20]. When using the same number of processors for calculations, in many cases, mixed programming can be used to reduce the amount of communication and the number of communications. In some cases, the communication overhead of message delivery has little or even negligible impact on performance. For example, the ratio of calculation time to total time is much greater than communication time. But when the calculation time is close to the communication time, the communication overhead between MPI processes will have a great impact on performance. So this puts forward higher requirements for programmers, and it is necessary to reduce the communication overhead between processes in the program as much as possible. When the mixed programming model is used to calculate this type of problem with a large communication overhead on the SMP cluster, the use of intranode calculation as much as possible will greatly improve the calculation performance [21]. As shown in Figure 9, the performance comparison of FOX improved algorithm on SMP cluster and ordinary cluster and the influence of MPI process communication on the performance of FOX improved algorithm.

The LM3D hybrid program was tested on a supercomputer, and the calculation amount of the program was changed only by changing the grid size. Table 4 shows the test results of the LM3D hybrid program.

Using the Web to collect relevant information on the innovation and entrepreneurship environment, calculate the risks of college students' innovation and entrepreneurship through the scientific computing system. Using the analytic hierarchy process to determine the index weight, the comprehensive evaluation of entrepreneurship is divided into four categories: excellent, good, fair, and poor. According to the characteristics of undergraduate entrepreneurs, the selected entrepreneurial projects should reduce risks as much as possible while giving full play to their advantages. Figure 10 shows the consistency index and the comprehensive evaluation level of innovation and entrepreneurship risk.

5. Discussion

Students can make full use of small start-up capital and short-term investment by choosing a suitable innovation and entrepreneurship direction. Chinese entrepreneurial students mainly use their own funds or family funds to start their businesses in the form of entrepreneurial funds. Most of these students' families are working-class families with

Table 3: Measurement method of the performance-fixed scalable model.

Measurement method	Fixed performance indicators	Instruction
Equal efficiency	E	Parallel efficiency is fixed
Constant velocity	V	Average speed is fixed
Equal time	t_p	Fixed parallel execution time
Equal average overhead	t_o/p	Fixed average cost

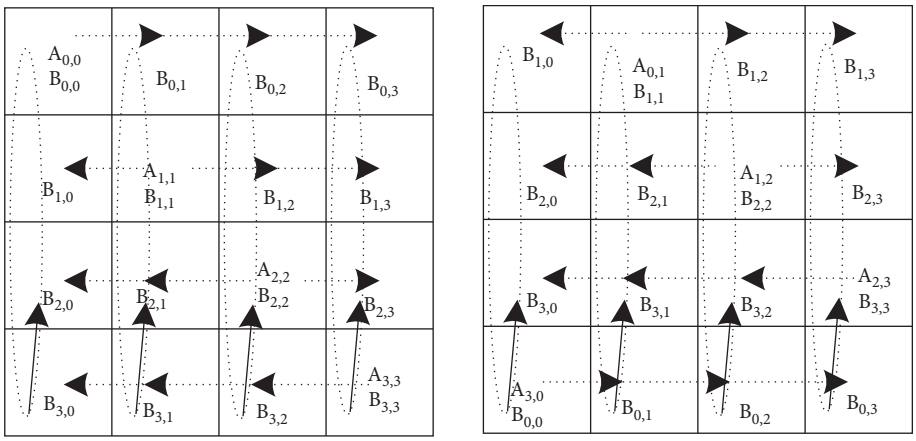


Figure 6: A_{00}, A_{01} Algorithm process.

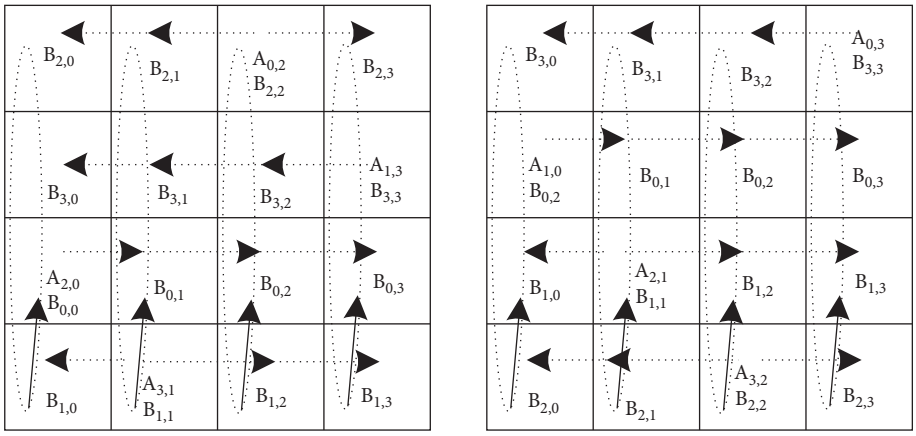


Figure 7: A_{02}, A_{03} Algorithm process.

very little entrepreneurial funds. Self-employed students should first choose projects with a low initial investment and fast investment to ensure the flow of funds for normal business activities. The contractor should also avoid selecting projects with high safety requirements. In fact, it is difficult for small capital to solve the problem of slowing capital expenditures caused by rising securities. As the market changes again, the company may invest less and face the risk of bankruptcy [22, 23].

They choose projects that are in the growth stage and avoid new projects that have just been developed and old projects that are fully mature. A project can be divided into an initial stage, a growth stage, and a mature stage. Although the projects in the early stages are less competitive, they have no market foundation. Although the projects in the mature stage are stable, they lack objective profits. The entrepreneurial projects in the growth stage not only have lower entrepreneurial risks but also have relatively large profit margins. Undergraduate entrepreneurs are generally not old, get in touch with new things quickly, and easily choose projects that are in their early stages. Such projects are very risky and are not suitable for college student entrepreneurs who lack social experience. Therefore, entrepreneurial projects in the growth period are more suitable for college students to start their own businesses, and the probability of success will be much greater.

Facing the increasingly severe employment pressure, college graduates must first resolve their misunderstandings about innovation and entrepreneurship and have a correct understanding of innovation and entrepreneurship. We must integrate current development trends, actively participate in social practice, and improve professional skills.

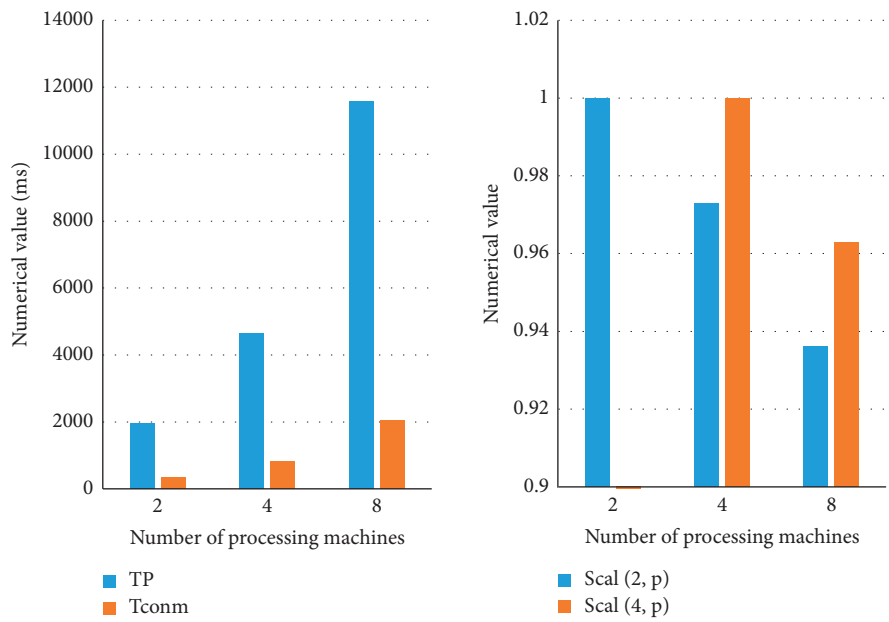


Figure 8: Scalability test results.

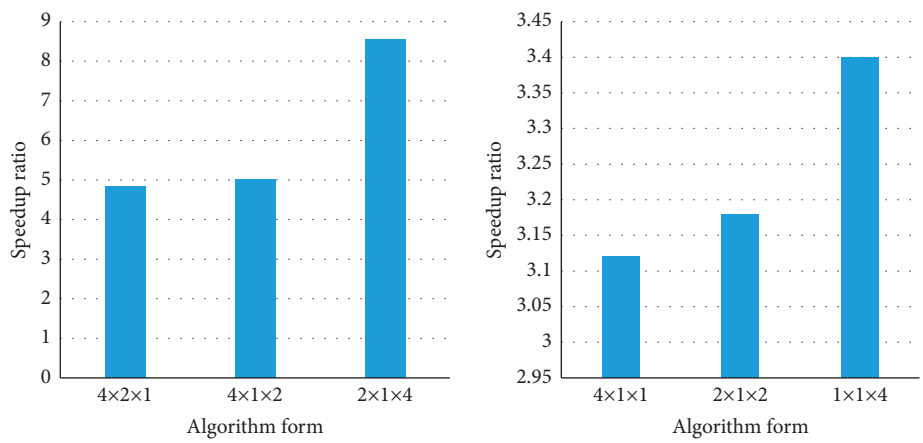


Figure 9: Improvement effect comparison chart.

Table 4: Test results of LM3D hybrid program on a supercomputer.

Grid	Processor topology	Threads	Operation hours (s)
$30 \times 30 \times 40$	$1 \times 2 \times 2$	1	0.325
		2	0.195
		4	0.174
		8	0.126
		16	0.211
	$2 \times 1 \times 2$	1	0.374
	$2 \times 2 \times 2$	1	0.162
$60 \times 30 \times 40$	$2 \times 1 \times 2$	1	0.801
		2	0.603
		4	0.394
		8	0.282
		16	0.416
	$2 \times 2 \times 1$	1	0.831
	$2 \times 2 \times 2$	1	0.346

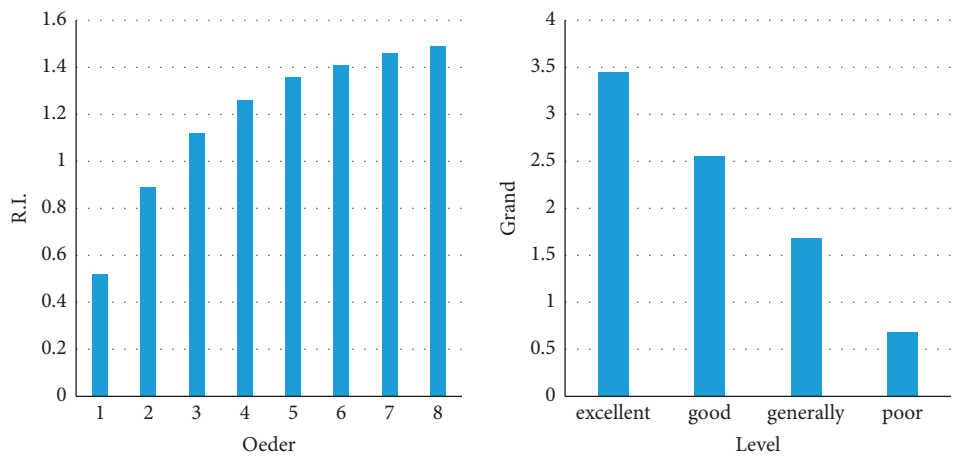


Figure 10: Comprehensive evaluation of innovation and entrepreneurship risk.

Exam-oriented education has been implemented in our country for a long time, and it is often unable to teach students a skill to develop wholeheartedly. Therefore, many graduates ignore innovation and entrepreneurship. With the development of science and technology, digital technology is changing people's lives, so innovation and entrepreneurship education should also keep pace with the times, using technology and information to study innovation and entrepreneurship [24].

6. Conclusion

With the development of economy and the progress of society, college students, as the most potential group, have higher quality and active innovation ability, and they should practice innovation. Innovation is the soul of social progress, and entrepreneurship is an important way to promote the social and economic development of our country and improve people's livelihood. Newly graduated college students every year are like fresh blood injected into the army of innovation and entrepreneurship, occupying an important weight. Moreover, innovation and entrepreneurship will also promote popular employment, enhance people's livelihood security, and help the country's development. This article introduces the concepts of Web and scientific computing and conducts research on the innovation and entrepreneurship of college students. The article develops a WEB-based scientific computing system, specifically providing scientific computing services to apply the system and optimize the stand-alone performance of the scientific computing system. This article starts a preliminary forecasting study. In view of the limited data sources and academic level, there are unavoidable omissions in the study. The analysis of the status quo analysis stage is not thorough enough, only showing the changes in relevant indicators and lacking internal judgment and analysis. The future research direction can apply the equal communication scalability model to practical problems and multilevel parallel scalability evaluation criteria.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This research study was sponsored by the Teaching Reform Research Project of Jiangxi Province in 2021; the name of the project is Research on Cooperative Education Path of Integrating Labor Education into Innovation and Entrepreneurship Education in Colleges and Universities and the project number is JXJG-21-10-27.

References

[1] R. Kumar, "Future for scientific computing using Python," *International Journal of Engineering Technologies and Management Research*, vol. 2, no. 1, pp. 30–41, 2020.

[2] J. West, "Large-scale scientific computing in the fight against COVID-19," *Computing in Science & Engineering*, vol. 23, no. 1, pp. 89–92, 2021.

[3] F. Gerardo Barroso-Tanoira and F. Tanoira, "Motivation for increasing creativity, innovation and entrepreneurship. An experience from the classroom to business firms," *Journal of Innovation Management*, vol. 5, no. 3, pp. 55–74, 2017.

[4] R. R. Kumar, K. P. Singh, and L. Ete, "Social innovation and entrepreneurship in Arunachal Pradesh: opportunities and challenges," *Space and Culture, India*, vol. 8, no. 4, pp. 48–59, 2021.

[5] S. Suharyati, "Strengthening innovation and entrepreneurship in improving smes competitiveness," *Riset*, vol. 2, no. 1, pp. 219–241, 2020.

[6] B. Niu, Q. Liu, Q. Liu, and Y. C. Yiming Chen, "Research on the university innovation and entrepreneurship education comprehensive evaluation based on AHP method," *International Journal of Information and Education Technology*, vol. 9, no. 9, pp. 623–628, 2019.

[7] O. Oyelakin and U. M. Kandi, "The moderating role of government policies on the relationship between technology, innovation and entrepreneurship development in Nigeria: a partial least square approach," *Universal Journal of Management*, vol. 5, no. 10, pp. 477–484, 2017.

[8] C. Mcphee and P. Saurabh, "Editorial: innovation and entrepreneurship in India (january 2018)," *Technology Innovation Management Review*, vol. 8, no. 1, pp. 3-4, 2018.

[9] S. Bhagavatula, R. Mudambi, and J. P. Murmann, "Management and organization review special issue "the innovation and entrepreneurship ecosystem in India"," *Management and Organization Review*, vol. 13, no. 1, pp. 209–212, 2017.

[10] I. Danaila, P. Joly, S. M. Kaber, and M. Postel, "An introduction to scientific computing," *Texts in Computational Science & Engineering*, vol. 8, no. 2, pp. 246–267, 2017.

[11] R. Henriquez-Auba, J. D. Lara, D. S. Callaway, and C. Barrows, "Transient simulations with a large penetration of converter-interfaced generation: scientific computing challenges and opportunities," *IEEE Electrification Magazine*, vol. 9, no. 2, pp. 72–82, 2021.

[12] W. Cai, "A focused section on deep neural network machine learning for scientific computing," *Communications on Applied Mathematics and Computation*, vol. 3, no. 2, p. 291, 2021.

[13] J. Jeon and H. U. Kim, "Setup of a scientific computing environment for computational biology: simulation of a genome-scale metabolic model of *Escherichia coli* as an example," *Journal of Microbiology*, vol. 58, no. 3, pp. 227–234, 2020.

[14] Y. Sönmez, H. Kutlu, and E. Avci, "A novel approach in analyzing traffic flow by extreme learning machine method," *Tehnicki vjesnik-Technical Gazette*, vol. 26, no. 1, pp. 107–113, 2019.

[15] V. Skala and S. Karim, "Scientific computing and computer graphics with GPU: application of projective geometry and principle of duality," *International Journal of Mathematics and Computer Science*, vol. 15, no. 3, pp. 769–777, 2020.

[16] C. González-Zapatero, J. González-Benito, and G. Lannelongue, "Effect of purchasing and marketing integration on new product development speed: the moderating role of environmental dynamism," *Advances in Production Engineering & Management*, vol. 14, no. 2, pp. 213–224, 2019.

[17] M. Souza, T. Z. Torres, M. P. Júnior et al., "Organizational guidelines for embrapa advanced quantitative methods and scientific computing area," *Open Journal of Business and Management*, vol. 08, no. 4, pp. 1816–1830, 2020.

[18] N. Sremcev, B. Stevanov, M. Lazarevic, J. Mandic, Z. Tesic, and B. Kuzmanovic, "Improving process of quotation creation through value stream mapping and simulation," *International Journal of Simulation Modelling*, vol. 18, no. 4, pp. 563–573, 2019.

[19] P. Virtanen, R. Gommers, T. E. Oliphant et al., "Author Correction: SciPy 1.0: fundamental algorithms for scientific computing in Python," *Nature Methods*, vol. 17, pp. 1–12, 2020.

[20] J. L. Shi, S. J. Fan, Y. J. Wang, and J. S. Cheng, "A quantitative analysis method of greenhouse gas emission for mechanical product remanufacturing based on Petri net," *Advances in Production Engineering & Management*, vol. 13, no. 4, pp. 442–454, 2018.

[21] E. Ipek, "Memristive accelerators for dense and sparse linear algebra: from machine learning to high-performance scientific computing," *IEEE Micro*, vol. 39, no. 1, pp. 58–61, 2019.

[22] V. Lanore, "Fostering reuse in scientific computing with embedded components," *Computing in Science & Engineering*, vol. 21, no. 2, pp. 36–47, 2019.

[23] D. Bebic, L. Stazic, and I. Komar, "Ships shore service optimization using the queueing theory," *International Journal of Simulation Modelling*, vol. 18, no. 4, pp. 596–607, 2019.

[24] M. M. Crockatt and A. J. Christlieb, "Low-storage integral deferred correction methods for scientific computing," *SIAM Journal on Scientific Computing*, vol. 40, no. 5, pp. A2883–A2904, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9706046, 9 pages
https://doi.org/10.1155/2022/9706046

Research Article

The Effect of Mental Toughness on Learning Burnout of Junior Middle School Students: Putting School Adaptation as a Mediator Variable

Qi Fengjun,[1] **Zhou Jing**,[2] **and Li Liguang**[3]

[1]*Krirk University, No. 3 Soi Ramintra 1, Ramintra Road, Anusaowaree, Bangkhen, Bangkok 10220, Thailand*
[2]*Beihai Campus of Guilin University of Electronic Technology, Beihai, China*
[3]*Work Unit, Krirk University, Bangkok, Thailand*

Correspondence should be addressed to Qi Fengjun; 6119213@student.krirk.ac.th

Received 10 March 2022; Revised 15 April 2022; Accepted 26 April 2022; Published 23 May 2022

Academic Editor: Lele Qin

Learning burnout has always been a key problem in school education. Junior high school students, as an important part of the student population, cannot be ignored. To explore the impact of resilience, school adaptation on learning burnout is helpful to improve students' learning level and reduce learning burnout. In this study, the junior high school students in A city were selected as the research objects, and questionnaires were used to explore the effect of mental toughness on learning burnout and the mediating effect of school adaptation. Statistical analysis methods such as descriptive statistics, correlation analysis, and regression were used. Based on the theoretical model of job burnout, data analysis showed that mental toughness of junior high school students in A city could significantly negatively predict learning burnout. Adolescent mental toughness can significantly affect the prediction of school adjustment school adjustment has a significant negative impact on learning burnout, and mental toughness can indirectly affect learning burnout through school adjustment.

1. Introduction

Junior high school students are in the adolescent period, which is the key period for individuals to develop positive psychological quality and form sound personality. Yu and Chae [1] Mental health and personality development has been highly concerned by social and psychologists. As the capital of Shaanxi Province, Xi'an has a serious problem of misallocation of educational resources for junior high school students and a high level of academic burnout of students. Zhuo [2] in the current social environment, junior high school students are faced with increasing pressure in the face of parents' expectations, urgent needs for college entrance and employment, and fast-paced lifestyle. Especially in the current Chinese society with a high proportion of only children, junior high school students shoulder unprecedented responsibilities and expectations. In the study of Zhang et al [3], with the continuous development of the economy, people's lives are gradually improving, so parents are paying more and more attention to students' learning, especially for junior high school students, which is considered to be the critical time for learning.

In the study of Zhao Hao and Song Tianjiao [4], with the increase of expectations from society, school, and family in recent years, students can hardly bear it, resulting in an increasingly serious level of learning burnout. "Student Burnout" derived from the concept of "Job Burnout," it refers to the phenomenon of boredom occurring in the learning process of students and exists as a specific research field of burnout. Lenaert et al [5] found that the learning situation of students is not optimistic, and many students suffer from learning burnout, which reduces their interest and motivation in learning. Therefore, how to help junior high school students overcome their learning slack has become an important part of school education.

School is an important place for students to study and live, so students' adaptation to school has always been an important topic in education and psychology. School adaptation refers to the state in which students happily participate in school activities and achieve learning success under the school background. Students' adaptation is evaluated by the indicators of explicit problems, implicit problems, adaptive skills, and behavioral symptoms. It is found that students' mental health level is related to their adaptive ability. Moreover, Yanqin et al. [6] took school adaptation as the mediating variable to explore the relationship between social support and life satisfaction of urban immigrants' children, proving the mediating effect of school adaptation.

2. Research Objectives

Based on the above research background, this study will explore the relevant factors of mental toughness, learning burnout, and school adaptation among junior high school students in Xi'an, Shaanxi Province. Therefore, the purpose of this study is as follows:

(a) To explore the impact of school adaptation on learning burnout of junior high school students in Shaanxi Province

(b) To explore the impact of mental toughness on school adaptation of junior high school students in Xi 'an, Shaanxi Province

(c) To explore the impact of mental toughness on learning burnout among junior high school students in Xi'an, Shaanxi Province

(d) To explore the mediating effect of school adaptation on mental toughness on learning burnout among junior high school students in A Province

3. Literature Review

In order to explore the relationship between mental toughness, learning burnout, and school adjustment, the definitions, theories, and measurement tools related to mental toughness, learning burnout, and school adjustment were explored by collecting relevant literature, and then the literature was collected to explore the relationship between the three, which laid the foundation for this study.

3.1. Mental Toughness. Folke [7] named the word Resilience in a variety of ways, including five parts, "Resilience," "psychological Resilience," "Resilience," "overcome," and "strong Resilience" [8]. In folk culture, mental toughness usually represents an individual's strong will and fortitude. However, researchers Hu Yueqin and Gan Yiqun [9] believe that all positive concepts, such as personality, coping, resources, and adaptation results, can constitute or enhance individual mental toughness. Gucciardi [10] believes that psychological resilience is the ability of an individual to withstand severe pressure and adapt to it without abnormal behavior. Anthony et al [11] proposed that resilience, as a psychological phenomenon of individuals, can still adapt and develop well when individuals are faced with serious threats. As for mental toughness, this paper attempts to conduct research from the perspective of constructing a process model or theory among factors of mental toughness [12].

For example, Kumpfer [13] constructed a framework model of mental toughness, which includes three aspects. Second, the individual characteristics of mental resilience; third is the dynamic mechanism of mediating effect and the elastic recombination of good individual development results. Risk factors interact with protective factors, and the effect of protective factors is related to the number and level of risk factors, so mental toughness as a protective factor is related to learning burnout as a risk factor. The increase in the number of protective factors will also effectively buffer the impact of risk factors, that is, the improvement of mental toughness will help buffer the learning burnout behavior [14].

3.2. Learning Burnout. In the 1970s, the psychological community began to study burnout. Lusheng and Yongxin [15] found through investigation that the main research object of learning burnout is the industry practitioners who serve people. Freudenbery (1989) published an article named "Staff Burnout" which first aroused people's attention and interest in burnout research. The term "Burnout" describes the physical and mental changes he experiences while working with substance abuse patients, and he believes Burnout refers to the physical and mental fatigue an individual experiences when their work goes unrecognized and unrewarded for a long period of time. On this basis, the estranged attitude towards work and related personnel and the phenomenon of reduced self-evaluation developed [16].

Attribution theory, which plays an important role in cognitive schools, is a causal analysis made by individuals for their own success or failure (Miao Rui and Xu Jian, 2018). Fishman and Husman [17] proposed the basic hypothesis that seeking to understand is the basic motivation of behavior. They believed that people have two needs to understand the world and control the environment, and the reason for people's behavior is the fundamental means to meet these two needs, and thus predicted people's behavior [18]. Li Yuan explained the reasons for academic success or failure: first, whether the reasons are internal or external; second, whether the reasons are stable or unstable; third, whether the reasons are controllable or uncontrollable. Each dimension of attribution has different effects on individual students. For the emotional response of attributing success or failure, if the success is attributed to internal causes, the individual will feel proud; if the success is attributed to external causes, the individual will feel grateful; if the failure is attributed to internal causes, the individual will feel remorse and shame; if the failure is attributed to external causes, individuals feel angry [19].

When students ascribe success or failure to stable factors, they have expected the outcome of the event at the beginning. When students attributed success or failure to unstable

factors, individual expectations of the outcome had little effect. The effect of attributions of success or failure on effort, if success or failure is attributed to effort, then he will redouble his efforts and overcome setbacks. Success or failure depends on ability; he will choose to give up, because no matter how hard he tries, he cannot achieve success. So, the success or failure attribution theory to provide a basis for the intervention experiment design, such as success or failure due to internal, unstable factors, and controllable factors will have a positive effect on learning burnout.

4. Data and Methodology

In this section, the research structure of the study and the subjects and data of the study are presented.

4.1. Research Framework. The purpose of this study was to investigate the relationship between mental toughness, school adjustment, and school burnout among adolescents in Province A. Based on the motivation and purpose of the study and the analysis of the literature, each research variable was developed. Mental toughness was used as the independent variable, school burnout as the dependent variable, and school adjustment as the mediating variable, as shown in Figure 1.

4.2. Research Subjects. Through the survey, it was found that middle school students in province A have more serious learning burnout, and it was also found that students in different areas have different learning burnout, so this study selected three middle school institutions in different areas of Xi'an, Shaanxi province as the main research object through the information published on the official website of the Education Bureau of Xi'an, Shaanxi province. These three schools in province A we used school B, school C, and school D instead, where the number of students in school B is 956, School C 859, School D 1021, the total number of students in the three institutions is 2836, in terms of data collection, the principle of Simple Random Sampling (SRS) was adopted to conduct sampling.

4.3. Research Tools. This study mainly uses questionnaire survey to collect data, and scales are mainly developed according to literature discussion and the purpose of this study. The scales used in this study are divided into three parts. It includes the mental toughness scale developed by Hu Yueqin and Gan Yiqun [9]; the school Adaptation Scale developed by Na [20], and the learning burnout scale developed by Qiao and Chunlin [21].

5. Descriptive Statistics

The descriptive statistical analysis results of the research variables are shown in Table 1. The average learning burnout of junior middle school students ($M = 2.433$, $\mathrm{SD} = 0.512$) is less than 3, so the learning burnout of the tested junior middle school students is at the lower level of learning burnout. The average school adaptation of junior middle

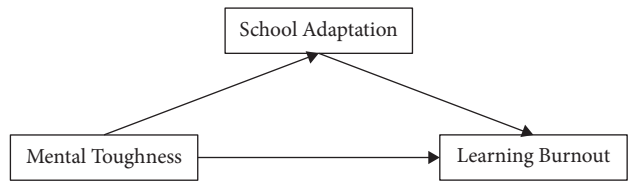


Figure 1: Research framework diagram.

school students ($M = 3.221$, $\mathrm{SD} = 0.809$) was greater than 3, indicating that the school adaptation of the tested junior middle school students was above the middle level. The average mental toughness of junior middle school students ($M = 3.461$, $\mathrm{SD} = 0.573$) was greater than 3. Objective attentiveness ($M = 3.517$, $\mathrm{SD} = 0.766$), emotion control ($M = 3.075$, $\mathrm{SD} = 0.853$), positive cognition ($M = 3.332$, $\mathrm{SD} = 0.817$), family support ($M = 3.610$, $\mathrm{SD} = 0.809$), and person and assistance ($M = 3.772$, $\mathrm{SD} = 0.92606$), and the mean values of these dimensions were all greater than 3, indicating that most of the subjects tended to focus on goals, emotion control, positive cognition, family support, people and assistance. According to Kline [29], when the absolute value of the skewness coefficient is less than 3 and the absolute value of the kurtosis coefficient is less than 10, it can be regarded as the normal distribution. The absolute value of the skewness coefficient is less than 3, and the kurtosis coefficient is less than 10, so they all follow the normal distribution.

5.1. Analysis of Differences of Different Background Variables in Learning Burnout, School Adaptation, and Mental Toughness. The independent sample T test and ANOVA were used to test whether there were differences in gender, education level, and subject of each research variable. Differences in mental toughness of subjects with different background variables A were analysed. The difference analysis of mental toughness of subjects of different genders was conducted with the independent sample T test, as shown in Table 2. The results showed that there was no significant difference in mental toughness between different genders ($t = .363$, $P = .717$). There were no significant differences in the dimensional-objective specificity of resilience ($t = 1.471$, $P = .142$), positive cognition ($T = .539$, $P = .590$), family support ($t = .868$, $P = .062$), and interpersonal assistance ($t = 1.668$, $P = .769$). However, there was significant difference in emotion of junior middle school students of different genders ($t = 4.074$, $P = .000$), and the degree of emotion control of male students was significantly lower than that of female students.

B. With grade as independent variable and mental toughness, goal focus, emotional control, positive cognition, family support, and interpersonal assistance as dependent variables, ANOVA test results are shown in Table 3. The results showed that there were no significant differences in mental toughness, goal focus, emotion control, integral-pole cognition, family support, and interpersonal assistance among junior high school students of different grades. Dunnett's T3 test was used for post hoc comparison when

Table 1: Summary table of descriptive statistics.

	Mean value	The standard deviation	Skewness coefficient	Kurtosis coefficient
Learning burnout	2.433	0.512	0.128	0.206
Emotional exhaustion	2.451	0.640	0.456	0.089
Low sense of achievement	2.422	0.705	0.199	−0.017
Distance between teachers and students	2.243	0.756	0.425	−0.127
The depletion of physiological	2.655	0.931	0.064	−0.492
Mental toughness	3.461	0.573	−0.463	1.599
Goal focus	3.517	0.766	−0.425	0.394
Emotional control	3.075	0.853	−0.023	−0.450
Positive cognitive	3.331	0.817	−0.578	0.398
Family support	3.610	0.809	−0.636	0.394
People and assistance	3.772	0.926	−0.314	−0.225
School adjustment	3.221	0.809	0.256	−0.487
Academic adjustment	3.166	0.823	0.080	−0.286
School attitude and emotion	3.247	0.904	0.183	−0.405
Peer relations	3.179	1.045	0.406	−0.878
The relationship between teachers and students	3.124	0.937	0.156	−0.769
Conventional adaptive	3.379	0.975	0.307	−0.735

Sources: the data collated was organized in the study.

Table 2: Summary of difference analysis of mental toughness of middle school students with different genders.

The name of the variable	Mean value (standard deviation)		df	t	P
	Male	Female			
Mental toughness	3.451(0.553)	3.469(0.592)	496.900	0.363	0.717
Focused	3.534(0.760)	3.504(0.769)	510.271	1.471	0.142
Emotional control	3.271(0.816)	3.376(0.862)	491.363	4.074	0.000
Positive cognitive	3.714(0.849)	3.715(0.793)	490.962	0.539	0.590
Family support	3.513(0.801)	3.533(0.813)	510.159	0.868	0.620
Interpersonal assist	3.220(0.937)	3.215(0.916)	492.582	0.668	0.796

Note. ***means $P < 0.001$; **, $P < 0.01$; *, $P < 0.050$. Sources: the data collated was organized in the study.

Table 3: Summary of the difference analysis of mental toughness among students of different grades.

The name of the variable	Mean value (standard deviation)			f	P	Posterior comparisons
	1	2	3			
Mental toughness	3543(0.554)	3.398(0.579)	3.441 (0.580)	3.045	0.048	1 > 2
Focused	3.601(0.797)	3.457 (0.715)	3.493(0.781)	1.537	0.216	
Emotional control	3.194(0.784)	3.061(0.856)	3.068(0.920)	1.342	0.338	
Positive cognitive	3.746(0.784)	3.719(0.868)	3.750(0.793)	1.821	0.163	
Family support	3.701(0.780)	3.560(0.832)	3.568(0.810)	1.711	0.182	
Interpersonal assist	3.470(0.875)	3.194(0.968)	3.326(0.917)	3.857	0.022	1 > 2

Source: the data collated was organized in the study.

Levene test variance was not equal. When Levene test of variance is equal, Scheff method is used for post hoc comparison (Qiu Haozheng, 2008). After Levene test ($P = .455$), the variance of mental toughness variables is found to be equal. Therefore, Scheff method is used for post-hoc comparison. The variance of interpersonal assistance ($P = .571$) of psychological resilience was found to be equal after Levene test, so Scheff method was used for post hoc comparison. When comparing the mental toughness of junior high school students in different grades, it was found that the mental toughness of junior two was significantly higher than that of junior one. The post-hoc comparison of interpersonal assistance in grade one is significantly higher than that in grade two.

5.1.1. Analysis of Differences in Mental Toughness of Subjects with Different Background Variables. A. Difference analysis of school adaptation of junior high school students of different genders. The analysis results of independent sample T test are shown in Table 4. The results showed that there was no significant difference in school adaptation among primary school students of different genders ($t = 1.390$, $P = .165$) in the dimension of school adaptation, academic fitness ($t = .482$, $P = .630$), school attitude and emotion ($t = 1.693$, $P = .189$), peer relationship ($t = .526$, $P = .599$), teacher-student relationship ($T = 1.239$, $P = .216$), and routine adaptation ($t = 1.008$, $P = .314$). To sum up, there is no significant difference in school adaptation and its various dimensions among junior middle school students of different genders.

Table 4: Summary of school adaptation difference analysis of middle school students of different genders.

The name of the variable	Mean value (standard deviation)		DF	t	P
	Male	Female			
School adjustment	3.181(0.836)	3.251(0.779)	351.256	1.390	0.165
Academic adjustment	3.060(0.839)	3.133(0.812)	351.256	0.482	0.630
School attitude and emotion	3.275(0.957)	3.366(.859)	352.953	1.693	0.189
Peer relations	3.147(0.492)	3.168(0.454)	346.650	0.526	.599
The relationship between teachers and students	3.074(0.944)	3.143(0.920)	352.077	1.239	0.216
Conventional adaptive	3.349(0.985)	3.445(0.965)	348.419	1.008	0.314

Note: *** means $P < .001$; **, $P < 0\ 01$; *, $P < .05$ Sources: the data collated was organized in the study.

B. Difference analysis of school adaptation of tested junior high school students of different grades. The analysis results of ANOVA test are shown in Table 5. The results showed that there were significant differences in school adaptation among junior high school students of different grades ($F = 4.353$, $P = .017$) in the school adaptation variable dimension, academic adaptation ($F = 3.434$, $P = .033$), school attitude and emotion ($F = 3.269$, $P = .039$), peer relationship ($F = 7.205$, $P = 0.001$), teacher-student relationship ($F = 2.839$, $P = 0.046$), and conventional adaptation ($F = 3.66$, $P = 0.026$). Dunnett's T3 test was used for post hoc comparison when Levene test variance was not equal. Scheff method was used for post hoc comparison when Levene's test variances were equal. The Levene test showed that the variables and dimensions of school adaptation were significant, including school-industry adaptation, school attitude and emotion, peer relationship, teacher-student relationship, and conventional adaptation, indicating that the variables and dimensions of school adaptation were unequal in variance. Therefore, Scheff test was used in the post hoccomparison. After comparing the school adaptation of students in different grades, it is found that the school adaptation of students in grade 3 is significantly higher than that in grade 1. In terms of school adaptation variables, academic adaptation, school attitude and emotion, teacher-student relationship, and routine adaptation, the comparison results show that the degree of grade 3 students is significantly higher than that of grade 1 students. In terms of peer relationship of school adaptation dimension, the comparison results showed that the degree of peer relationship of grade 3 students was significantly higher than that of grade 1 and grade 2 students. To sum up, there are significant differences in school adaptation and its dimensions of middle school students in different grades, and the degree of school adaptation and its dimensions of middle school students in grade 3 are significantly higher than those in grade 1 and grade 2.

5.2. Correlation Analysis. In order to study the logical relationships between variables, they pointed out that the correlation range of .900 is very high correlation, .700–0.900 is high correlation, .500–0.700 is medium correlation, .300–.500 is low correlation, and 0.000–0.300 is very little correlation. It shows that there is significant correlation between variables. The study of correlation analysis plays a very important role, which is directly related to whether the hypothesis testing of the next part is needed. If the correlation is good, the hypothesis should be tested in the next step; if the correlation is bad, the hypothesis should not be tested in the next step (see Table 6).

As can be seen from the correlation analysis in Table 6, mental toughness is negatively correlated with learning burnout ($r = -0.379$, $P < 0.001$), and positively correlated with school adaptation ($r = 0.649$, $P < .001$). School adaptation was negatively correlated with learning burnout ($r = -0.438$, $P < .001$).

5.3. Regression Analysis. In this study, linear regression analysis was used to test the direct hypothesis of this study, including the impact of mental toughness on school adaptability, the impact of school adaptation on learning burnout, and the impact of school adaptation on learning burnout. Regression analysis was used to test the direct influence of variables.

As shown in Table 7, R2 is .422 in the impact of psychological toughness and school adaptation, and the adjusted R2 is .421. The result of ANOVA is $F = 447.922$, $P < .001$, indicating that the result is suitable for regression analysis. There is a significant positive correlation between mental toughness and school adaptation ($\beta = .766$, $P < .001$, $t = 21.166$), indicating that the better the students' mental toughness, the better the school adaptation. Therefore, hypothesis H1 is valid.

As shown in Table 8, in the influence of mental toughness and learning burnout, R2 is .144, and adjusted R2 is .142, wherein the result of ANOVA is $F = 103.253$, $P < .001$, indicating that the result is suitable for regression analysis. There is a significant negative influence between mental toughness and learning burnout ($\beta = -.435$, $P < .001$, $t = -10.161$), indicating that the better the students' mental toughness, the lower learning burnout. Therefore, hypothesis H2 is true.

As shown in Table 9, in the influence of school adaptation and learning burnout, R2 was 0.208, and the adjusted R2 was 0.206. The result of ANOVA was $F = 80.682$, $P < .001$, indicating that the result was suitable for regression analysis. There is a significant negative influence between school adaptation and learning burnout ($\beta = 2212.319$, $P < .001$, $t = -6.949$), indicating that the stronger the school adaptation, the lower the learning burnout. Therefore, hypothesis H3 is true.

Table 5: Summary table of school adaptation difference analysis of middle school students in different grades.

Variable the name of the	Mean value (standard deviation)			f	P	Posterior comparisons
	1	2	3			
School adjustment	3.103(0.872)	3.212(0.774)	3.345(0.749)	4.353	0.017	3 > 1
Academic adjustment	3.043(0.754)	3.128(0.817)	3.313(0.881)	3.434	0.033	3 > 1
School attitude and emotion	3.037(0.877)	3.107(0.927)	3.281(0.898)	3.269	0.039	3 > 1
Peer relations	3.153(0.952)	3.183(1.003)	3.301(1.130)	7.205	0.001	3 > 1; 3 > 2
The relationship between teachers and students	3.022(0.888)	3.129(0.914)	3.200(0.989)	2.839	0.046	3 > 1
Conventional adaptive	3.410(0.929)	3.513(0.942)	3.630(1.035)	3.660	0.026	3 > 1

Note. 1 = Grade 1; 2 = Grade2; 3 = Grade 3; *, *, *, $P < 0.001$; *, *, $P < 0.01$; *, $P < .05$. Source: The data collated was organized in the study.

Table 6: Correlation coefficients.

	Mental toughness	Learning burnout	School adjustment
Mental toughness	1		
Learning burnout	−0.379***	1	
School adjustment	0.649***	−0.438***	1

Note. *** means $P < .001$; *, *, $P < 0.01$; * indicates $P < .05$. Sources: The data collated was organized in the study.

Table 7: Analysis table of psychological resilience and school adaptation hypothesis.

	School adjustment		
	β		t
Mental toughness	0.766		21.166***
R2		0.422	
Adj R2		0.421	
F		447.992***	

Note. *** means $P < .001$; *, *, $P < 0\ 01$; *, $P < .05$. Sources: The data collated was organized in the study.

Table 8: Hypothesis analysis of mental toughness and learning burnout.

	Learning burnout	
	β	t
Mental toughness	−0.435	−10.161***
R2	0.144	
Adj R2	0.142	
F	103.253***	

Note. *** means $P < 0\ 001$; *, *, $P < 0\ 01$; *, $P < .05$. Sources: The data collated was organized in the study.

Table 9: School adaptation and learning burnout hypothesis analysis table.

	Learning burnout	
	β	t
School adjustment	−0.319	−6.949***
R2	0.208	
Adj R2	0.206	
F	80.682***	

Note. *** means $P < .001$; *, *, $P < .01$; *, $P < .05$. Sources: the data collated was organized in the study.

As shown in Table 10, R2 in model 1 is .144 and adjusted R2 is .142. The result of ANOVA is $F = 103.253$, $P < .001$, indicating that the result is suitable for regression analysis. Psychological toughness has a significant negative impact on learning burnout ($\beta = 2212.435$, $T = -10.161$, $P < .001$). The R2 of model 2 was .422, and the adjusted R2 was .421. The result of ANOVA was $F = 447.992$, $P < .001$, indicating that the results were suitable for regression analysis. Psychological toughness had a significant positive effect on school adaptation ($\beta = .766$, $T = 21.166$, $P < .001$). The R2 of model 3 was .208, and the adjusted R2 was .206. The result of ANOVA was $F = 80.682$, $P < .001$, indicating that the results were suitable for regression analysis. Psychological toughness had a significant negative effect on learning burnout ($\beta = -0.193$, $T = -3.572$, $P < .001$). School adaptation had a significant negative effect on learning burnout ($\beta = -0.319$, $t = -6.949$, $P < 0.001$). To sum up, the results show that the strength of the student's mental toughness, adaptability, the better school, and learning burnout is lower, because the independent variable mental toughness has a significant effect on the dependent variable learning burnout, as a result, the said school adjustment in the relationship between the mental toughness and learning burnout plays a partial intermediary role, therefore this study founded the H4 intermediary effect (see Table 10).

5.4. Research Findings. According to the research results, hypothesis H1 in this study is supported: adolescents' mental toughness has a positive impact on school adaptation; H2: Psychological toughness has a negative impact on learning burnout, which is supported; H3: School adaptability of adolescents has a negative impact on learning burnout. H4: School adaptation plays a partially mediating role in the

Table 10: Mediation analysis table.

	Learning burnout Model 1		School adjustment Model 2		Learning burnout Model 3	
	β	t	β	t	β	t
Mental toughness	−0.435	−10.161***	0.766	21.166***	−0.193	−3.572***
School adjustment					−0.319	−6.949***
R2	0.144		0.422		0.208	
Adj R2	0.142		0.421		0.206	
F	103.253***		447.992***		80.682***	

Note. *** means $P < .001$; *, *, $P < .01$; *, $P < .05$. Sources: the data collated was organized in the study.

Table 11: Summary of research results.

The research hypothesis verifies the results	The verification results
H1: Adolescents' mental toughness has a significant positive impact on school adaptation. Set up	Set up
H2: Adolescents' mental toughness and learning burnout have a significant negative impact. Set up	Set up
H3: School adaptation and learning burnout of adolescents have a significant negative impact. Set up	Set up
H4: School adaptation has a mediating effect on psychological toughness and learning burnout. Set up	Set up

Sources: The data collated was organized in the study.

relationship between mental toughness and learning burnout, so the mediating effect of school adaptation can be supported. As shown in Table 11:

6. Research Conclusions

Based on the statistical analysis performed in subsection IV, the corresponding conclusions are now drawn:

6.1. The Impact of Mental Toughness on School Adaptation. When students' mental toughness increases, students' school adjustment also increases, and the scores of each dimension will be in an upward trend, and when students' mental toughness decreases, students' school adjustment will decrease, concluding that the lower the mental toughness, the lower the degree of school adjustment. Therefore, mental toughness as an individual subjective psychological factor will naturally have a certain impact on school adaptation, and individuals have a higher level of mental toughness, indicating that their ability to adapt and develop is still good in different environments and states.

6.1.1. The Impact of Mental Toughness on Learning Burnout. According to the investigation and analysis of junior high school students, the same situation will occur in junior high school students. With the increase of mental toughness, learning burnout will decrease. Data analysis shows that the increase of mental toughness will lead to the decrease of learning burnout, that is to say, the higher mental toughness, the lower the degree of learning burnout. The reason can be explained that mental toughness can improve students' academic status, so that individuals can maintain a positive learning attitude, promote individual mental health and adaptation, and reduce learning burnout. If the individual has a high level of mental toughness, it will not easily produce learning burnout, If individuals have high mental toughness, they are less prone to learning burnout, which is consistent with our previous findings, while such findings are also consistent with our previous literature, but Gerber et al [30] suggested that the effect of mental toughness on learning burnout is limited by age, when age increases mental toughness decreases learning burnout will increase, the subjects of this study are fixed. So the conclusion is correct in our study.

6.1.2. The Impact of School Adaptation on Learning Burnout. There was a significant negative correlation between school adjustment and academic burnout and a significant negative correlation between school adjustment and academic burnout. We found a significant negative correlation between school adjustment and learning burnout. School adaptation significantly predicted learning burnout, that is, the stronger the school adaptation, the lower the students' learning burnout. Poor school adaptation affects their level of learning burnout, and improving middle school students' adaptation is beneficial to improving learning burnout. Learning adaptability, as an external environmental factor, can be expected as a result of learning burnout as a behavior. The higher the level of school adaptability, the lower the level of learning burnout naturally, this finding is in line with what was mentioned in the previous literature, but Ezenwaji et al [26] suggested that students' school adaptability is related to school facilities and when the school facilities are updated, students' adaptability will also be more adaptable and learning burnout will diminish.

6.1.3. The Mediating Relationship between School Adaptation and Mental Toughness and Learning Burnout. It was found that school fit had a significant mediating effect between mental toughness and academic burnout. First, mental

toughness has a direct effect on academic burnout. Therefore, to help students reduce or alleviate academic burnout, students can build strong mental toughness, improve their ability to cope with different environments, crises, and difficulties, and promote positive attitudes. Through our study, we found that school adaptability has a significant negative relationship with academic burnout. After introducing school adaptability as a mediating variable, we found that school adaptability partially mediated the relationship between mental toughness and academic burnout. Therefore, improving adolescents' mental toughness and further improving their school adjustment will be more effective in reducing their academic burnout. However, Mind et al [30] suggested that school adjustment is the moderating effect between mental toughness and academic burnout, and their research subjects are different from those of college students.

6.2. Research Recommendations. According to the research results confirmed that the school adjustment, there is close relationship between learning burnout and mental toughness, according to the results and conclusions of this study, put forward concrete suggestions, when the sample quantity reach a certain value, can affect the results of our produce, in the future research can expand the choice of the object of study samples, there are differences between different areas, and different schools. However, due to the limited samples selected in this research, all types of samples cannot be completely covered, and the existing samples cannot fully demonstrate the differences of learning burnout in different regions and schools.

(A) In terms of the mediating mechanism, this study only selects school adaptation as A mediating variable. Other mediating variables, such as family environment, can also be selected in future studies to enrich the research on related theories.

(B) In terms of research methods, we can also adopt a combination of qualitative and quantitative research methods. In addition to quantitative research using question-paper analysis, qualitative research methods such as interview method, field investigation method, and observation method can also be adopted to understand students' in-depth thoughts.

Data Availability

All data used in this study can be accessed by request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] J. Yu and S. Chae, "The mediating effect of resilience on the relationship between the academic burnout and psychological well-being of medical students," *Korean journal of medical education*, vol. 32, no. 1, pp. 13–21, 2020.

[2] Z. Xiaoxia, "The relationship between perceived campus climate and academic burnout among high school students and satisfaction," *Mental Health Education in Primary and Secondary School*, vol. 3, no. 2, pp. 16–19, 2019.

[3] L. Zhang, Y. Yan, W. Xu, J. Sun, and Y. Zhang, "Carbon emission calculation and influencing factor analysis based on industrial big data in the "double carbon" era," *Computational Intelligence and Neuroscience*, vol. 2022, Article ID 2815940, 2022.

[4] H. Tianjiao, "The relationship between school adjustment and academic burnout in upper elementary school students and countermeasures," *Literature Education*, vol. 5, no. 9, pp. 110–113, 2017.

[5] B. Lenaert, Y. Boddez, J. W. S. Vlaeyen, and C. M. van Heugten, "Learning to feel tired: a learning trajectory towards chronic fatigue," *Behaviour Research and Therapy*, vol. 100, pp. 54–66, 2018.

[6] P. Yanqin, J. Bo, and T. Tingting, "Social support and life satisfaction of urban immigrant children: schools adaption to the intermediary role," *Psychological Exploration*, vol. 21, no. 2, pp. 554–558, 2011.

[7] W. Pengjun and Z. Shichao, "Resilience (republished)," *Ecology and Society*, vol. 21, no. 4, pp. 44–226, 2016.

[8] K. Wi and T. Ye, "The impact of school exclusion on middle school students' internalizing problems: the mediating role of peer relationships and core self-evaluation," *Psychological Development and Education*, vol. 36, no. 5, pp. 594–604, 2020.

[9] Y.-Q. Hu, "Development and psychometric validity of the resilience scale for Chinese adolescents," *Acta Psychology Sinica*, vol. 40, no. 8, pp. 902–912, 2008.

[10] D. F. Gucciardi, "Mental toughness: progress and prospects," *Current Opinion in Psychology*, vol. 16, no. 13, pp. 17–23, 2017.

[11] D. R. Anthony, D. F. Gucciardi, and S. Gordon, "A meta-study of qualitative research on mental toughness development," *International Review of Sport and Exercise Psychology*, vol. 9, no. 1, pp. 160–190, 2016.

[12] N. Garmezy, "Stress-resistant children: the search for protective factors," *Recent research in developmental psychopathology*, vol. 4, no. 19, pp. 213–233, 1985.

[13] K. L. Kumpfer, "Factors and processes contributing to resilience," *Longitudinal Research in the Social and Behavioral Sciences: An Interdisciplinary Series*, vol. 5, no. 8, pp. 179–224, 2002.

[14] T. Hailei and Z. Wenxin, "Revie w of the studies on psychological resilience," *Journal of Shanxi Normal University (Philosophy and Social Sciences edition)*, vol. 51, no. 3, pp. 149–152, 2006.

[15] D. Lusheng and D. Yongxin, "The relationship between prof essional commitment, learning burnout and learning engagement of undergraduates," *China J ournal of Health Psychology*, vol. 14, no. 4, pp. 407–409, 2008.

[16] X. Youyun, "Learning burnout and coping style of undergraduates," *China Journal of Health Psychology*, vol. 15, no. 3, pp. 246–251, 2007.

[17] E. J. Fishman and J. Husman, "Extending attribution theory: considering students' perceived control of the attribution process," *Journal of Educational Psychology*, vol. 109, no. 4, pp. 559–573, 2017.

[18] B. Weiner, "Achievement Motivation and Attribution Theory," *Review of Educational Research*, vol. 42, 1974.

[19] Z. Aiqing, "New advances in attributional theory," *Educational Research and Experiment*, vol. 21, no. 1, pp. 38–41, 2003.

[20] C. Na, *A Study on School Adaptation and Self-Concept of Junior High School Students*, Southwest University, Chongqing, 2008.

[21] H. Qiao and D. Chunlin, "A research on middle school students' learning burnout structure," *Psychological Science*, vol. 30, no. 1, pp. 162–164, 2007.
[22] J. E. Juvonen and K. R. Wentzel, *Social Motivation: Understanding Children's School Adjustment*, Cambridge University Press, UK, 1996.
[23] B. K. Hamre and R. C. Pianta, "Early teacher-child relationships and the trajectory of children's school outcomes through eighth grade," *Child Development*, vol. 72, no. 2, pp. 625–638, 2001.
[24] D. Zengyun, "Relationship between Personality,Social support and university adaptation of college students," *Chinese Journal of Clinical Psychology*, vol. 11, no. 5, pp. 642–648, 2010.
[25] K. E. Perry and R. S. Weinstein, "The social context of early schooling and children's school adjustment," *Educational Psychologist*, vol. 33, no. 4, pp. 177–194, 1998.
[26] I. O. Ezenwaji, C. Eseadi, S. C. Ugwoke et al., "A group-focused rational emotive behavior coaching for management of academic burnout among undergraduate students," *Medicine*, vol. 98, no. 30, Article ID e16352, 2019.
[27] R. Zhang, M. Jun, and S. Palacios, "M-shopping Service Quality Dimensions and Their Effects on Customer Trust and Loyalty: An Empirical Study," *International Journal of Quality & Reliability Management*, 2021.
[28] A. S. Masten and F. Motti-Stefanidi, "Multisystem resilience for children and youth in disaster: reflections in the context of COVID-19," *Adversity and resilience science*, vol. 1, no. 2, pp. 95–106, 2020.
[29] M. Gerber, A. K. Feldmeth, C. Lang et al., "The relationship between mental toughness, stress, and burnout among adolescents: a longitudinal study with Swiss vocational students," *Psychological Reports*, vol. 117, no. 3, pp. 703–723, 2015.
[30] J. Davidson, J. Dunne, J. S. Eccles, A. Engle, M. Greenberg, and D. Vago, "Mind and life education research network (MLERN):,Contemplative practices and mental training: prospects for American education," *Child development perspectives*, vol. 6, no. 2, pp. 146–153, 2012.
[31] E. Aprile, J. Aalbers, F. Agostini et al., "Physics reach of the XENON1T dark matter experiment," *Journal of Cosmology and Astroparticle Physics*, vol. 22, no. 4, p. 027, 2016.
[32] X. Haiying, "Attribution theory of achievement motivation and teaching reform," *School of Educational Science , Shandong Teachers' University*, vol. 12, no. 6, pp. 55–59, 2000.
[33] M. E. McCarthy, G. M. Pretty, and V. Catano, "Psychological sense of community and student burnout," *Journal of College Student Development*, vol. 31, 1990.
[34] G. Shuang, "Characteristics of learning burnout and its prevention," *Modern Communication*, vol. 7, no. 1, pp. 98-99, 2017.
[35] P. Sigley-Taylor, T. Chin, and D. A. Vella-Brodrick, "Do subjective and objective resilience measures assess unique aspects and what is their relationship to adolescent well-being?" *Psychology*, vol. 58, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9772416, 12 pages
https://doi.org/10.1155/2022/9772416

Research Article

The Impact of Artificial Intelligence and Digital Economy Consumer Online Shopping Behavior on Market Changes

Ying Xiong

Business School of Dongguan City University, Dongguan, Guangdong, 523000, China

Correspondence should be addressed to Ying Xiong; xiongy@ccdgut.edu.cn

Received 14 March 2022; Accepted 22 April 2022; Published 17 May 2022

Academic Editor: Lele Qin

The rapid development of online technology has facilitated the gradual growth and development of e-commerce and online marketing, creating a new business model and new opportunities. This has had a major impact on the future development of the market economy and the international competitiveness of companies and countries. At the same time, its appearance has also subverted the traditional retail market, and the convenience, reliability, and security of payment have been quickly recognized by people. Technological innovations represented by artificial intelligence have driven the development of the digital economy for decades. In order to better strengthen the statistics of the online shopping market and promote the development of the real economy, this study discusses the analysis of consumer behavior in online shopping based on the market changes of artificial intelligence and digital economy. Through the questionnaire, it can be found that all age groups have been exposed to online shopping, most of them are young people, and the number of shopping per month is still concentrated between 4 and 11 times. The study also examined the size of China's online retail market and found that there were 820 million Internet shoppers in China by December 2021, which is forecast to be 910 million by 2022. The report also found that the B2C market share will reach nearly 61% in 2021 due to the B2C model featuring higher quality goods and more guaranteed services.

1. Introduction

As computer technology and the Internet develop rapidly, the number of people using computers and the Internet has increased dramatically, and the Internet has become the main tool for people to access various resources and information. The number of Internet users accounts for 48.8% of China's total population. The widespread use of Internet technology marks the entry of human society into "network economy"; e-commerce is one of the main features of today and exposure to e-commerce has created the most direct connection between consumers and buyers. Buyers provide consumers with various information and sales activities directly through online channels. Manufacturers, wholesalers, retailers, and service providers have all seen significant improvements, resulting in a significant increase in the impact of business operations, which greatly increases the efficiency of marketing and transactions. In this situation, almost every business and consumer realize the need to switch from offline sales to online sales.

In the future, the main driving force for the development of China's digital economy will be artificial intelligence, and online transactions will be one of the important components of the digital economy. After more than 10 years of development, China's online shopping market has now entered a stage of prosperity. From the perspective of industry life cycle, the e-commerce industry with e-commerce platform as its main feature is currently in the rising stage of its life cycle. Online shopping is already one of the major developments in the modern digital economy; therefore, it is very important to monitor consumer behavior data for online shopping and predict market changes in a timely manner.

In terms of social development, the number of Internet users in China will continue to expand in the future, creating a very favorable market for the development of online shopping. A knowledge-based online shopping customer behavior analysis and prediction system is proposed to

address the above situation. The real-time prediction of online shopping customer behavior is accomplished based on the real-time browsing behavior data and personal data of customers, as well as the existing knowledge in the machine knowledge database.

2. Related Works

In order to study the transaction situation of modern consumers' online shopping, many scholars have conducted research in this area. Park and Lee leverage online home shopping by extending its online services (telephone, ARS, and Internet site) to mobile platforms. Four years of transaction data were obtained by the provider, using a multivariate probability model including sociodemographic variables, communication strategy, ordering time, and product group. Results show that age and gender significantly influence channel choice behavior [1]. The study by Krasonikolakis et al. is related to online retailing and seeks to examine the impact of shopping environment in retail climate on the behavior of consumers in a three-dimensional online shopping environment, focusing on store design as the main influencing factor [2]. The major aim of the project by Díaz et al. is to analyze the differences among online and offline consumer behaviors. The results show that there is a link that exists between the use of technology and its impact on behavior. The link was stronger between values and actions and between behaviors and future intents than the influence of lifestyle on behavior [3]. Xu et al. examined the factors influencing consumer behavior during the World Online Shopping Carnival (OSC) such as Double 11. Using theories of binge and herd behavior, an explanatory model was developed to explain how informational motivation and social influence affect consumers' OSC behavior. Herd behavior is a special kind of irrational behavior, which refers to the behavior of being influenced by others, imitating others' decision-making, or relying too much on public opinion without considering their own information when the information environment is uncertain. Partial least squares (PLS) regression was employed to validate the conceptual mold. Partial least squares is a mathematical optimization technique that finds the best functional fit for a set of data by minimizing the sum of squares of errorsSome absolutely unknowable truth values are found in the simplest way, while minimizing the sum of squared errors. Results show that engagement, interactivity, and acceptability jointly influence consumers' OSC-related behavior [4]. Chiou et al. examine customer-selling partnerships, customer acceptance of online store shopping, and their impact on customer attitudes toward multi-channel shopping behaviors when companies decide to build online stores. The results show that buyer-seller partnerships significantly reduce shoppers' attitudes toward offline shopping but not online shopping. The adoption of online shopping has a significant impact on buyer attitudes [5]. Singh and Katiyar explore an online shopping system that allows shoppers to order goods and services online from individual stores and online shops. The online shopping system displays the customer's selected goods order with the associated due date and delivery window. The customer browses and makes changes to the order, but it has not been widely used [6]. Lee and Wu investigate the virtual experience of consumers in an online shopping environment and use participating online consumers to explore how consumers' desire influences customer satisfaction and unplanned shopping behavior to create valuable shopping relationships. Results show that perceived flow control and attentiveness positively influence consumers' utilitarian value, while attentiveness and cognitive enjoyment positively influence hedonic value [7]. Weeks et al. use behavioral statistics gathered on a popular social networking site (Polyvore.com) from its two neighbourhoods. By studying consumer behavior in curating on social shopping sites, style brand managers can better understand how consumers shape their perceptions of brands collectively [8]. International online shopping (IOO) is a concept. Ramkumar and Ellie Jin experimentally tested a two-stage theoretical model of U.S. consumer behavior in Chinese and UK e-commerce and found that trust positively influences initial e-commerce intention in these two countries [9]. Duarte et al.'s study aimed to determine the components of online shopping expediency that influence the online shopping preferences of consumers, and the findings extend earlier work on online expediency and contribute to the overall understanding of the factors that contribute to online satisfaction and improved behavior [10]. Driediger and Bhatiasevi's research is one of the earliest studies to investigate Thai people's receptive and usability behavior toward online shopping. The results obtained using partially minimal solution structural formula modeling (PLS-SEM) indicate that a statistical link between percentages of perceived usability, perceived usefulness, intention to use, topic norms, subjective norms, and perceived pleasantness was found to be correlated with the acceptance of online shopping among Thais [11]. It is clear that the Internet has fundamentally changed retail practices, both in terms of consumer and business behavior, and the Nisar and Prabhakar's study aimed to analyze customer satisfaction in the e-business market. Findings indicate that in terms of spending abroad, there is an immediate link between online service quality, online satisfaction, and online loyalty. Yet, the results of the analysis indicated that e-commerce still suffers from some problems than conventional retail outlets offline because customers are unable to try and test offerings and might eventually select offerings, which they would not desire [12]. Rogus et al. provided policy recommendations for online shopping for Supplemental Nutrition Assistance Program (SNAP) welfare through a study of SNAP recipients' behaviors, beliefs, and attitudes. Costs were particularly affected by quality control of porous foods and mistrust of the total process. Participants reported interest in advisory services to augment the benefits of online grocery shopping [13]. The above studies have conducted a detailed analysis of online shopping. It is undeniable that these studies have greatly promoted the development of the corresponding fields. We can learn a lot from methodology and data analysis. However, there are relatively few studies on online shopping in the field of artificial intelligence and digital

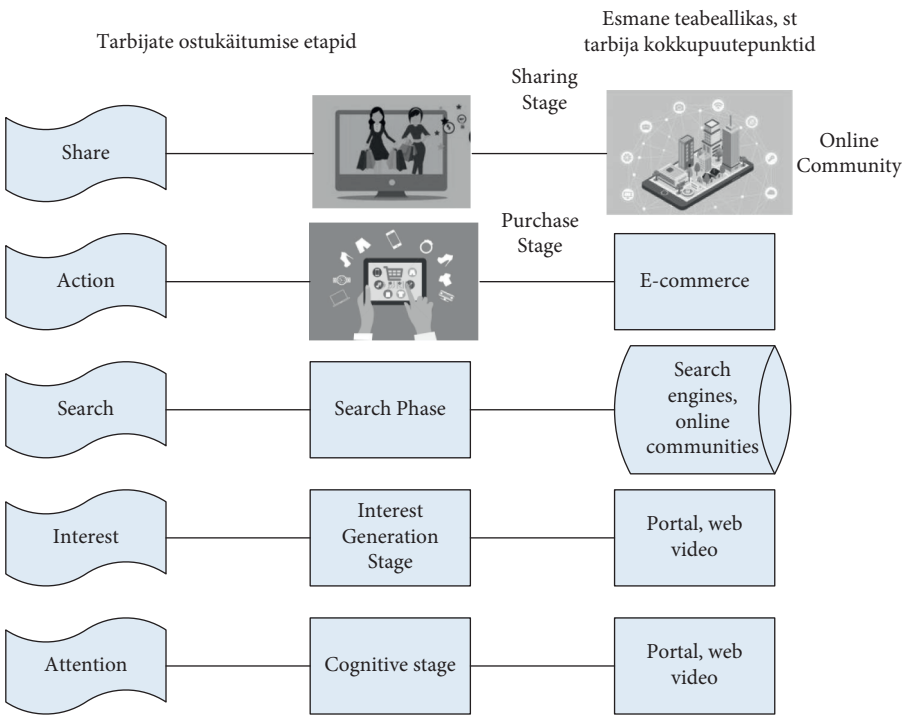


Figure 1: Consumers have online touchpoints at different stages of purchase.

economy, and it is necessary to fully apply these algorithms to the research in this field.

3. Methods and Models

3.1. Artificial Intelligence and Digital Economy. Online shopping is the purchase of goods through the Internet, which is a typical shopping behavior in the Internet environment. Traditional consumer behavior surveys use the following indicators to measure purchase behavior: product brand purchased, quantity purchased, and cost spent, mainly measured by current purchase behavior [14].

It can be said that in the 21st century, Internet technology has the greatest impact on economic and social development. Its rapid development has brought unprecedented vitality and opportunities to the global economy, especially the use and development of the Internet and business technologies, and it has also facilitated network marketing using Internet technologies [15]. Because e-commerce has the main advantages of low cost and high efficiency, the emergence and rapid development of e-commerce have brought a new consumption method for netizens—online consumption. This has also brought about major changes in their consumption behavior, norms, and status and promoted the dominance and purchasing freedom of Internet consumers, while also rationalizing their purchasing decisions [16]. In recent years, both the number of Internet users and the number of online shopping have been increasing year by year.

Today, customers have become the core of the company's development and competitiveness and the source of company value. With a large population, China has a huge potential for growth in the quantity and scale of the consumer electronics market. Although Internet technology and network application technology have developed rapidly in recent years, they still lag behind the developed countries such as Europe, USA, and Japan [17].

Consumers are the product of the times. Different historical and cultural environments, especially different media environments, have created different user groups. Online audience buying behavior usually goes through several stages: product awareness stage, product interest stage, product information collection and comparison stage, product purchase stage, and product purchase and use stage to share experiences with others. In the product awareness and product interest stage, the main exposure is the integrated portal and web video. In the product information search stage, the main contact is with search engines and online communities; in the purchase stage, the main contact is with e-commerce websites; after using the product, the main contact is with the online community. As shown in Figure 1, external information is required to support brand or product information in both the preconsumption and postconsumption stages. Each website provides different brand or product information, some directly promote the brand, and some directly sell. While the brand or product message delivered at each stage will vary, each stage requires accurate publicity and the right message strength to achieve the perfect media mix.

The basic course of buying goods electronically from the consumer's point of view can usually take place in terms of three levels: preparations leading up to the purchase, purchase, and postpurchase communication. The preparatory tasks before purchase include gathering information, finding

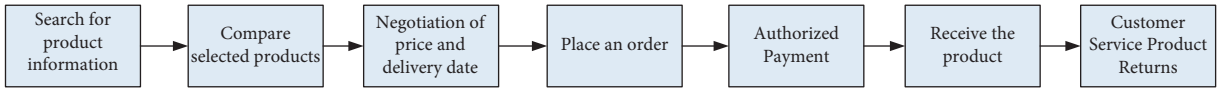


Figure 2: Basic flow chart of online shopping.

Table 1: Comparison of online shopping with other shopping methods.

	Diversity of products	Interactivity	Not controlled by business hours	Trial availability	After-sales service
Internet shopping	1	2	1	2	2
TV shopping	3	4	2	3	3
Mailing	4	3	3	4	4
Malls	2	1	4	1	1

the right product line for the needs, and selecting the product after comparison; the buying stage includes the circulation of information and related products and the negotiation of price and delivery method between buyers and sellers, selecting payment method and term. After-sales communication, including after-sales service provision, complaint handling, and product return, is shown in Figure 2.

Online shopping is the development and supplement of traditional shopping. In this sense, the traditional and network factors that affect consumers' shopping behavior have a common scope and are similar. When consumers choose traditional purchasing methods, the choice of retailers or stores usually takes into account factors such as their geographical location, store traffic location, sales network circulation, and store word-of-mouth and product advertisements. The choice of shoppers for online shopping is mainly reflected in the choice of commercial websites. Key factors to consider are the size of the site, the adequacy of the product information provided, and the availability of similar sites. In inclusion, as consumers selected conventional purchasing methods, they were primarily concerned with the quality of customer service and after-sales service at the time of purchase, the convenience of the shopping environment, and the exploration of the product during the purchase process. Consumers are increasingly concerned about online shopping, the security and privacy of information during the purchasing journey, and the usability and ease of the electronic shopping interface. In addition, from an individual point of view, purchasing experience and past purchasing experience influence the purchasing behavior of traditional consumers, while online experience and computer experience have a greater impact on online shop consumers. Table 1 presents a comparison of online purchases with other purchase methods (ranked in numerical order).

As can be seen from Table 1, a simple comparison between online shopping and other shopping methods shows that online shopping has the advantages of time saving, convenience, speed, interaction with consumers, and unlimited shopping time. However, there are shortcomings in the selection of products and samples.

Communication between businesses and consumers reduces the time lag between information and feedback, enabling businesses to provide consumers with adequate and effective information, thereby reducing the risk of asymmetric decision-making. When consumers actively collect and analyze information, they can make psychologically balanced purchasing decisions, reduce their sense of risk, and increase their confidence in products.

A system was developed for analyzing and predicting customers' online buying behavior. The architecture of the system is shown in Figure 3. According to the architecture scheme, the system is divided into three subsystems, namely, customer knowledge acquisition subsystem, knowledge service subsystem, and real-time customer behavior prediction subsystem. The main function of the customer knowledge acquisition subsystem is to acquire knowledge to predict customer behavior and transfer the acquired knowledge to the knowledge service subsystem. The main function of the knowledge service subsystem is to organize and store the knowledge obtained by the customer acquisition subsystem and provide cognitive support for the customer behavior prediction subsystem in real time. The real-time customer behavior prediction subsystem mainly analyzes the products browsed by customers in the current visit behavior and completes the real-time customer behavior prediction according to the knowledge in the knowledge base.

From a technical point of view, payment security and privacy are key issues and critical issues in Internet marketing. Business security is currently among the top factors affecting the development of e-commerce, and it is very critical to all aspects of online shopping. Ensuring that trade secrets are not disclosed or stolen, database confidentiality, fraud prevention, safe operation of online transaction systems and buyer identification, credit, electronic signature verification, antifraud, and the safety of merchants when collecting money provides a theoretical basis for shaping the good attitude and behavior of consumers toward online shopping. In addition, the model will be extended and combined with other theories to better predict and explain consumer buying behavior to study consumer buying behavior. Based on perceived risk theory, perceived trust theory, and innovation diffusion theory (IDT), a widely extended online consumer purchase intention model has been developed, as shown in Figure 4.

Conjoint analysis is a multivariate statistical analysis method. It uses quantitative analysis features to study consumers' purchasing preferences, in particular, to assess

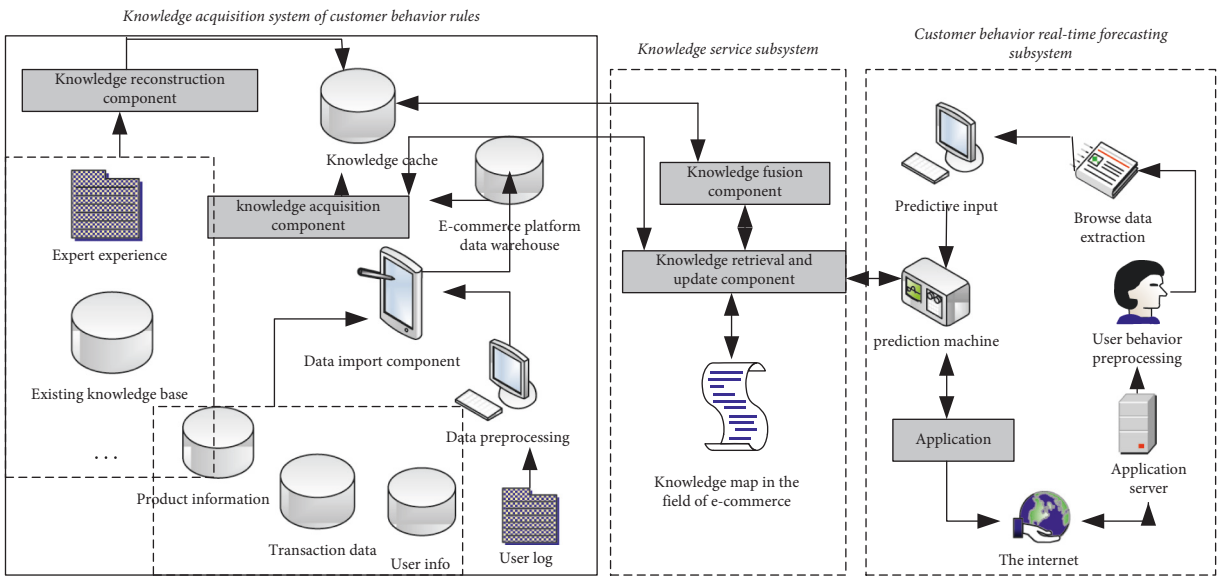


Figure 3: System architecture diagram.

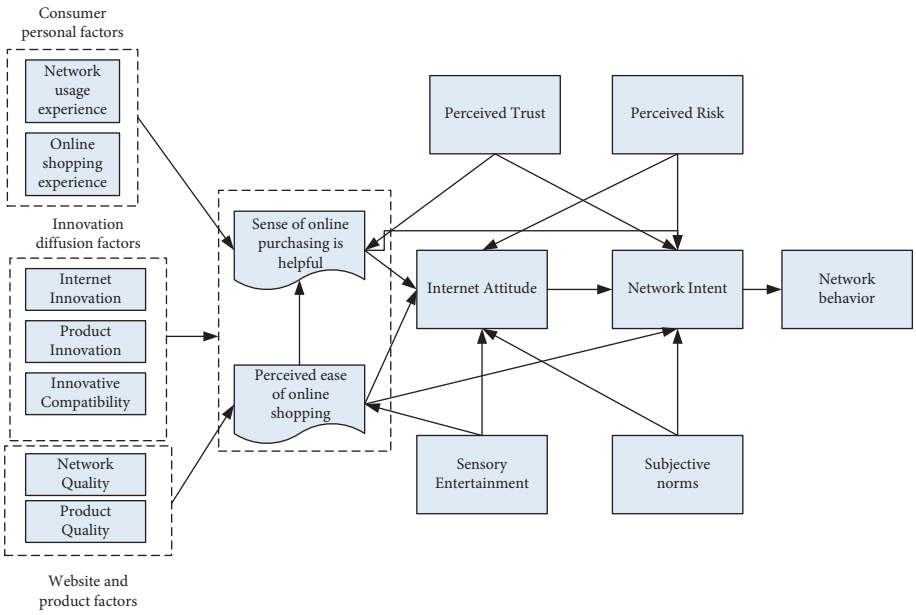


Figure 4: Extended model of consumer online shopping intention.

the overall level of preference, the relative importance of different product features in consumer preferences, and the level of utility that each level of feature can provide to consumers. The conjoint analysis calculates preference scores, weights, and desirability scores by asking consumers to rate some product profiles. Although not originally designed for marketing research, it has become one of the most popular tools in consumer research due to its unique advantages.

When using the conjoint analysis method, the terms that are often used are as follows:

(1) *Attributes*. Attributes are indicators or main characteristics of a product or service that may affect consumer behavior decisions. For example, online commodity prices and online purchase evaluations in this article are attributes of group-buying products.

(2) *Level of Attribute*. There are different values of product attributes, and the level of the attribute price can be below 100 yuan, 100–200 yuan, etc.

(3) *Full Profiles*. Full profiles are all combinations of product or service levels.

(4) *Utility Functions*. Utility functions describe the utility value given by consumers to each profile, in which layman's terms mean the effect on consumer behavior preference.

(5) *Relative Importance of Weights*. When consumers make purchasing decisions, the relative importance of weights describes the importance of the attributes of products or services on consumers' purchasing decisions.

(6) *Internal Validity*. The degree of correlation between the user assessment tool and the prediction tool indicates the reliability of the survey results.

(7) *Maximum Validity Simulation*. The most common market segment simulation model, the highest utility simulation, assumes that consumers will definitely buy the highest value product or service and make a choice when making a purchase decision.

Users appreciate feature-level usage through a variety of features and different levels of selection in product images. The product is expected to have some key characteristics, the actual results are simulated and combined, the user evaluates or evaluates the substantive product combination according to their own preferences, and finally, the multivariate statistical analysis method is used to compare these attributes. There is a distinction between each attribute and each attribute level. Feature-level functions are used to describe the importance of each feature in each product profile, and horizontal utility predictions are used as independent variables:

$$S = w + \sum_{i=1}^{p}\sum_{j=1}^{q} v_{ij}x_{ij}, \tag{1}$$

where S represents the full-profile preference score, w represents the utility value of the consumer choice profile, v_{ij} represents the j-th estimated high-level usefulness of the i-th parameter, and x_{ij} represents the j-th estimated level utility of different attribute levels:

$$x_{ij} = \begin{cases} 1, & \text{The } j\text{th level of the } i-\text{th attribute} \\ 0, & \text{Other} \end{cases}. \tag{2}$$

The relative importance of an attribute is usually considered to be the bigger the variance of the horizontal utility value of the attribute, indicating that users prefer it, the more important the attribute is. Conversely, an attribute has little impact on consumers' purchasing decisions. Usually, the difference between the price of the highest-level attribute and the price of the lowest-level attribute is the difference below the attribute, and the formulas are shown in formulas (3) and (4):

$$R_i = \left\{\text{Max}\left(v_{ij}\right) - \text{Min}\left(v_{ij}\right)\right\}, j = 1, 2, \ldots, m. \tag{3}$$

$$w_i = \frac{R_i}{\sum_{i=1}^{m} R_i}, \quad i = 1, 2, \ldots, m, \tag{4}$$

where i stands for the quantity of attributes, j stands for the quantity of levels, R_i stands for the importance of product attributes, and w_i stands for the relative importance of attributes among those of total properties. $\text{Max}(v_{ij})$ stands for the value of an attribute's utility at the greatest level and $\text{Min}(v_{ij})$ stands for the valuation of an attribute's utility at the smallest level.

The summation type model is the least sophisticated model for calculating the whole spectrum of joint contour utilities. Generally speaking, a combined profile utility is to add up the utility values of each attribute. Here is the most commonly used model—the linear vector model:

$$U_c(x) = w + \sum_{i=1}^{p}\sum_{j=1}^{q} w_i v_{ijc} x_{ijc} c = 1, 2, 3, \ldots, m, \tag{5}$$

where i represents the number of attributes, j represents the total number of profiles, and w represents the utility value when consumers do not choose profiles, which is a constant. $U_c(x)$ represents the total utility value of the c-th profile, w_i represents the religious value of the i-th parameter, and v_{ijc} represents the utility value of the j-th level of the i-th profile of the c-th profile:

$$x_{ijc} = \begin{cases} 1, & \text{The } j\text{th level of the } i-\text{th attribute of the c}-\text{th contour} \\ 0, & \text{Other} \end{cases} \tag{6}$$

There are three main modeling methods for segmented market share: BTL module, logit module, and maximum utility model, of which the most widely used is the maximum utility model. The greatest possible model of utility presumes the idea that shoppers will always buy what they think is the best value for money. If U is the maximum utility value of the product's overall benefit function, then the probability that the consumer chooses the product is 1; otherwise, it is 0. We calculate the average probability value of all consumers choosing the product and use T to simulate the market share of the product portfolio:

$$T = \frac{\sum_{i=1}^{N} 1/n\text{pi}}{N}, \tag{7}$$

where n is the number of people who are estimated to have the maximum utility for all products. N is the total number of people who participated in the survey:

$$p_i = \begin{cases} 1, & \text{When} U_c = \max\{U_c(x)\} \\ 0, & \text{When} U_c \neq \max\{U_c(x)\} \end{cases}. \tag{8}$$

The results of joint analysis, including attribute significance analysis and attribute utility value analysis, are interpreted and analyzed. The results of the analysis can be interpreted from the perspective of a single user, the preferences of each user can be examined, the usefulness and importance of attributes at different levels can be measured, and whether each user is significantly different in the product can be measured. Group effects can also be analyzed, and the results of group analysis can also be divided into groups, allowing important or useful groups of users, identifying market segments, and estimating market shares for different target markets, to analyze product profit margins, allow market segmentation, and identify the largest, profitable product bundles, as well as assess the achievable market share for all product bundles.

The TOPSIS method is a widely used method for analyzing multipurpose terminal solutions. The basic principle is to sort by detecting the distance between the evaluation object and the optimal solution and the worst solution. If the evaluation object is closest to the optimal solution and farthest from the worst solution, it is the best; otherwise, it is not optimal. Among them, each index value of the optimal solution reaches the optimal value of each evaluation index. Each index value of the worst solution reaches the worst value of each evaluation index. It is also known as the upper and lower level resolution method. It can be explored by studying the correlation between customer attributes and the products the customer wants to buy. Suppose there are q evaluation items and p evaluation indices, $X_{ij}(i = 1, 2, \ldots, q; j = 1, 2, \ldots, p)$ represents the value of the i-th item to the j-th index.

The steps to solve the problem using the TOPSIS algorithm are as follows:

Step 1. Building the original matrix.

According to the original data, the corresponding matrix A can be established:

$$A = \begin{bmatrix} X_{11} & X_{12} & \ldots & X_{1p} \\ X_{21} & X_{22} & \ldots & X_{2p} \\ \ldots & \ldots & \ldots & \ldots \\ X_{q1} & X_{q2} & \ldots & X_{pq} \end{bmatrix}. \tag{9}$$

Step 2. Preprocessing the matrix data.

With the TOPSIS method for evaluation, the direction of change should be consistent, that is, the same trend. High-quality indicators (benefit indicators) can be converted to low-quality indicators (cost indicators), and vice versa; the latter is often used. The low-quality indicators are converted to high-quality indicators using formula (10), and the original data table is also determined. The same data are processed as shown in formula (11):

$$X_{ij}' = \frac{1}{X_{ij}}, \tag{10}$$

$$X_{ij}' = \begin{cases} X_{ij} \text{ High} - \text{performance indicators} \\ \dfrac{1}{X_{ij}} \text{ Low} - \text{performance indicators} \end{cases}, \tag{11}$$

where X_{ij}' stands for the j-th index upon reciprocity of the i-th evaluation object.

Step 3. Calculating the original data matrix of the same trend, and the calculation method is shown in the following formula:

$$T_{ij} = \begin{cases} \dfrac{X_{ij}}{\sqrt{\sum_{i=1}^{q}\left(X_{ij}\right)^2}} \text{ (Original high superiority index)} \\ \dfrac{X'_{ij}}{\sqrt{\sum_{i=1}^{q}\left(X_{ij}\right)^2}} \text{ (Former low or neutral indicator)} \end{cases}. \tag{12}$$

From this, the normalized matrix is obtained as follows:

$$T = \begin{bmatrix} T_{11} & T_{12} & \ldots & T_{1p} \\ T_{21} & T_{22} & \ldots & T_{2p} \\ \ldots & \ldots & \ldots & \ldots \\ T_{q1} & T_{q2} & \ldots & T_{pq} \end{bmatrix}. \tag{13}$$

Step 4. Finding the best and worst-case vectors. That is, based on a finite number of best and worst-case solutions of matrix T, the best solution T^+ consists of the maximum value of each column of T, as shown in the following formula:

$$T^+ = \left(\max T_{i1}, \max T_{i2}, \ldots, \max T_{ip}\right) 1 \le i \le n. \tag{14}$$

The worst-case scenario Z− consists of the minimum value in each column of Z, as shown in the following formula:

$$T^- = \left(\min T_{i1}, \min T_{i2}, \ldots, \min T_{ip}\right) 1 \le i \le n. \tag{15}$$

Step 5. Calculating the distances of all the index values of the evaluation objects and the optimal plan R_i^+ and the worst plan R_i^-, respectively:

$$\begin{aligned} R_i^+ &= \sqrt{\sum_{j=1}^{p}\left(\max T_{ij} - T_{ij}\right)^2}, \\ R_i^- &= \sqrt{\sum_{j=1}^{p}\left(\min T_{ij} - T_{ij}\right)^2}. \end{aligned} \tag{16}$$

If each indicator has a weight W_{ij}, then the distance formula is as follows:

$$\begin{aligned} R_i^+ &= \sqrt{\sum_{j=1}^{p} W_{ij}\left(\max T_{ij} - T_{ij}\right)^2}, \\ R_i^- &= \sqrt{\sum_{j=1}^{p} W_{ij}\left(\min T_{ij} - T_{ij}\right)^2}, \end{aligned} \tag{17}$$

where W_{ij} is the weight coefficient of the j-th indicator.

Step 6. Calculating the closeness K_i of the evaluation objects to the optimal solution. The calculation formula is shown in the following formula:

$$K_i = \frac{T_i^+}{T_i^+ + T_i^-} 0 \le K_i \le 1. \quad (18)$$

Step 7. Sorting each evaluation object according to the size of K_i to obtain the optimal solution.

The basic idea of using a Markov model is to draw conclusions about future movement trends from past commodity movement patterns. The steps are as follows:

(1) Predicting the sales rate of each type of online product based on historical data, and redistributing the sales rate to the shift matrix.

(2) Calculating the distribution of different types of transactions as a starting point.

(3) Building a Markov model to predict the future supply of each commodity.

The key to using the Markov model to predict the availability of goods online is to determine the table of sales rates of goods. In actual forecasting, due to the influence of various factors, it is difficult to accurately determine the sales rate of goods, and it is often a rough estimate, which affects the accuracy of the forecasting results.

The prediction subsystem is one of the core components of the prediction system, which realizes the real-time behavior prediction of the current user. Its specific working principle is as follows: the system monitors the current browsing status of customers, and when the user visits a specific product page, the customer behavior prediction process is started. The system obtains the browsing data of the customer at this time and the personal information data of the customer. Taking these two parts as the input of the prediction machine, the prediction machine obtains the most likely product sequence that the user purchases based on the input and the knowledge in the knowledge graph. Its prediction flow chart is shown in Figure 5.

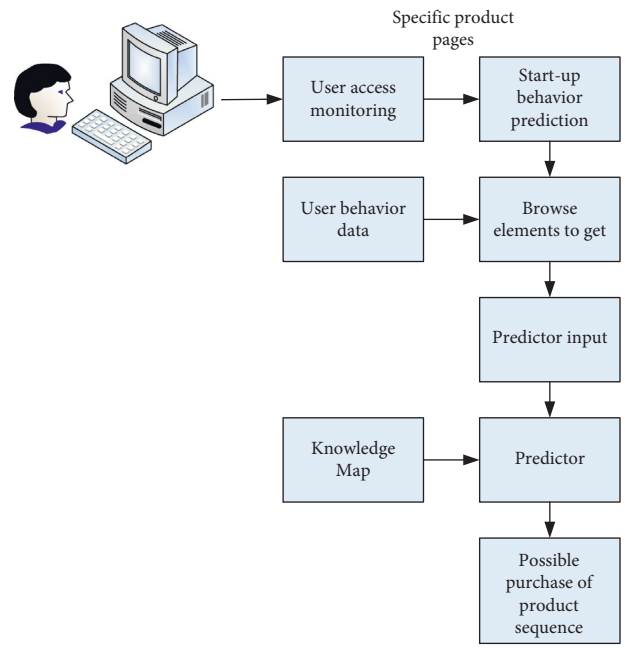


Figure 5: Prediction flow chart.

3.2. Model Design of Consumer Online Shopping Behavior. Online shopping is essentially a social exchange between consumers and retailers in an online environment. The main body of the market is the consumer, and the consumer is the key force that determines the survival and development of the enterprise. The consumer's demand has a fundamental impact on the enterprise's marketing decision and becomes the basic basis for the enterprise to choose the marketing strategy. Therefore, the characteristics of the two main actors involved in online commerce, consumers, and e-merchants, inevitably affect the possibility of e-commerce between them, that is, online shopping. Consumers choose online shopping mainly because it is more convenient and time saving than physical shopping. Socially oriented customers may be less keen on the e-shop format. The Internet is the backdrop for online transactions, so it is clear that the security and privacy issues that affect online transactions also affect consumer behavior when shopping online. The impact of consumer characteristics, consumer demographics, e-merchant characteristics, and security and privacy issues in online transactions on consumer behavior when shopping online will be analyzed and used to guide future research. Figure 6 shows a model of factors influencing online shopping.

In order to understand the current situation of consumers' online shopping, this study investigates the consumption of online shopping in district A. About 100 netizens were randomly selected as research objects for research, and descriptive statistics were used to conduct statistical analysis on the information of 100 investigators. The details of the outcomes are listed in Table 2.

4. Data Analysis and Results

Figure 7 shows the educational background and monthly income of the respondents, and Figure 8 shows the online shopping of the respondents. A month in the statistics below refers to a normal month, excluding shopping festivals, such as Double 11.

Most young people prefer to surf the Internet and understand the online shopping process; their educational backgrounds are concentrated in college and undergraduate degrees, accounting for 92.7%. This group of them is familiar with group buying and uses it frequently. The shopping expenses are mainly concentrated on catering, cosmetics, clothing, daily necessities, and other products. Students do not have a fixed source of income yet. Most students have no monthly income, and others concentrate on 2000–5000 yuan. This part of the group has a certain economic income and is relatively price sensitive. However, the number of shopping is still concentrated between 4 and 11 times, and the number of more than 15 times is relatively small. Table 3 lists the monthly spending on online shopping of respondents of different age groups.

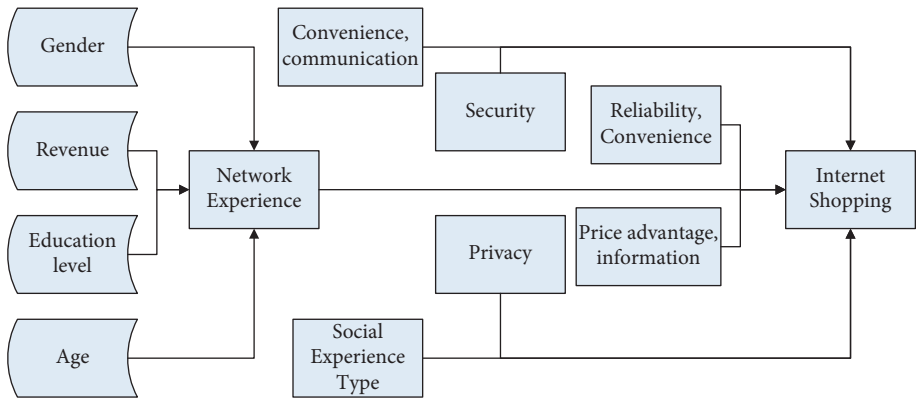


Figure 6: Model of influencing factors of online shopping.

Table 2: Basic information of respondents.

Age	Male	Female
Under 20 years old	12	8
20–25 years old	20	28
26–35 years old	8	10
Over 36 years old	6	8

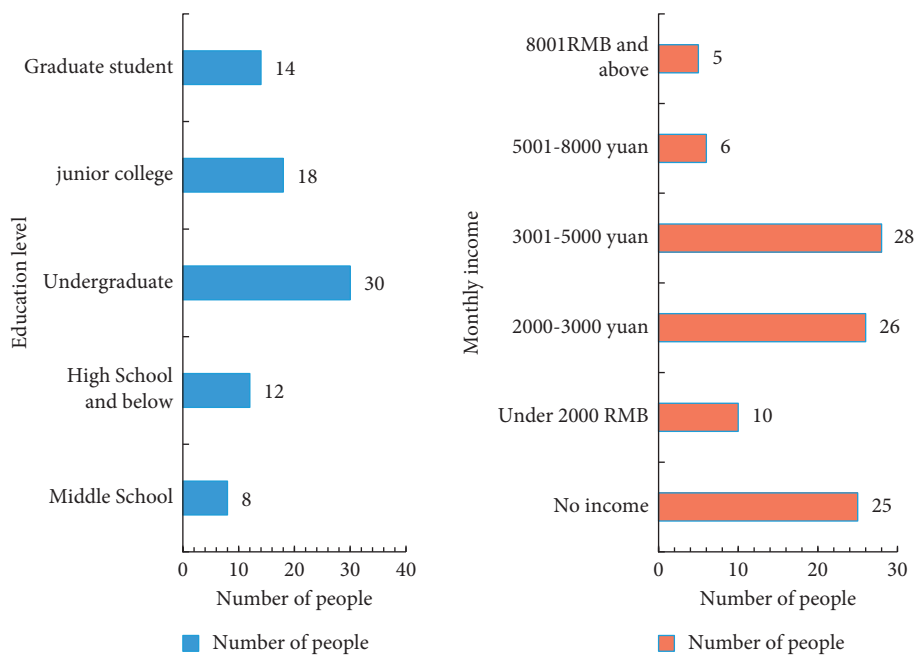


Figure 7: Respondents' educational background and monthly income.

In this study, we take the data of the past three months and the past six months respectively and compare the prediction results in the customer shopping behaviors prediction system with the traditional Markov model-based customer behaviors prediction results. We conducted 5 groups of prediction experiments and comparisons, and the times of each group's prediction of customer online shopping behavior were 3 times, 6 times, 9 times, 12 times, and 15 times, respectively. The corresponding comparison diagram is shown in Figure 9.

The horizontal axis in Figure 9 shows the number of customer behavior predictions for each test group, while the vertical axis shows the average error of each test group prediction. From Figure 9, we can see that the prediction error of the customer shopping behavior prediction system in this study is smaller than the prediction error of the traditional Markov model. Because the system has user access status monitoring, users will predict customers every time they visit a specific product page, which reflects the real-time prediction of users. After adding customer

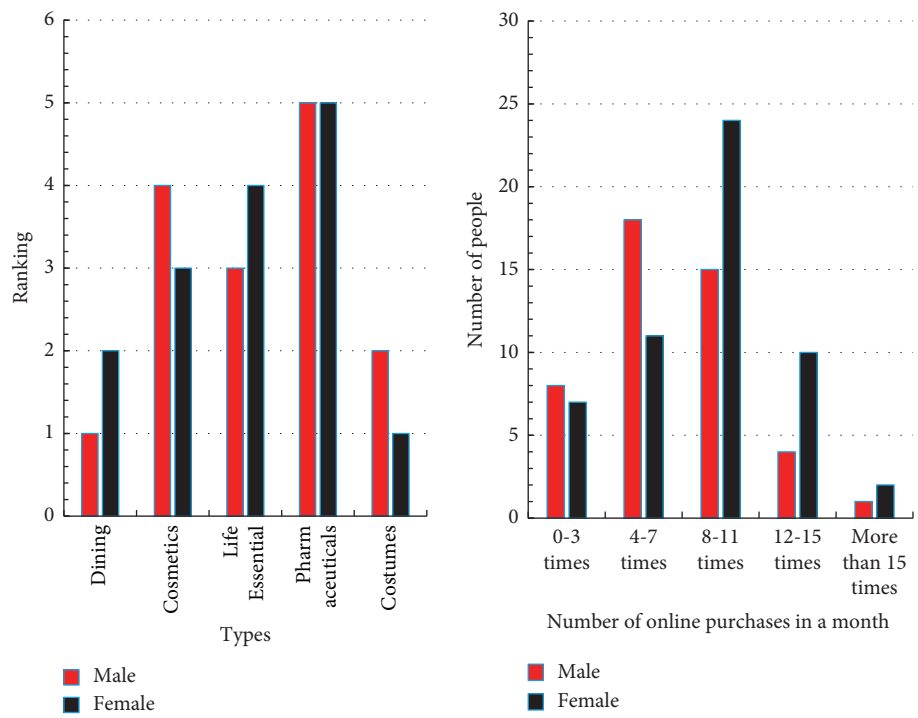


Figure 8: Online shopping of respondents.

Table 3: Amount spent on online shopping in one month by respondents of different age groups.

Age	Less than 50 yuan	50–250 yuan	250–500 yuan	500–1000 yuan	Over 1000 RMB
Under 20 years old	10	8	1	1	0
20–25 years old	2	20	15	5	6
26–35 years old	0	5	5	1	7
Over 36 years old	3	5	2	3	1

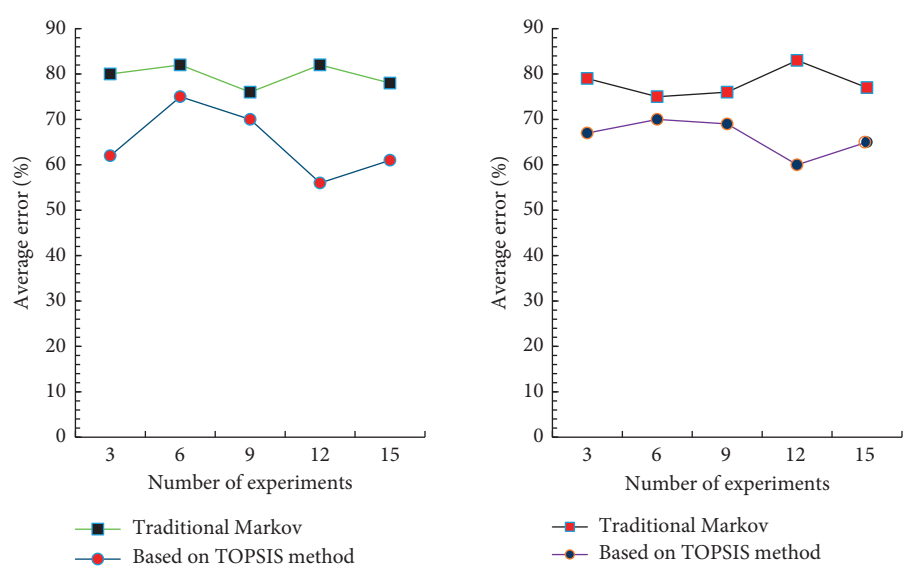


Figure 9: Comparison of forecast mean errors.

attribute information, it can provide customers with more personalized predictions. Figure 9 shows the superiority of the present system in terms of prediction accuracy.

B2C refers to the e-commerce model and the direct-to-consumer retailing of products and services in a commercial setting. The payment method is a combination of cash and

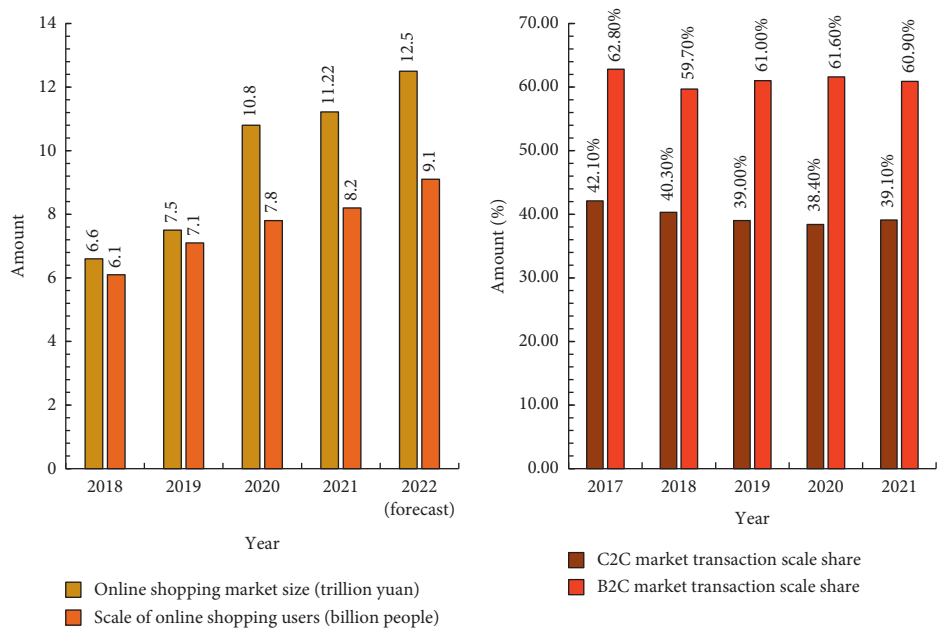


Figure 10: Market size of Internet shopper and comparison of B2C and C2C market shares in China.

electronic payments, and most businesses choose to outsource distribution to save on operating costs. C2C is a user-to-user direct business model, such as Taobao and Paipai. Figure 10 shows the market size of Chinese online shoppers and a comparison of B2C and C2C market shares.

By December 2021, the number of online shoppers in China will reach 820 million, an increase of 5% from the end of 2020. In 2018, the B2C market share of the total online shopping market in China was 40.3%, a slight decrease from 42.10% in 2017, mainly due to the rapid development of C2C social network stores such as Pinduoduo. In 2021, the B2C market share will reach nearly 61%, becoming a new growth driver for online shopping. Compared with C2C, due to the higher quality of goods and safer services, B2C has surpassed C2C in terms of growth rate and market share in recent years, becoming the main growth model of the online shopping market. In the background of modernized consumption, investors are more conscious of the product's reputation for the brand and good taste.

After nearly 20 decades of evolution and sophistication, the e-commerce industry has now reached the perfect stage of growth, which has undoubtedly dealt a major blow to the traditional retail industry. In recent years, it has been the sales of Internet celebrities and star products, and there are more like-minded people. There is also physical traffic brought by the sales of products. As long as the category selection is accurate and there are more adequate preparations, relatively good results can be achieved.

5. Conclusion

As a convenient sales channel, online shopping continues to rise in the total sales of consumer goods, becoming an important sales channel in China and injecting fresh blood into the market consumption economy. From refrigerators and TVs to food and clothing, and even cleaning services, all areas of life are easily accessible through online shopping. The development of the digital economy has become a common choice for major powers and regions in the world to reshape their global competitiveness. The transformation of the digital economy has improved traditional industries and developed emerging industries. The impact of e-shopping on the traditional retail market is reflected in reducing circulation costs and commodity prices, expanding the range of choices, accelerating commodity circulation, improving commodity circulation efficiency, and promoting logistics development. However, the impulse consumption brought by online shopping is prone to unnecessary waste. The quality of online merchants varies, and it is difficult to guarantee business integrity. There are loopholes in network information security, and personal information is easily leaked. It is necessary to improve the relevant laws of e-commerce, strengthen the supervision of the online market, and improve the identification ability of the public online shopping, so as to lead the online shopping market to a stable and healthy development. In the future, with the further advancement of 5G and other technologies, the market environment will continue to be optimized, the platform ecology will continue to improve, and the quality and brand will gradually improve. The large-scale development of e-commerce and social e-commerce is expected to be serious, which will continue to stimulate the consumption potential of China's online retail market.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] S. Park and D. Lee, "An empirical study on consumer online shopping channel choice behavior in omni-channel environment," *Telematics and Informatics*, vol. 34, no. 8, pp. 1398–1407, 2017.

[2] I. Krasonikolakis, A. Vrechopoulos, A. Pouloudi, and S. Dimitriadis, "Store layout effects on consumer behavior in 3D online stores," *European Journal of Marketing*, vol. 52, no. 5/6, pp. 1223–1256, 2018.

[3] A. Díaz, M. Gómez, and A. Molina, "A comparison of online and offline consumer behaviour: an empirical study on a cinema shopping context," *Journal of Retailing and Consumer Services*, vol. 38, pp. 44–50, 2017.

[4] X. Xu, Q. Li, L. Peng, T.-L. Hsia, C.-J. Huang, and J.-H. Wu, "The impact of informational incentives and social influence on consumer behavior during Alibaba's online shopping carnival," *Computers in Human Behavior*, vol. 76, pp. 245–254, 2017.

[5] J.-S. Chiou, S.-Y. Chou, and G. C. C. Shen, "Consumer choice of multichannel shopping," *Internet Research*, vol. 27, no. 1, pp. 2–20, 2017.

[6] M. Singh and A. K. Katiyar, "Consumers buying behavior towards online shopping-A study of literature review," *Asian Journal of Management*, vol. 9, no. 1, pp. 490–492, 2018.

[7] C. Lee and J. Wu, "Consumer online flow experience: the relationship between utilitarian and hedonic value, satisfaction and unplanned purchase," *Industrial Management & Data Systems*, vol. 117, no. 10, p. 1, 2017.

[8] J. B. Weeks, K. M. Smith, and J. Hulland, "Consumer brand curation on social shopping sites," *Journal of Business Research*, vol. 133, no. 4, pp. 399–408, 2021.

[9] B. Ramkumar and B. Ellie Jin, "Examining pre-purchase intention and post-purchase consequences of international online outshopping (IOO): the moderating effect of E-tailer's country image," *Journal of Retailing and Consumer Services*, vol. 49, pp. 186–197, 2019.

[10] P. Duarte, S. Costa e Silva, and M. B. Ferreira, "How convenient is it? Delivering online shopping convenience to enhance customer satisfaction and encourage e-WOM," *Journal of Retailing and Consumer Services*, vol. 44, pp. 161–169, 2018.

[11] F. Driediger and V. Bhatiasevi, "Online grocery shopping in Thailand: consumer acceptance and usage behavior," *Journal of Retailing and Consumer Services*, vol. 48, pp. 224–237, 2019.

[12] T. M. Nisar and G. Prabhakar, "What factors determine e-satisfaction and consumer spending in e-commerce retailing?" *Journal of Retailing and Consumer Services*, vol. 39, pp. 135–144, 2017.

[13] S. Rogus, J. F. Guthrie, M. Niculescu, and L. Mancino, "Online grocery shopping knowledge, attitudes, and behaviors among SNAP participants," *Journal of Nutrition Education and Behavior*, vol. 52, no. 5, pp. 539–545, 2020.

[14] Y.-P. Chiu, S.-K. Lo, A.-Y. Hsieh, and Y. Hwang, "Exploring why people spend more time shopping online than in offline stores," *Computers in Human Behavior*, vol. 95, pp. 24–30, 2019.

[15] H. Zhang, H. Feng, Y. Cui, and Y. Wang, "A fuzzy Bayesian network model for quality control in O2O e-commerce," *International Journal of Computers, Communications & Control*, vol. 15, no. 1, pp. 1–15, 2020.

[16] Z. Akhtar, "Digital technology, internet research and benefits of a virtual library," *International Journal of Legal Information*, vol. 48, no. 3, pp. 110–121, 2020.

[17] P. Zou, B. Hou, J. Lei, and Z. Zhang, "Bearing fault diagnosis method based on EEMD and LSTM," *International Journal of Computers, Communications & Control*, vol. 15, no. 1, pp. 1–14, 2020.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4691533, 11 pages
https://doi.org/10.1155/2022/4691533

Research Article

An Empirical Study on the Influence of Consolidated Financial Statement's Amplification Effect on Audit Fees

Ximing Zhan,[1] **Mengying Zhao**,[2] **and Lijuan Yan**[1]

[1]*Management College, Beijing Union University, Beijing, China*
[2]*Renmin Business School, Renmin University of China, Beijing, China*

Correspondence should be addressed to Lijuan Yan; gltyanlijuan@buu.edu.cn

Received 21 February 2022; Accepted 2 April 2022; Published 16 May 2022

Academic Editor: Lele Qin

As the investing enterprise brings the invested enterprise into the consolidation scope, the number of the items in the consolidated financial statements is enlarged relative to the parent company's financial statements, which is called the amplification effect of the consolidated financial statements. Using a sample of A-share listed companies in China from 2007 to 2019, this paper investigates the impact of consolidated financial statements' amplification effect on audit fees. We find that the amplification effect of consolidated financial statements is positively related to audit fees, and the audit risk plays a mediating role. More specifically, the amplification effect of consolidated financial statements increases the audit risk and then increases the audit fees. Furthermore, the effect is more significant in state-owned enterprises (SOEs). This study contributes to a comprehensive understanding of the economic consequences of accounting standards for consolidated financial statements.

1. Introduction

In China, the status of consolidated financial statements has been continuously improved and even has surpassed the individual financial statements of the parent company and has become a dominant player. For example, the consolidated financial statements are not only the primary basis for the State-owned Assets Supervision and Administration Commission (SASAC) of the State Council to evaluate the operating performance of the heads of central enterprises but also an essential basis for the China Securities Regulatory Commission (CSRC) to supervise listed companies and the China Banking and Insurance Regulatory Commission (CBIRC) to supervise related financial enterprises. Users' emphasis on the consolidated financial statements determines that the enterprise management has a strong motivation to manipulate the consolidated financial statements. What is more, under the "control standards" of the current accounting standards, there is a lot of manipulation space in determining the scope of consolidation in the consolidated financial statements. In practice, there are cases in which an investee is included in a consolidated financial statement with a particularly low shareholding ratio and cases in which an investee is not included in a consolidated financial statement with a particularly high shareholding ratio. The determination of the consolidation scope is highly uncertain and subjective, which poses a great challenge to independent audits and affects audit quality [1, 2]. For example, Konka Group (stock code: 000016) reported a net profit of 330 million yuan in 2019, of which 146 investees included in the consolidated financial statements have an impact of 890 million yuan. Compared to 2018, consolidation scope of Konka Group in 2019 increased by 56 investees and decreased by 18 investees. If the influence of these 146 investees is excluded, it will be difficult for Konka Group to turn losses into profits.

The standard for defining the scope of consolidation has undergone a transition from the "majority interest" to the "substantial control" [3]. According to "*China Accounting Standards for Business Enterprises No. 33-Consolidated Financial Statements (2014)*" (referred to as CAS33 (2014)), the consolidation scope of consolidated financial statements should be determined based on "control." That is to say, the parent company should incorporate its controlled subsidiaries into the consolidation scope and prepare consolidated financial statements to reflect the operating results, financial status, and cash flow of the entire enterprise group consisting of the parent company and all its subsidiaries. As an investment enterprise brings an invested enterprise into the scope of consolidated financial statements, the number of assets, liabilities, incomes, expenses, profit elements, cash inflow, cash outflow, and other statement items reflected in the consolidated financial statements are magnified compared with the individual financial statements of the parent company, which is called the amplification effect of consolidated financial statements (referred to as amplification effect). The amplification effect of the consolidated financial statements includes the amplification effect of the consolidated income statement, the consolidated balance sheet, and the consolidated cash flow statement.

Audit fees include the input of audit efforts, audit risk premium, and nonaudit risk premium [4, 5]. Prior literature has studied that the increase of the input of audit efforts and audit risk contributes to improving audit fees. The amplification effect could influence audit fees from the three following aspects: First, a more significant amplification effect means more professional judgment and greater subjectivity are applied in the preparation of consolidated financial statements, increasing the risk of material misstatement [2]. In addition, enterprises with a significant amplification effect require auditors to make more professional judgments, and auditing is more complicated. This requires the auditor to have a higher professional competence, and increases inspection risk. With the increase of material misstatement risk and inspection risk related to amplification effect, audit risk and corresponding audit fee increase. Second, audit institutions will expand the audit scope, add auditing procedures and working hours, and assign more experienced auditors when facing with high-risk clients [6]. Compared with companies with minor amplification effects, companies with large amplification effects have a higher risk, which will increase the audit input and lead to higher audit fees. Third, audit institutions are likely to face a higher risk of litigation or punishment when auditing companies with a large amplification effect. Auditors will demand a higher nonaudit risk premium to compensate for this additional risk.

Controversial studies on accounting treatment rules for consolidated financial statements mainly focused on whether consolidated financial statements are useful for decision-making and whether consolidated financial statements are more useful than the parent statements. The first stream of the literature is whether consolidated financial statements are useful for decision-making. One view holds no value relevance in the consolidated financial statements [3, 7, 8]. Another view is that consolidated financial statements are useful as they are an important basis for bank loan decisions and can play an early warning role in the financial crisis [9–12]. The second stream of the literature is whether consolidated financial statements are more useful than parent statements. The first view holds that the information content of consolidated financial statements is not better than that of parent statements [13–15]. The second view is that consolidated financial statements are more value-relevant than the statements of the parent company [16–18]. The third view is that the parent statement information and consolidated financial statements complement each other and provide useful information for stakeholders [19–21]. Among the existing studies on the accounting rules of consolidated financial statements, few studies focus on the amplification effect of consolidated financial statements and the influence on audit fees. Thus, this paper investigates the impact of amplification effect on audit fees by using Chinese A-share listed companies in Shanghai and Shenzhen from 2007 to 2019 as a sample.

This paper has three contributions. First, this paper creatively proposes the concept of amplification effect and empirically tests the relationship between the amplification effect and audit fees, which is helpful for a more comprehensive evaluation of the entity theory adopted by the accounting rules for consolidated financial statements. Second, this paper enriches the research on the influencing factors of audit pricing. The existing research on the influencing factors of audit pricing mainly focuses on the digital transformation of enterprises [22], investor sentiment [23], business and finance integration [24], customer relationship [25], and fair value measurement [2]; few studies research the impact of amplification effect on audit pricing. By investigating the impact of amplification effect on audit fees and its mechanism, this paper helps enrich the study of audit pricing influencing factors. Third, this paper provides empirical evidence for the essential role of property rights in corporate governance. Audit pricing results from negotiation between auditors and clients under specific circumstances [4]. This paper researches the differences in the impact of amplification effects on audit pricing under different property rights.

2. Literature Review and Hypothesis Development

2.1. Literature Review. Controversial studies on accounting rules for consolidated financial statements have focused on whether consolidated financial statements are helpful for decision-making and whether consolidated financial statements are more valuable than the parent company's financial statements.

There are two different views on whether the consolidated financial statements are helpful for decision-making. One view is that consolidated financial statements cannot provide helpful information for report users to make decisions [3, 7, 8]. Another view holds that consolidated financial statements are essential for bank loan decisions and can play an early warning role in a financial crisis. Therefore, they are useful [9–12].

There are three views on comparing the information value of the consolidated financial statements and that of the parent company. The first view holds that the information value of consolidated financial statements is not better than that of parent company statements [13–15]. The second view is that consolidated financial statements are more value-relevant than the statements of the parent company [16–18]. The third view is that the parent company's statement information and consolidated financial statements complement each other and provide valuable information for stakeholders [19–21].

The existing research on the economic consequences of the accounting rules of the consolidated financial statements mainly focuses on the decision-making usefulness of the consolidated financial statements [3, 12] and the comparative research on the decision-making usefulness of the consolidated financial statements and the statements of the parent company [18, 19]. Some studies suggest that defining the consolidation scope based on control standards brings greater discretion to the management. The enterprise management can determine the scope of the consolidation according to subjective intention [3, 8]. However, there is little literature on the amplification effect of the current accounting standards for consolidated financial statements in determining the consolidation scope based on the control standard.

The greater the amplification effect of the consolidated financial statements is, the more professional judgment is used to prepare the consolidated financial statements. As a result, there is more subjectivity, which will increase audit risk. In addition, accounting firms will expand the audit scope, improve audit procedures and working hours, and assign more experienced auditors when auditing high-risk customers [6]. Therefore, auditors may charge higher audit fees to make up for their risks and increased investment when they audit firms with greater amplification effect. This paper examines the impact of the amplification effect on audit fees and the mechanism of their relationship.

2.2. The Amplification Effects of Consolidated Financial Statements. The standard for determining the scope of consolidation in China's consolidated financial statements has roughly gone through the development process from "proportional standard" to "combination of proportional standard and control standard" and then to "control standard." The "*Accounting Standards for Business Enterprises No.33-Consolidated Financial Statements*" (referred to as *CAS33*) issued in 2006 stipulates that the consolidation scope of the consolidated financial statements shall be determined based on "control." *CAS33*(2014) redefines "control" as follows: the investor has power over the investee, enjoys variable returns by participating in the relevant activities of the investee, and can use its dominance over the investee to influence the number of its returns. Although the "control standard" helps the investor to determine the consolidation scope according to the economic essence [26, 27], there is no reasonable and clear judgment standard for deciding the consolidation scope based on the "control standard." In other words, the information contained in the consolidated financial statements lacks a clear boundary, so consolidated financial statements' reliability is controversial [3]. The "control standard" is featured by solid subjectivity and poor operability, making the determination of the consolidation more influenced by management's intentions, which provides the possibility for companies to adjust their financial performance [28].

There are two exceptional cases of consolidation of financial statements in accounting practice. First case, as shown in Table 1, the investor holds the lower equity of the investee but brings the investee into the scope of consolidation. Second one, as shown in Table 2, the investor has more than 50% of the investee's equity but omits the investee in the scope of consolidation.

Whether the determination of the consolidation scope is appropriate will directly affect the decision-making of the users of the consolidated financial statements and the effect of the evaluation of the regulatory authorities. According to China's current business accounting standards, the scope of consolidation should be determined based on "control." That is to say, the parent company should incorporate its controlled subsidiaries into the scope of consolidation and prepare consolidated financial statements to reflect the operating results, economic status, and cash flow of the entire enterprise group consisting of the parent company and all its subsidiaries. For example, in 2016, three real estate companies, Poly Real Estate (stock code: 600048), Binjiang Group (stock code: 002244), and Hangzhou Binlan Enterprise Management Co., Ltd. (from now on referred to as Binlan Management), respectively, held 34%, 33%, and 33% of the shares of Binbaobao Real Estate Development Co., Ltd. (from now on referred to as Binbao Company). According to Poly Real Estate's 2016 annual financial report, the Poly Real Estate holds less than half of the equity of Binbao Company. However, Poly Real Estate has the majority of seats on the board of directors of Binbao Company. Among the five board members of Binbao Company, the Poly Real Estate holds three seats. Therefore, the Poly Real Estate can control Binbao Company. As a result, Poly Real Estate incorporated Binbao Company into the consolidation scope, and the consolidated net profit of Poly Real Estate included 100% of the profit of Binbao Company. Poly Real Estate only holds 34% of Binbao's shares at the firm level, but the consolidated financial statements include 100% of Binbao's profits. The accounting treatment method of forming all the earnings of Binbao Company in the consolidated financial statements of Poly Real Estate has an amplification effect on the earnings of the consolidated financial statements of Poly Real Estate. This study defines the amplification effect of consolidated financial statements as follows. As an investment enterprise brings an invested enterprise into the scope of consolidated financial statements, the number of assets, liabilities, incomes, expenses, profit elements, cash inflow, cash outflow, and other statement items reflected in the consolidated financial statements are magnified compared with the individual financial statements of the parent company, which is called the amplification effect of consolidated financial statements.

Table 1: Statistics of the relationship between shareholding ratio and consolidation (shareholding ratio <30%).

Stock code	Company abbreviation	Year	Shareholding ratio (%)	Consolidation or not	Investees
000009	China Baoan	2019	20	Yes	Guangzhou Rixin Baoan new material industry investment center
000009	China Baoan	2019	19.80	Yes	Wuhan Tongdaohe technology partnership
600057	Xiangyu Gufen	2016	0.07	Yes	Xiamen Yushang investment partnership
600238	Hainan Yedao	2019	15.87	Yes	Hainan Yedao Investment Management Co., Ltd.
600239	Yunnan real estate	2019	0.64	Yes	Yunnan Ansheng Chuangxiang tourism industry investment partnership
600239	Yunnan real estate	2019	1	Yes	Yunnan Rongcheng investment partnership

Data source: annual report of listed companies.

Table 2: Statistics of the relationship between shareholding ratio and consolidation (shareholding ratio >50%).

Stock code	Company abbreviation	Year	Shareholding ratio (%)	Consolidation or not	Investees
000089	Shenzhen airport	2019	51	No	Asiaray media group limited
000632	Sanmu group	2019	90	No	Qingdao Senchengxin Investment Co. Ltd.
000632	Sanmu group	2019	90	No	Shanghai Yuanfu Real Estate Co., Ltd.
000753	Zhangzhou development	2019	54.17	No	Fujian Huaxing Zhangfa Venture Capital Co. Ltd.
600512	Tengda construction	2018	58.33	No	Shanghai Panshi Tengda investment partnership
603618	Hangzhou cable	2019	80	No	Zhejiang Hangdeng Graphene Technology Co. Ltd.
603618	Hangzhou cable	2019	60	No	Zhejiang Hangdian Industrial Co., Ltd.

Data source: annual report of listed companies.

2.3. Amplification Effect of Consolidated Financial Statements and Audit Fees. Audit pricing is affected by audit input and a risk premium [4, 29]. The risk premium is mainly used to compensate for reputational damage, litigation, and other risks that the accounting firm may face. Risk premium can be divided into audit risk premium and nonaudit risk premium [5]. So, how will the amplification effect of consolidated financial statements affect audit fees? First, audit risk depends on the risk of material misstatement and the detection risk. Although control standards help investors determine the scope of consolidation based on economic substance [26, 27], the control standards are highly subjective, poorly operable, and greatly influenced by management's intentions [30]. The current accounting standards for consolidated financial statements determine the scope of consolidation based on control standards, resulting in an amplification effect. On the one hand, the greater the amplification effect, the more professional judgment will be used to prepare consolidated financial statements. It will increase the risk of material misstatement [2]. On the other hand, compared with companies with small amplification effect, companies with significant amplification effect rely on more professional judgments, making auditing more complicated and having higher requirements for the professional competence of auditors, which is likely to lead to an increase in detection risks. Audit risk increases along with the increased risk of material misstatement and detection risk associated with the amplification effect. As a result, auditors will demand a higher audit risk premium. Second, auditors will expand the audit scope and increase auditing procedures and working hours when auditing high-risk clients. Auditor firms will assign more experienced auditors [6]. The efforts of auditors and auditing firms will increase audit investment and lead to higher audit fees. Third, if the auditor's portfolio risk is high, it is more likely to be the object of litigation. Thus, the auditor may purchase more litigation insurance, increasing the nonaudit risk premium [31]. A significant magnification effect may arise from management's manipulation of the consolidation scope to embellish financial statement data. Manipulation of the consolidation scope may lead to damage to the interests of investors, and audit institutions are likely to face a higher risk of litigation or penalties as a result. Auditors demand a higher nonaudit risk premium to compensate for this additional risk. Therefore, our hypothesis is as follows:

H1. Firms with a high amplification effect of consolidated financial statements are more likely to pay high audit fees.

3. Research Design

3.1. Sample Selection and Data Sources. To examine the effects of amplification effect on audit fees, we use Chinese A-share listed companies to construct a sample covering 2007–2019. On February 15, 2006, the Ministry of Finance issued a new accounting standard system including 38 specific accounting standards and a basic accounting standard. Therefore, the sample period begins in 2007 when the new accounting standards are fully implemented. The variable data involved is obtained from the CSMAR database.

Table 3: Variable definition.

Variables	Definition
LNFEE	Natural logarithm of audit fees
MAGNIFICATION1	Magnification of consolidated financial statements, the ratio of minority equity to total equity in the consolidated financial statements
SIZE	Natural logarithm of sales revenue in the company's consolidated financial statements
LEV	Total liabilities to total assets in the consolidated balance sheet
TOBINQ	(Number of tradable shares × closing price at the end of the year + nontradable shares × net assets per share + total liabilities)/total assets
DUAL	The value is 1 if the same person holds the chairman and the general manager; otherwise, it is 0
INDRATIO	The ratio of the number of independent directors to the number of directors
AGE	The number of years since the company was founded
SOE	For state-owned enterprises, the value is 1; otherwise, the value is 0
TOP1	Percentage of shareholding of the largest shareholder
BIG4	If the auditor is from "big four accounting firms," the value is 1; otherwise, it is 0
DELAY	Natural logarithm of the number of days between the end of the accounting period and the issuance of the auditor's report
REC	The ratio of accounts receivable to total assets
RISK1	The volatility of ROA, calculation of the rolling standard deviation of the 3-year ROA
RISK2	The volatility of ROA, calculation of the rolling standard deviation of the 5-year ROA
SINDEX	The sum of the shareholdings of the second-largest shareholder to the tenth largest shareholder of the company

All continuous variables are winsorized at 1% and 99% percentile to eliminate the influence of extreme values.

3.2. Regression Model and Variable definition. Following the works of Simunic [4] and Hu et al. [2], we construct model (1) to test the impact of the amplification effect on audit fees:

$$\begin{aligned}\mathrm{LNFEE}_{i,t} = {} & \lambda_0 + \lambda_1 \mathrm{MAGNIFICATION1}_{i,t} + \lambda_2 \mathrm{SIZE}_{i,t} \\ & + \lambda_3 \mathrm{LEV}_{i,t} + \lambda_4 \mathrm{TOBINQ}_{i,t} + \lambda_5 \mathrm{DUAL}_{i,t} \\ & + \lambda_6 \mathrm{INDRATIO}_{i,t} + \lambda_7 \mathrm{AGE}_{i,t} + \lambda_8 \mathrm{SOE}_{i,t} \\ & + \lambda_9 \mathrm{TOP1}_{i,t} + \lambda_{10} \mathrm{BIG4}_{i,t} + \lambda_{11} \mathrm{DELAY}_{i,t} \\ & + \lambda_{12} \mathrm{REC}_{i,t} + \sum \mathrm{INDUSTRY} + \sum \mathrm{YEAR} + \phi_{i,t}. \end{aligned} \tag{1}$$

Audit fees are remuneration and compensation for audit-related resource consumption and risks [32]. Following Ettredge et al. [33] and Dong et al. [25], we measure the audit fees (*LNFEE*) by the natural logarithm of the audit fees. Following the work of Yan [34], the test variable is the magnification of the consolidated financial statements (*MAGNIFICATION1*), the ratio of minority interests to the total equity in the consolidated financial statements. The larger the magnification of the consolidated financial statements, the greater the amplification effect. The test variable can measure the amplification effect because minority interests reflect ownership interests that the parent company does not own. After the subsidiaries are included in the consolidated financial statements, their assets, liabilities, and owner's equity belonging to minority shareholders will be reflected in the consolidated balance sheet, inevitably magnifying the company's assets, liabilities, and owner's equity, creating a magnifying effect. According to Hypothesis 1, *MAGNIFICATION1* is expected to be significantly positively correlated with *LNFEE*.

Referring to prior studies (see, e.g., [35, 36]), we also control the following factors: audit workload, measured by the natural logarithm of sales revenue (*SIZE*); operating risk, measured by the asset-liability ratio (*LEV*) and Tobin Q (*TOBINQ*); corporate governance characteristics, measured by the integration or separation of chairman and general manager (*DUAL*) and proportion of independent director (*INDRATIO*); firm-level characteristics, measured by firm age (*AGE*), firm nature (*SOE*), and shareholding of the largest shareholder (TOP1); auditor size (*BIG4*); audit delay (*DELAY*); and proportion of accounts receivable ratio (*REC*). Definitions for all variables are provided in Table 3. In addition, we also include year-fixed effect (*YEAR*) and industry-fixed effect (*INDUSTRY*) in the regression model.

4. Analysis of Empirical Results

4.1. Descriptive Statistics. Table 4 presents the summary statistics of the variables included in our baseline regression model. All continuous variables are winsorized at the 1st and 99th percentiles to reduce the influence of outliers. As a result, the minimum of the natural logarithm of audit fees (*LNFEE*) is 12.301, the maximum of the natural logarithm of audit fees (*LNFEE*) is 15.850, the mean of the natural logarithm of audit fees (*LNFEE*) is 13.543, and the standard deviation of the natural logarithm of audit fees (*LNFEE*) is 0.651. The descriptive statistics of audit fees (*LNFEE*) demonstrate that the audit fees of listed companies in China are quite different, which is generally consistent with the estimates in the study of Yuan et al. [36]. The mean (median) of the amplification effects (*MAGNIFICATION1*) is 0.067 (0.028), which indicates that the average amplification effects of listed companies in China are 6.7%. The minimum of the amplification effects (*MAGNIFICATION1*) is −0.044, and the maximum of the amplification effects (*MAGNIFICATION1*) is 0.490, which indicates that the amplification effects of listed companies in China vary widely. The mean of

Table 4: Descriptive statistics.

Variable	Obs	Mean	Min.	Median	Max.	Std. dev.
LNFEE	25688	13.543	12.301	13.459	15.850	0.651
MAGNIFICATION1	25688	0.067	−0.044	0.028	0.490	0.097
SIZE	25688	21.346	17.188	21.241	25.349	1.464
LEV	25688	0.441	0.050	0.437	0.999	0.211
TOBINQ	25688	2.080	0.854	1.628	10.130	1.413
DUAL	25688	0.244	0.000	0.000	1.000	0.430
INDRATIO	25688	0.372	0.308	0.333	0.571	0.053
AGE	25688	15.908	3.000	16.000	31.000	5.651
SOE	25688	0.414	0.000	0.000	1.000	0.493
TOP1	25688	35.087	8.497	33.078	74.870	15.049
BIG4	25688	0.052	0.000	0.000	1.000	0.223
DELAY	25688	4.501	3.401	4.564	4.779	0.256
REC	25688	0.112	0.000	0.087	0.462	0.102

the company's property rights (*SOE*) is 0.414, which suggests that 41.4% of the sample companies are state-owned enterprises (SOEs). The mean of *BIG4*, is 0.052, indicating that about 5.2% of listed companies choose the big four accounting firms to audit their annual reports.

4.2. Empirical Regressions. In order to investigate whether firms with high amplification effects pay higher audit fees, we present OLS regression results in Table 5 according to equation (1). Column 1 investigates the association between amplification effect (*MAGNIFICATION1*) and audit fees (*LNFEE*) controlling firm characteristics. The coefficient on amplification effect (*MAGNIFICATION1*) is positive and significant at the 5% level (0.197, $t = 2.452$). We control for year-fixed effects and industry-fixed effects in column 2. The coefficient on amplification effect (*MAGNIFICATION1*) is also positive and significant (0.224, $t = 2.970$). These results indicate that firms pay higher audit fees when the firms have a higher amplification effect, which supports Hypothesis 1.

In addition, we implement a series of robust tests such as changing the measurement of the amplification effect, using Heckman's two-stage model, using the instrumental variable approach, and controlling audit fees' stickiness to ensure the validity of our main result. The results of robust tests prove that firms with high amplification effects pay more audit fees than firms with low ones.

4.3. Test of Mediating Effect: Audit Risk. Since the amplification effect will have an impact on audit risk and thus on audit fees, audit risk is used as a mediating variable. The mediating effect of audit risk is verified by referring to the methods of Sobel [37], Wen and Ye [38], and Zhang et al. [39]. The first step is to examine the effect of amplification on audit fees. It can be seen from Table 5 that the amplification effect is significantly positively correlated with audit fees, indicating that the greater the amplification effect, the higher the audit fees. The second step is to examine the impact of the amplification effect on audit risk. Following prior studies (see, e.g., [40, 41]), we measure audit risk through performance fluctuations. We measure audit risk in two ways: the standard deviation of 3-year ROA (*RISK1*) and the standard deviation of 5-year ROA (*RISK2*).

Table 5: The impact of amplification effect on audit fees.

Variables	*LNFEE*	
	(1)	(2)
MAGNIFICATION1	0.197**	0.224***
	(2.452)	(2.970)
SIZE	0.279***	0.262***
	(41.937)	(37.584)
LEV	0.022	0.146***
	(0.639)	(4.142)
TOBINQ	0.005	0.003
	(1.348)	(0.771)
DUAL	0.019	0.004
	(1.528)	(0.296)
INDRATIO	0.342***	0.154
	(3.172)	(1.501)
AGE	0.010***	−0.001
	(8.734)	(−0.975)
SOE	−0.176***	−0.133***
	(−11.191)	(−8.375)
TOP1	−0.001**	−0.001***
	(−2.206)	(−2.720)
BIG4	0.732***	0.726***
	(18.519)	(18.552)
DELAY	0.256***	0.166***
	(15.767)	(10.772)
REC	−0.198***	−0.359***
	(−3.161)	(−5.911)
Constant	6.196***	6.908***
	(39.374)	(41.184)
YEAR	No	Yes
INDUSTRY	No	Yes
N	25,688	25,688
Adj. R^2	0.552	0.596

Note. Cluster-adjusted t-values are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (when $1.65 < |t| < 1.96$, $p < 0.10$; when $1.96 < |t| < 2.58$, $p < 0.05$; and when $|t| > 2.58$, $p < 0.01$).

To test the effect of amplification effect on the audit risk, we use audit risk as the dependent variable. We model audit risk as a function of amplification effect and other firm characteristics.

Table 6: The impact of amplification effect on audit risk.

Variables	*RISK1* (1)	*RISK1* (2)	*RISK2* (3)	*RISK2* (4)
MAGNIFICATION1	0.029***	0.026***	0.046***	0.040***
	(4.994)	(4.424)	(5.388)	(4.707)
SIZE	−0.005***	−0.005***	−0.006***	−0.005***
	(−11.503)	(−9.387)	(−10.217)	(−7.952)
TOBINQ	0.006***	0.007***	0.008***	0.009***
	(8.753)	(9.144)	(7.450)	(7.759)
INDRATIO	0.015*	0.018**	0.022**	0.026**
	(1.893)	(2.233)	(2.014)	(2.430)
AGE	0.000***	0.001***	0.001***	0.001***
	(4.952)	(5.830)	(6.045)	(7.126)
SOE	−0.000	−0.002	0.000	−0.002
	(−0.206)	(−1.544)	(0.234)	(−1.395)
BIG4	0.003*	0.002	0.002	0.001
	(1.700)	(1.348)	(1.158)	(0.484)
SINDEX	−0.000	−0.000	−0.000	0.000
	(−1.049)	(−0.381)	(−0.690)	(0.235)
Constant	0.120***	0.117***	0.130***	0.115***
	(11.712)	(9.343)	(10.276)	(7.420)
YEAR	No	Yes	No	Yes
INDUSTRY	No	Yes	No	Yes
N	26,311	26,311	26,311	26,311
Adj. R^2	0.071	0.089	0.082	0.101

Note. Cluster-adjusted *t*-values are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

$$\begin{aligned}\mathrm{RISK}_{i,t} = {} & \gamma_0 + \gamma_1 \mathrm{MAGNIFICATION1}_{i,t} + \gamma_2 \mathrm{SIZE}_{i,t} \\ & + \gamma_3 \mathrm{TOBINQ}_{i,t} + \gamma_4 \mathrm{INDRATIO}_{i,t} + \gamma_5 \mathrm{AGE}_{i,t} \\ & + \gamma_6 \mathrm{SOE}_{i,t} + \gamma_7 \mathrm{BIG4}_{i,t} + \gamma_8 \mathrm{SINDEX}_{i,t} \\ & + \sum \mathrm{INDUSTRY} + \sum \mathrm{YEAR} + \varphi_{i,t}.\end{aligned} \tag{2}$$

Table 6 shows the OLS regression analysis of the impact of amplification effect (*MAGNIFICATION1*) on audit risk (*RISK*) according to equation (2). The dependent variables in column 1 and column 2 are the standard deviation of 3-year ROA (*RISK1*). The dependent variables in column 3 and column 4 are the standard deviation of 5-year ROA (*RISK2*). Columns 1 and 3 investigate the association between amplification effect (*MAGNIFICATION1*) and audit risk controlling firm characteristics. The coefficients of the variable amplification effect (*MAGNIFICATION1*) in columns 1 and 3 are 0.029 and 0.046, respectively, and both are statistically significant at the 1% level ($t = 4.994$; $t = 5.388$), indicating that firms with higher amplification effects have high audit risk. We control for year-fixed and industry-fixed effects in columns 2 and 4. The coefficients on amplification effect (*MAGNIFICATION1*) continue to be positive and statistically significant at the 1% level (0.026, $t = 4.424$; 0.040, $t = 4.707$). Our results suggest that the firms with higher amplification effects are associated with higher audit risk.

The third step examines the relationship between amplification effect, audit risk, and audit fees. To explore the relationship between amplification effect, audit risk, and audit fees, we constructed the following model:

$$\begin{aligned}\mathrm{LNFEE}_{i,t} = {} & \eta_0 + \eta_1 \mathrm{MAGNIFICATION1}_{i,t} + \eta_2 \mathrm{RISK}_{i,t} \\ & + \eta_3 \mathrm{SIZE}_{i,t} + \eta_4 \mathrm{LEV}_{i,t} + \eta_5 \mathrm{TOBINQ}_{i,t} \\ & + \eta_6 \mathrm{DUAL}_{i,t} + \eta_7 \mathrm{INDRATIO}_{i,t} + \eta_8 \mathrm{AGE}_{i,t} \\ & + \eta_9 \mathrm{SOE}_{i,t} + \eta_{10} \mathrm{TOP1}_{i,t} + \eta_{11} \mathrm{BIG4}_{i,t} \\ & + \eta_{12} \mathrm{DELAY}_{i,t} + \eta_{13} \mathrm{REC}_{i,t} + \sum \mathrm{INDUSTRY} \\ & + \sum \mathrm{YEAR} + \varphi_{i,t}.\end{aligned} \tag{3}$$

Table 7 presents the regression results of the relationship among amplification effect, audit risk, and audit fees. Columns 1 and 3 investigate the association between amplification effect, audit risk, and audit fees controlling firm characteristics. The coefficient on audit risk (*RISK1*) is positive and significant at the1% level in column 1 (0.654, $t = 6.841$), the coefficient on audit risk (*RISK2*) is positive and significant at the 1%level in column 3 (0.468, $t = 4.784$), and the coefficients on amplification effect (*MAGNIFICATION1*) are positive and significant at the 5% level in columns 1 and 3 (0.185, $t = 2.300$; 0.179, $t = 2.234$). It is indicated that the audit risk is an incomplete intermediary effect. That is, the effect of amplification effect on audit fees is not entirely realized through audit risk. Next, we head for year-fixed and industry-fixed results in columns 2 and 4. The coefficient on audit risk (*RISK1*) is positive and significant at the 1% level in column 2 (0.608, $t = 6.849$), the coefficient on audit risk (*RISK2*) is positive and significant at the 1% level in column 4 (0.462, $t = 5.076$), and the coefficients on amplification effect (*MAGNIFICATION1*) are positive and

Table 7: The impact of amplification effect and audit risk on audit fees.

Variables	*LNFEE*			
	(1)	(2)	(3)	(4)
MAGNIFICATION1	0.185**	0.214***	0.179**	0.209***
	(2.300)	(2.841)	(2.234)	(2.778)
RISK1	0.654***	0.608***		
	(6.841)	(6.849)		
RISK2			0.468***	0.462***
			(4.784)	(5.076)
SIZE	0.282***	0.266***	0.282***	0.265***
	(41.249)	(37.191)	(40.967)	(37.026)
LEV	0.001	0.129***	0.007	0.134***
	(0.039)	(3.573)	(0.193)	(3.720)
TOBINQ	0.000	−0.001	0.001	−0.001
	(0.074)	(−0.265)	(0.171)	(−0.217)
DUAL	0.019	0.002	0.019	0.002
	(1.468)	(0.173)	(1.451)	(0.148)
INDRATIO	0.332***	0.141	0.332***	0.140
	(3.033)	(1.352)	(3.032)	(1.346)
AGE	0.011***	−0.002	0.010***	−0.002
	(8.595)	(−1.036)	(8.483)	(−1.149)
SOE	−0.179***	−0.134***	−0.180***	−0.134***
	(−11.280)	(−8.365)	(−11.300)	(−8.359)
TOP1	−0.001**	−0.001***	−0.001**	−0.001***
	(−2.244)	(−2.822)	(−2.387)	(−2.941)
BIG4	0.732***	0.728***	0.733***	0.729***
	(18.019)	(18.148)	(18.054)	(18.180)
DELAY	0.253***	0.166***	0.255***	0.167***
	(15.245)	(10.477)	(15.366)	(10.552)
REC	−0.176***	−0.334***	−0.179***	−0.339***
	(−2.753)	(−5.373)	(−2.802)	(−5.449)
Constant	6.142***	6.844***	6.154***	6.860***
	(37.993)	(39.698)	(37.923)	(39.751)
YEAR	No	Yes	No	Yes
INDUSTRY	No	Yes	No	Yes
N	24,497	24,497	24,497	24,497
Adj. R^2	0.553	0.597	0.552	0.597

Note. Cluster-adjusted *t*-values are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

significant at the 1% level in columns 2 and 4 (0.214, $t = 2.841$; 0.209, $t = 2.778$). The results in Table 7 indicate that audit risk plays an incomplete intermediary role in the relation between the amplification effect and audit fees.

The fourth step is the Sobel test. This method mainly tests whether the coefficients of the cross terms of γ_1 and η_2 are significant, and the test statistic $Z = \gamma_1\eta_2/S$ (where $S = (\gamma_1{}^2 s_\eta{}^2 + \eta_2{}^2 s_\gamma{}^2)\ \sqrt{\gamma_1^2 S_\eta^2 + \eta_2^2 S_\gamma^2}\ ½$; s_γ and s_η represent the standard errors of γ_1 and η_2, respectively). If the absolute value of Z is greater than 0.97, the mediating effect is significant; otherwise, the mediating impact is not substantial. Based on the results of the previous three steps, it can be derived that $\gamma_1 = 0.026$, $\eta_2 = 0.608$, $s_\gamma = 0.006$, and $s_\eta = 0.089$ for *RISK1*. Thus, the statistic Z is calculated to be equal to 3.65, the absolute value of which is greater than 0.97, proving that the amplification effect affects audit fees through audit risk. It can be derived that $\gamma_1 = 0.040$, $\eta_2 = 0.462$, $s_\gamma = 0.009$, and $s_\eta = 0.091$ for *RISK2*. Thus, the statistic Z is calculated to be equal to 3.34, the absolute value of which is greater than 0.97, proving that audit risk is a mediating variable in the relationship between the amplification effect and audit fees.

4.4. Effect of the Nature of Property Rights. The manager incentive contract of state-owned enterprises pays more attention to the company's performance compared to that of non-state-owned enterprises due to the explicit performance requirements of state-owned enterprises for managers, more substantial social supervision, and weaker tunneling motivation for SOEs [42]. In economic practice, the State-owned Assets Supervision and Administration Commission (SASAC) issued the *Measures for Business Performance Appraisal of the Heads of Central Enterprises*, which link the business performance appraisal of the heads of central enterprises to the total profit or net profit of the consolidated financial statements. That makes the management of SOEs more likely to engage in opportunistic behavior such as earnings management. In this case, the amplification effect of SOEs implies higher risk. Therefore, auditors will demand a higher audit risk premium when faced with the amplification effects of SOEs than when faced with the amplification effects of non-SOEs. [43]. SOEs are subject to more substantial social supervision [42], which makes auditors face higher violation costs when auditing SOEs. Compared with the amplification

Table 8: Amplification effect and audit fees: effect of the nature of property rights.

Variables	*LNFEE*	
	(1)	(2)
MAGNIFICATION1	−0.007	0.093
	(−0.071)	(0.939)
MAGNIFICATION1 × SOE	0.362**	0.232*
	(2.468)	(1.659)
SOE	−0.202***	−0.150***
	(−10.965)	(−8.052)
SIZE	0.279***	0.262***
	(41.946)	(37.564)
LEV	0.029	0.149***
	(0.816)	(4.240)
TOBINQ	0.005	0.003
	(1.439)	(0.846)
DUAL	0.018	0.003
	(1.432)	(0.243)
INDRATIO	0.332***	0.149
	(3.087)	(1.455)
AGE	0.011***	−0.001
	(8.878)	(−0.852)
TOP1	−0.001**	−0.001***
	(−2.183)	(−2.710)
BIG4	0.731***	0.725***
	(18.572)	(18.586)
DELAY	0.256***	0.167***
	(15.749)	(10.788)
REC	−0.208***	−0.363***
	(−3.319)	(−5.991)
Constant	6.210***	6.913***
	(39.489)	(41.231)
YEAR	No	Yes
INDUSTRY	No	Yes
N	25,688	25,688
Adj. R^2	0.552	0.596

Note. Cluster-adjusted *t*-values are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

effect of non-SOEs, auditors will demand a higher nonaudit risk premium when facing the amplification effect of SOEs. In summary, we expect that the amplification effect of SOEs will have a more significant impact on audit fees than non-SOEs.

As shown in Table 8, the coefficients on the interaction terms of amplification effect (*MAGNIFICATION1*) and the indicator of state-owned enterprises (*SOE*) are both positive and statistically significant in columns 1 and 2 (0.362, $t = 2.468$; 0.232, $t = 1.659$), suggesting that the amplification effect of SOEs has a more significant impact on audit fees compared to non-SOEs. The results in Table 8 show that, auditors will charge higher audit fees when facing the amplification effect of SOEs.

5. Discussion

This paper investigates the influence of consolidated financial statements' amplification effect on audit fees and the mechanism of their relationship. We found the following: (1) Audit fees are positively related to the amplification effect of consolidated financial statements. (2) Audit risk plays an intermediary role among the relationship between the amplification effect and audit fees. (3) In state-owned enterprises (SOEs), the positive correlation between amplification effect and audit fees is more significant. Compared with prior studies, this paper creatively proposes the concept of amplification effect and studies its impact on audit fees which can help us better understand the economic consequences of accounting standards. What is more, we enrich the literature on influencing factors of audit fees, while previous research mainly focused on the digital transformation of enterprises, investor sentiment, business and finance integration, customer relationship, and fair value measurement. Furthermore, we provide empirical evidence for the vital role of property rights in corporate governance.

Our results have significant practical consequences. First, this paper emphasizes the importance of perfecting accounting standards for consolidated financial statements and supervision of consolidation scope. Second, it provides enlightenment to auditing. Auditors should pay more attention to the application of control standards in determining the scope of consolidated financial statements and increase audit input to ensure the reliability of accounting information. Third, it enriches the standard of management compensation. The evaluation of management performance and the supervision of enterprises should avoid relying too much on the consolidated financial statement, and it can be considered to rely on both the consolidated financial statement and the parent company's statement.

There are still some limitations suggesting further research. First, we study the effect of consolidated financial statements' amplification effect on audit fees by using the empirical method. Thus, further analysis can adopt case studies and add interviews with executives and auditors to enhance the conclusions of this paper. Second, other firm-level characteristics may also affect the relationship between the amplification effect and audit fees in addition to property rights. For example, the audit period of the institution on the company may lead to different levels of the audit fees. Thus, other characteristics can also be considered in the future. Finally, the consolidated financial statements' amplification effect may impact the decisions of other agents. Existing literature finds that the aggregate data of enterprise statement information is helpful to predict GDP changes [44]. Therefore, whether the amplification effect of consolidated statements will affect the forecasting ability of aggregate information of enterprise accounting data to GDP can be further studied.

Data Availability

All relevant variable data come from the China Stock Market & Accounting Research Database.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

The first two authors contributed equally to this work.

Acknowledgments

This work was funded by the Youth Project of Beijing Social Science Foundation (Grant no. 21GLC037).

References

[1] N. H. Cannon and J. C. Bedard, "Auditing challenging fair value measurements: evidence from the field," *The Accounting Review*, vol. 92, no. 4, pp. 81–114, 2017.

[2] G. Hu, S. Fu, and J. Zhu, "Does low-level fair value measurement lead to higher audit fees? —evidence from Chinese listed banks," *Accounting Research*, vol. 5, pp. 17–29, 2020.

[3] H. Zhou, J. Wu, D. Dai, and C. Mo, "Research on the potential impact of the pros and cons of consolidated financial statements on economic regulation rules: taking Jiangshan Pharmaceutical as an example," *China Soft Science*, vol. 2, pp. 177–185, 2018.

[4] D. A. Simunic, "The pricing of audit services: theory and evidence," *Journal of Accounting Research*, vol. 18, no. 1, pp. 161–190, 1980.

[5] R. W. Houston, M. F. Peters, and J. H. Pratt, "The audit risk model, business risk and audit-planning decisions," *The Accounting Review*, vol. 74, no. 3, pp. 281–298, 1999.

[6] X. Liu, M. Li, and L. Sun, "Negative media reports, audit pricing, and audit delay," *Accounting Research*, vol. 4, pp. 88–94, 2017.

[7] M. Darrough and T. Harris, "Do management forecasts of earnings affect stock returns in Japan?" *Journal of Accounting, Auditing and Finance*, vol. 6, pp. 119–154, 1991.

[8] C. Ewelt-Knauer, "Determining reporting entity boundaries in the light of neoinstitutional theories beyond the conceptual framework of IFRS," *Journal of Business Economics*, vol. 84, no. 6, pp. 827–864, 2014.

[9] J. R. Sánchez-Serrano, D. Alaminos, F. García-Lagos, and A. M. Callejón-Gil, "Predicting audit opinion in consolidated financial statements with artificial neural networks," *Mathematics*, vol. 8, no. 8, pp. 1–14, 2020.

[10] K. M. Hyun, "Value relevance of the information attributable to non-controlling interests in consolidated financial statements," *Journal of Business Education*, vol. 35, no. 4, pp. 155–174, 2021.

[11] J. Kim, S. Jung, and M. Ha, "Consolidated financial reporting and the effect of mandatory IFRS adoption on the information content of earnings announcements: evidence from Korea," *Asia-Pacific Journal of Accounting & Economics*, vol. 28, no. 6, pp. 674–695, 2021.

[12] A. Bedford, M. Bugeja, and N. Ma, "The impact of IFRS 10 on consolidated financial reporting," *Accounting and Finance*, vol. 62, no. 1, pp. 101–141, 2022.

[13] R. G. Walker, "An evaluation of the information conveyed by consolidated statements," *Abacus*, vol. 12, no. 2, pp. 77–115, 1976.

[14] J. R. Francis, "Debt reporting by parent companies: parent-only versus consolidated statements," *Journal of Business Finance & Accounting*, vol. 13, no. 3, pp. 393–403, 1986.

[15] Y. Noorifard, M. Rabiei, and H. Haghshenas, "A survey of value relevance of the consolidate earnings and cash flows in the stock return of the companies listed in TSE," *International Research Journal of Applied and Basic Sciences*, vol. 6, no. 1, pp. 63–68, 2013.

[16] C. Abad, J. Laffarga, A. Garcia-Borbolla, M. Larran, J. M. Pinero, and N. Garrod, "An evaluation of the value relevance of consolidated versus unconsolidated accounting information: evidence from quoted Spanish firms," *Journal of International Financial Management & Accounting*, vol. 11, no. 3, pp. 156–177, 2000.

[17] K. M. Hyun, "A comparative study on earnings management between consolidated financial statements and separate financial statements," *Journal of Business Education*, vol. 29, no. 3, pp. 103–122, 2015.

[18] K. M. Choul, "Comparing the forecasting power of bankruptcy by financial statements based on international financial reporting standards," *Journal of Industrial Economics and Business*, vol. 33, no. 1, pp. 143–161, 2020.

[19] J. W. Tucker, Y. Zhou, and J. Zhu, *Incremental Usefulness of Parent-Only Balance Sheets to Debt Holders: Evidence from banks*, Working paper, 2021.

[20] L. Liu and J. Zheng, "Decision usefulness of information differences between consolidated statements and parent company statements," *Modern Management Science*, vol. 10, pp. 93–95, 2014.

[21] X. Zhang, A. Qian, and D. Chen, "The quality of financial condition of listed companies: theoretical framework and evaluation system," *Management World*, vol. 7, pp. 152–166, 2019.

[22] Y. Zhang, X. Li, and M. Xing, "Enterprise digital transformation and audit pricing," *Audit Research*, vol. 3, pp. 62–71, 2021.

[23] Y. Xiong and H. Hong, "Investor sentiment and audit fees: from the perspective of auditors' professional risk," *Audit and Economics*, vol. 36, no. 3, pp. 43–55, 2021.

[24] Y. Yu, J. Huang, and Z. Li, "Does the integration of industry and finance reduce audit fees? —based on the evidence of A-share listed companies," *Audit Research*, vol. 2, pp. 46–55, 2021.

[25] P. Dong, L. Cheng, and K. Qiao, "Does customer relationship affect audit fees and audit quality," *Management World*, vol. 34, no. 8, pp. 143–153, 2018.

[26] A. W.-H. Hsu and H. Pourjalali, "The impact of IAS No. 27 on the market's ability to anticipate future earnings," *Contemporary Accounting Research*, vol. 32, no. 2, pp. 789–813, 2015.

[27] E. T. De George, X. Li, and L. Shivakumar, "A review of the IFRS adoption literature," *Review of Accounting Studies*, vol. 21, no. 3, pp. 898–1004, 2016.

[28] M. Feng, J. D. Gramlich, and S. Gupta, "Special purpose vehicles: empirical evidence on determinants and earnings management," *The Accounting Review*, vol. 84, no. 6, pp. 1833–1876, 2009.

[29] S. Chen, J. Guo, Y. Tian, and L. Yan, "Insurance claims and audit quality: evidence from trade credit insurance in Chinese listed firms," *Asian Review of Accounting*, vol. 30, no. 1, pp. 97–120, 2022.

[30] C. Nobes, "The development of national and transnational regulation on the scope of consolidation," *Accounting, Auditing & Accountability Journal*, vol. 27, no. 6, pp. 995–1025, 2014.

[31] F. L. Jones and K. Raghunandan, "Client risk and recent changes in the market for audit services," *Journal of Accounting and Public Policy*, vol. 17, no. 2, pp. 169–181, 1998.

[32] M. DeFond and J. Zhang, "A review of archival auditing research," *Journal of Accounting and Economics*, vol. 58, no. 2-3, pp. 275–326, 2014.

[33] M. L. Ettredge, Y. Xu, and H. S. Yi, "Fair value measurements and audit fees: evidence from the banking industry," *Auditing: A Journal of Practice & Theory*, vol. 33, no. 3, pp. 33–58, 2014.

[34] L. Yan, *Research on the Amplification Effect of Consolidated Financial Statements and its Economic Consequences*, Renmin University of China, Beijing, China, 2020.
[35] H. Chang, Y. Guo, and P. L. L. Mo, "Market competition, audit fee stickiness, and audit quality: evidence from China," *Auditing: A Journal of Practice & Theory*, vol. 38, no. 2, pp. 79–99, 2019.
[36] R. Yuan, R. Li, and B. Li, "Directors and executives liability insurance and audit fees," *Audit Research*, vol. 2, pp. 55–63, 2018.
[37] M. E. Sobel, "Asymptotic confidence intervals for indirect effects in structural equation models," *Sociological Methodology*, vol. 13, pp. 290–312, 1982.
[38] Z. Wen and B. Ye, "Analyses of mediating effects: the development of methods and models," *Advances in Psychological Science*, vol. 22, no. 5, pp. 731–745, 2014.
[39] R. Zhang, M. Jun, and S. Palacios, "M-Shopping service quality dimensions and their effects on customer trust and loyalty: an empirical study," *International Journal of Quality & Reliability Management*, 2021, (Forthcoming).
[40] R. Yuan, W. Wen, and Z. Xie, "Directors and executives liability insurance and restatement of financial statements," *Accounting Research*, vol. 5, pp. 21–27, 2018.
[41] X. Han and W. Zhou, "Client performance fluctuation and audit risk prevention: information assurance or insurance function?" *Accounting Research*, vol. 9, pp. 71–78, 2013.
[42] F. Jiang, B. Zhu, and Y. Wang, "Do managers' incentive contracts in state-owned enterprises pay less attention to performance?" *Management World*, vol. 9, pp. 143–159, 2014.
[43] K. M. Johnstone and J. C. Bedard, "Risk management in client acceptance decisions," *The Accounting Review*, vol. 78, no. 4, pp. 1003–1025, 2003.
[44] Y. Konchitchki and P. N. Patatoukas, "Accounting earnings and gross domestic product," *Journal of Accounting and Economics*, vol. 57, no. 1, pp. 76–88, 2014.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 3960691, 11 pages
https://doi.org/10.1155/2022/3960691

Research Article

Human Capital and Rural Households' Vulnerability to Relative Poverty: Evidence from China

Jianfeng Su[1] **and Shurui Guo**[2]

[1]*School of Economics, Liaoning University, Shenyang 110036, China*
[2]*Department of Ideological and Political Theory, Shenyang Institute of Science and Technology, Shenyang 110167, China*

Correspondence should be addressed to Jianfeng Su; sujianfengha@163.com

Received 30 March 2022; Accepted 28 April 2022; Published 16 May 2022

Academic Editor: Lele Qin

Drawing on three-wave panel data from China Family Panel Studies (CFPS) of 2014, 2016, and 2018, this paper measures rural households' vulnerability to relative poverty using the three-stage feasible generalized least squares (FGLS) model. We analyze the impact of human capital on vulnerability to relative poverty by using the two-way fixed-effected model and panel quantile regression. Empirical results exhibited that labor force migration, health, education, and working experience all have a negative effect on vulnerability to relative poverty. Labor force migration has the greatest negative effect among the four factors. Heterogeneity analysis results exhibited that labor force migration has the biggest negative effect in the east region. Health and education have the greatest negative impact in the central region. Labor force migration, health, work experience, and education have a greater effect on nonpoor households than on poor households.

1. Introduction

Poverty is a great challenge that all countries face in the world [1]. In 1986, China began to carry out poverty alleviation work in an organized and planned way [2]. Great results have been achieved so far. China has completed the goal of eradicating absolute poverty by 2020 as scheduled. But it does not mean that China's poverty alleviation work is over [3]. In the postpoverty alleviation era, China's poverty reduction will face a new challenge: the relatively poor people will become the main body of poverty [4]. Relative poverty alleviation also meets the requirement of high-quality development in China [5]. Relative poverty puts more emphasis on a vulnerability of "sense of relative deprivation." Relative poverty has the characteristics of continuity, subjectivity, as well as dynamics, inequality, and relativity. Most existing studies identify poverty from a multidimensional perspective [6–8]. In December 2020, the Central Economic Work Conference pointed out that the government should consolidate and expand the achievements of poverty alleviation and resolutely prevent large-scale poverty return. At present, the global COVID-19 situation is still grim, and various sudden risk shocks are testing the risk management and coping abilities of families. The economic impact brought by the epidemic will cause greater harm to vulnerable groups and aggravate inequality and social class differentiation. Poverty is an important issue closely related to sustainable development and an important indicator of social and economic development [9]. At present, the government often uses the income poverty standard to calculate the headcount ratio to measure poverty. The poverty index is a static measure of a household's well-being at a particular time [10]. There are limitations in antipoverty policies made by the government based on the incidence of poverty. The headcount ratio is merely an ex post measure that does not take the household's future welfare and associated risks into account. Therefore, the poverty incidence rate cannot dynamically reflect future poverty trends of households and ignore the current households in nonpoverty status that are more likely to fall into poverty in the future [11].

The World Bank defines vulnerability to poverty as the possibility of a person or family's welfare decreasing to a certain socially accepted level under risk shocks in the future [12].

Vulnerability to poverty pays more attention to the long-term and dynamic nature of poverty, the stability of poverty reduction, and the possibility of returning to poverty [13]. It not only reflects the reality of current poverty but also depicts poverty deeply and dynamically. Poverty vulnerability overcomes the deficiency of the headcount ratio in measuring the economic status of households in the future. The government can identify households at risk of falling into poverty in the future by introducing the vulnerability to poverty measurement, which helps the government formulate effective preintervention policies for families or regions with high vulnerability to poverty. In addition, considering the influencing factors of vulnerability to poverty under the background of poverty alleviation has important guiding significance for improving the endogenous development motivation of households in relative poverty status.

Development economics theory points out that the crux of poverty problems such as backward national economic development and low level of national income lies in the lack of capital. Since then, scholars began to focus on the impact of human capital on poverty. From a macro point of view, the crux of poverty and backwardness in underdeveloped countries lies in the lack of human capital stock [14]. Endogenous growth theory also emphasizes the role of human capital in economic growth, thus laying a foundation for the poverty reduction effect of human capital [15]. From the micro point of view, some scholars believe that human capital can increase income [16]. Sen pointed out that low human capital, such as education and health, deprived individuals' ability to obtain income, thus leading to individual poverty [17]. Bawono analyzed household data in Indonesia during 1984–2019 and found that education can effectively increase income and reduce the rural poverty rate [18]. Brown found higher education can lead to poverty reduction [19]. Working experience can positively affect households' income, and the rate of return increases with increasing income [20]. Guo pointed out that rural labor migration can also effectively alleviate rural poverty [21]. However, some scholars have found that human capital has no significant impact on increasing income. Wedgwood analyzed data in Tanzanian and found that education failed to improve rural income and alleviate poverty [22]. Moeis et al. think simply moving out of agriculture does not guarantee that farmers, especially landless farmers, will become better off [23].

Most existing studies focus on the relationship between human capital and poverty stock [24, 25]. This is an analysis that statically measures the level of well-being of households at a particular time and does not extend the research perspective to vulnerability to poverty, which takes future risks into account. In addition, most of the existing literature focuses on the study of human capital on households' income, but few studies find that human capital can affect the vulnerability to poverty. Gloede found that risk shock would significantly increase farmers' risk avoidance probability in Thailand and Vietnam, and education could improve farmers' ability to avoid the risk of falling into poverty, that is to say, reduce their vulnerability to poverty [26]. By analyzing data from Vietnam and India, Imai found that education level would increase nonagricultural employment opportunities and then reduce vulnerability to poverty [27]. Chen analyzed data from China's Ministry of Civil Affairs and found the most vulnerable areas are concentrated in western China and human resources have some mitigating effect on poverty [28].

Vulnerability to poverty can estimate the probability of occurrence of households in the future and make up for the inadequacy of income poverty standard and improve the pertinence of poverty alleviation resources utilization. As an important method of antipoverty, human capital plays an important role in enhancing the sustainable development capacity of the poor population. Increasing human capital poverty alleviation is of great significance to the implementation of targeted poverty alleviation and the promotion of urban-rural integrated development under the new situation and helps the government reshape the poverty alleviation policy system.

Existing studies have recognized the effect of human capital on rural poverty reduction, but no consistent conclusions have been drawn. Most studies choose to study from the perspective of income growth, but we identify the impact of human capital on the relative poverty of farmers from the perspective of poverty vulnerability, providing a quantitative basis for the government to formulate policies. In terms of variable selection, most of the existing studies have chosen a single variable to represent human capital, such as the education and health. There are few studies on the relative poverty of rural households focusing on education, health, work experience, and labor migration at the same time. In terms of research data and methods, some studies usually adopt regional micro data or sectional data and use the OLS model for quantitative analysis. In addition, these studies seldom distinguish the difference in human capital's impact on households with different levels of vulnerability to relative poverty.

In the long run, the quality of poverty alleviation can be improved, and substantial progress can be made only by improving the sustainable development capacity of poor rural areas and populations. Promoting human capital accumulation in poor areas and forming a positive interaction mechanism with economic growth not only can directly reduce poverty but also can limit the negative effect of widening the income gap on poverty reduction. Inspired by these concerns, this study utilized three-wave data from China (2014, 2016, and 2018) to construct measures of vulnerability to relative poverty of households. We integrate education, health, work experience, and labor force migration into the analysis framework and analyze the impact of human capital on the vulnerability to relative poverty of rural households by using panel two-way fixed-effects regression and quantile regression. Furthermore, the effects of different dimensions of human capital on different relative poverty vulnerabilities are compared.

The remainder of the paper is structured as follows. The next section explains the methodology employed to determine the extent and nature of a household's vulnerability to relative poverty. Section 3 describes the data and variables used in the study. Section 4 discusses the estimation results, and Section 5 is conclusions. The final section concludes the paper.

2. Methods

2.1. Vulnerability to Relative Poverty Estimation. We adopt the definition of VEP and measure the vulnerability to relative poverty of rural households in China. Vulnerability as expected poverty (VEP) refers to the probability that households' expected future income is lower than the set poverty line [29]. According to this definition, vulnerability to poverty of households comes from the distribution characteristics of future income of households. Both their welfare expectation and welfare fluctuation are determined by family characteristic variables. The estimation method of vulnerability to relative poverty is as follows:

First, we define the vulnerability to relative poverty of household i in period t is: $Vul_{it} = prob(\ln Y_i \leq \ln \text{poor}|X_i)$, that is, the probability that a household's future per capita income is less than the set relative poverty line. It is generally believed that the income characteristics of high-income groups conform to the Pareto distribution, while the log-normal distribution is more suitable to describe the situation of low-income groups. Therefore, income needs to be taken natural logarithmic process.

$$\ln Y_{it} = \alpha_i X_{it} + e_{it}. \tag{1}$$

where X_{it} is a set of observable variables affecting household income and e_{it} is the residual term. e_{it}We use the three-stage least-squares method [30] to weighted regress the logarithm of per capita income and the square of the residual term in formula (1) to get asymptotic efficient estimators $\widehat{\alpha}_{FGLS}$ and $\widehat{\beta}_{FGLS}$. According to the FGLS estimator, we estimate the expectation and variance of logarithms of a household's future per capita income.

$$\begin{aligned} \widehat{E}(\ln Y_i|X_i) &= X_i\widehat{\alpha}_{fgls}, \\ \widehat{V}(\ln Y_i|X_i) &= \sigma^2_{e,i} = X_i\widehat{\beta}_{fgls}. \end{aligned} \tag{2}$$

We assume that the logarithm of income obeys normal distribution [31]. Then we select the appropriate relative poverty line to calculate the rural household's vulnerability to relative poverty as follows:

$$vul_{i,t} = prob\left(\ln Y_{i,t+1} < \ln \text{poor}\right) = \phi\left(\frac{\left(\ln \text{poor} - X_i\widehat{\alpha}_{fgls}\right)}{\sqrt{X_i\widehat{\beta}_{fgls,i}}}\right). \tag{3}$$

2.2. Empirical Strategy. We use the two-way fixed-effects model and panel quantile model to analyze the impact of human capital on rural households' vulnerability to relative poverty as follows:

$$\begin{aligned} Vul_{\text{it}} = \omega_0 + \omega_1\text{edu}_{\text{it}} + \omega_2\text{hea}_{\text{it}} + \omega_3\text{workexp}_{\text{it}} \\ + \omega_4\text{img}_{\text{it}} + \nu X + u_i + \lambda_t + \varepsilon_{\text{it}}. \end{aligned} \tag{4}$$

$$\begin{aligned} Q_{Vul_i}(\tau|x) = \eta_0 + \eta_1\text{edu}_{\text{it}} + \eta_2\text{hea}_{\text{it}} + \eta_3\text{workexp}_{\text{it}} \\ + \eta_4\text{img}_{\text{it}} + \kappa X + u_i + \lambda_t + \varepsilon_{it}. \end{aligned} \tag{5}$$

We also use the four dimensions of human capital to calculate the rural households' human capital index. The weight of each dimension is calculated by the entropy method. The calculation procedure is as follows:

$$Vul_{it}=_0 + \omega_1\text{hcindex}_{\text{it}} + \nu X + u_i + \lambda_t + \varepsilon_{\text{it}}. \tag{6}$$

In formulas (5)–(7), Vul_{it} is vulnerability to relative poverty of rural household i in time t. $Q_{Vul_i}(\tau|x)$ is vulnerability to relative poverty of rural household i in time t conditional quantile function quantile τ under given independent variables. edu_{it}, hea_{it}, $\text{workexp}_{\text{it}}$, and img_{it} are average years of education, average health level, average work experience, and the proportion of migrant workers in rural household i, respectively. X is a set of control variables. u_i is the individual fixed effect that controls the problem of missing variables in households that do not change over time. λ_t is the time fixed effect that controls an individual's heterogeneity in time trend. ε_{it} is a random disturbance term.

We also calculate the human capital index. In formula (7), $\text{hcindex}_{\text{it}}$ represents the human capital index of household i at time t. The human capital index used in this study had a different base and included positive indexes. Therefore, min-max normalization was employed to normalize the raw data for each index as previously described. In order to avoid the deviation caused by information overlap and subjective weighting, the human capital index is synthesized; we use the entropy method to calculate the weight of objective indicators and then synthesize the human capital index. The synthesis steps are as follows:

(1) Standardize the data:

$$X'_{ij} = \frac{X_{ij} - \min\left(X_j\right)}{\max\left(X_j\right) - \min\left(X_j\right)}. \tag{7}$$

(2) Calculate the entropy information of the human capital index of the j-th dimension:

$$\begin{aligned} e_j &= -\frac{1}{\ln m}\sum_{i=1}^{m}\left(Y_{ij} \times \ln Y_{ij}\right), \\ Y_{ij} &= \frac{X'_{ij}}{\sum_{i=1}^{m} i}. \end{aligned} \tag{8}$$

The coefficient of variation t of the j-th dimension human capital index is

$$\nu_j = 1 - e_j. \tag{9}$$

The index weight is

$$W_j = \frac{\nu_j}{\sum_{j=1}^{n} \nu_j}. \tag{10}$$

Human capital index of household i is

$$\text{hcindex}_i = \sum_{j=1}^{n} W_j \times X'_{ij}. \tag{11}$$

3. Data and Descriptive Statistics

3.1. Data. The data used for the analysis are three-wave panel data from China Family Panel Studies (CFPS) of 2014, 2016, and 2018. The related survey began in 2010. There have been five rounds of data (2010, 2012, 2014, 2016, and 2018) so far. The CFPS data samples have been covering individuals and households in 146 administrative villages in 105 counties (districts and county-level cities) in 25 provinces (provinces/municipalities/autonomous regions) that are reflecting the development of China's social population, economy, education, and health. Due to the lack of indicators of households' labor mobility in the 2012 survey, this paper selects data from surveys from 2014 to 2018 to investigate the impact of human capital on vulnerability to relative poverty of rural households in China. In the process of data cleaning, the author only retained peasant household samples that participated in more than two consecutive surveys.

3.2. Variables

3.2.1. Human Capital. We select four dimensions of health, education, work experience, and migration of labor force to represent rural household's human capital. The labor force excludes workers who are of working age but out of work and workers who are older than 65. The former cannot bring income to their families because they are in school or not in the labor market. The latter only can make up for the lack of family expenses by doing odd jobs due to family poverty. Their abilities to get income are very volatile. Health refers to the average health level of the household's labor force, which is calculated based on the answers to the question "self-rated health status" (in the questionnaire, there are five options for self-rated health status: unhealthy, general, relatively healthy, healthy, and very healthy, with the corresponding values ranging from 1 to 5. The higher the score, the healthier the person) in the questionnaire. Education refers to the average years of education received by the households' labor force. As for work experience, we use the age of the labor force minus the years of education and the preschool age to calculate the years of working to represent working experience. As for labor force migration, many scholars focus on the cross-area mobility of the rural labor force, that is, going out to work in cities. We measure the labor force migration by the proportion of the number of the labor force working in cities in the total labor force. hcindex_{it} represents the human capital index of household i at time t.

3.2.2. Vulnerability to Relative Poverty. A household's vulnerability to relative poverty is an ex ante indicator of household welfare that helps analyze which nonpoor households may fall into relative poverty in the future or which families that have been lifted out of relative poverty may fall into relative poverty and become poor again in the future. The difference between vulnerability to poverty and poverty is also inherent to the existence of risks. If families do not face risks, the state of household vulnerability to relative poverty and welfare risk management will be relatively stable over a certain period of time; nonpoor households will not fall into poverty; and families that have been lifted out of poverty will not return to poverty. As for the measurement of relative poverty, scholars have proposed two measurement standards, using a proportion of median income or average income as the measurement standard of relative poverty [32]. We adopt the OECD standard that is 50% of the median per capita income of the household. The household is identified in relative poverty if its per capita income is lower than this standard. We calculate that the relative poverty lines in 2014, 2016, and 2018 are 7,120 yuan/year, 8,540 yuan/year, and 8,499 yuan/year, respectively (at constant prices in 2010). Then we estimate vulnerability to relative poverty directly under the relative poverty standard.

3.2.3. Other Variables. Demographic, economic, and environmental characteristics of the head of household, household characteristics, and village characteristics are also included, for a total of 19 indicators across 3 categories. The corresponding characteristics for the head of household are age, age square, gender, years of education, and marital status. Household characteristics reflect the household situation and the extent to which the household can bear risk, captured through the aspects of social capital, material capital, financial capital, and other relevant indicators. The corresponding characteristics of households are social network, social status, social trust, drinking water, cooking fuel, land, car, house, financial products. The third category reflects the characteristics of the village to which the households belong. The corresponding characteristics of the village are whether there are high pollution enterprises within 5 kilometers of the village, whether the village is a mining area, whether the village is a minority area, and distance from the village to the county to which the village belongs (li).

3.3. Descriptive Statistics. We estimate vulnerability to relative poverty directly under the relative poverty standard. Results are shown in Figure 1. Vulnerability to relative poverty decreased from 2014 to 2018. However, vulnerability to relative poverty all exceeded 50% in these three years, indicating that the probability of rural households getting into the relative poverty trap in the future is still large. There is still a serious relative poverty problem among rural households in China. The eastern region (according to existing literature, the authors divide China into three areas: east region, central region, and west region. East region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai,

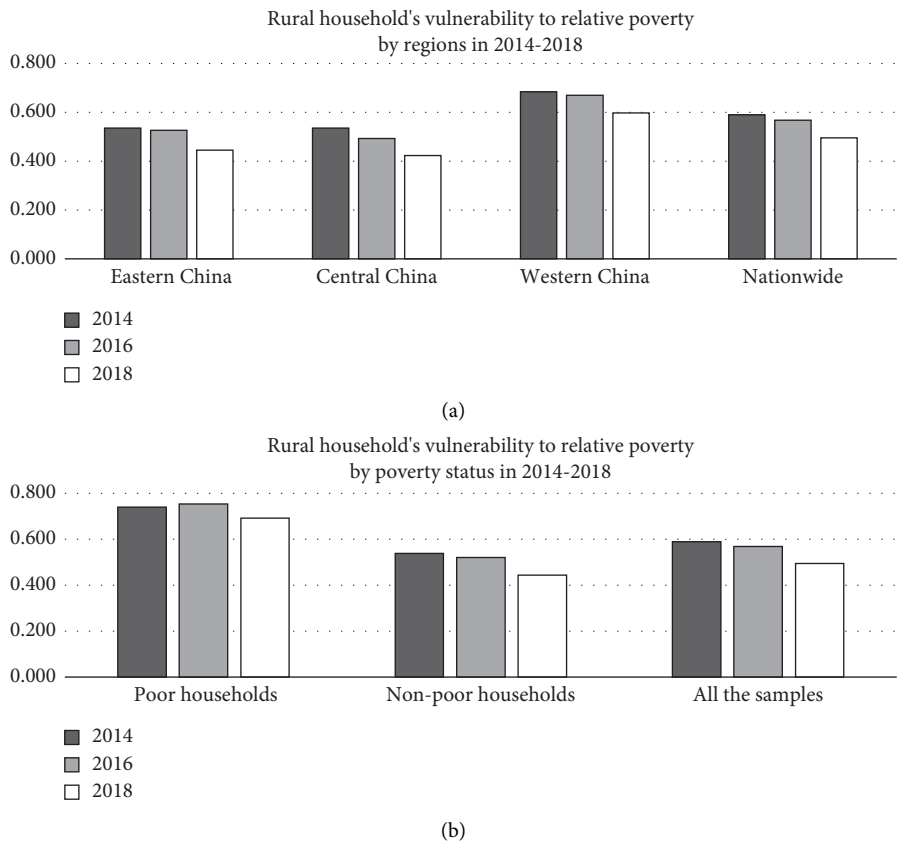


Figure 1: Stylized facts of rural household's vulnerability to relative poverty during 2014–2018.

Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan. The central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan. Western China includes Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, and Chongqing) with a higher level of economic development is associated with lower vulnerability to poverty. The western region with a lower level of economic development is associated with higher vulnerability to poverty. It indicates that the vulnerability to relative poverty has regional heterogeneity. The proportion of vulnerable rural households in central and eastern regions is significantly lower than that in the western region, which is consistent with the fact that most poor rural households in China come from the western region. Vulnerability to relative poverty is both highly correlated with relative poverty, and there are differences between them. Figure 1(b) shows that the vulnerability to relative poverty has poverty status heterogeneity. Under the relative poverty standard, the proportion of households vulnerable to relative poverty in households that are in relative poverty status is higher than that in households that are not in relative poverty status. Due to their own limitations, these poor households are still highly likely to be unable to escape from relative poverty in the future and continue to live in poverty. Rural households that in relative poverty are more likely to fall into relative poverty in the future.

Table 1 shows the relationship between vulnerability to relative poverty and relative poverty. Households in relative poverty and households that are vulnerable to relative poverty cross each other. There are both households that are vulnerable to relative poverty and households that are not vulnerable to relative poverty in households in relative poverty. In other words, rural households currently in relative poverty are not always vulnerable to relative poverty in the future. And rural households currently not in relative poverty are not always nonvulnerable to relative poverty in the future. Rural households are still vulnerable to relative poverty. It means that they have a more than 50% probability of trapping in the relative poverty in the future.

4. Results

4.1. Baseline Regression Results. First, we use the two-way fixed-effects model to analyze the impact of human capital on rural households' vulnerability to relative poverty. The results are shown in the first column of Table 2. On the whole, labor force migration, health, work experience, and education all have a significant negative impact on vulnerability to relative poverty. Among them, labor force migration has the greatest negative impact on vulnerability to relative poverty. The proportion of the labor force migrating to cities increases by 1%, and vulnerability to relative poverty decreases by 29.4%. Rural households' labor force

Table 1: Summary statistics.

Variables	Definitions	Mean	Sd
Vulnerability	Vulnerability to relative poverty	0.554	0.288
HC index	Human capital index	0.400	0.243
Migration	Proportion of labor force migrating to the city for work	0.366	0.383
Health	Average health levels of the labor force	2.973	1.016
Working experience	Average years of working in the labor force	29.32	9.391
Education	Year of education of the labor force	6.266	3.367
Social network	Gift expenditure (yuan) of a household per year, taking the logarithm in regression model	7.055	2.377
Social status	Average self-rated social status of adult respondents in a household	3.042	0.806
Social trust	Average self-rated social trust of adult respondents in a household	1.747	1.475
Dependency rate	Proportion of children under 14 and elders over 65 in a household	0.0850	0.159
Age	Age of head of a household	49.65	11.15
Age2	Age square of the head of a household	2,590	1,096
Marriage	Marriage status of head of a household (married = 1)	0.906	0.291
Gender	Gender of head of a household (male = 1)	0.568	0.495
Water	Household has clean water such as tap water (yes = 1)	0.578	0.494
Cook	Household has clean fuel such as gas (yes = 1)	0.464	0.499
Land	Household has land (yes = 1)	0.941	0.235
Financial asset	Household has a land financial asset (yes = 1)	0.00500	0.0730
House	Household has independent property rights to housing (yes = 1)	0.938	0.241
Car	Household has a car (yes = 1)	0.164	0.370
Minorities area	Village the household lives in is a minorities area (yes = 1)	0.141	0.348
Mining area	Village the household lives in is a mining area (yes = 1)	0.0630	0.244
Polluting enterprise	There is a polluting enterprise in the village the household lives in (yes = 1)	0.144	0.352
Distance to county	Nearest distance from the village the household (yes = 1) lives in the county to which the village belongs (li)	54.40	42.19

Table 2: The impact of human capital on vulnerability to relative poverty.

	Panel	QR_10	QR_25	QR_50	QR_75	QR_90
Mig	−0.294***	−0.306***	−0.303***	−0.294***	−0.285***	−0.282***
	(0.004)	(0.018)	(0.014)	(0.015)	(0.029)	(0.035)
Health	−0.025***	−0.025***	−0.025***	−0.025***	−0.026**	−0.026**
	(0.002)	(0.007)	(0.005)	(0.006)	(0.011)	(0.013)
Workexp	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Edu	−0.029***	−0.029***	−0.029***	−0.029***	−0.028***	−0.028***
	(0.001)	(0.004)	(0.003)	(0.003)	(0.006)	(0.007)
Observations	11,471	11,471	11,471	11,471	11,471	11,471
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note. Numbers in the parentheses represent robust standard error. Significance level: $*\,p < 0.1$, $**\,p < 0.05$, and $***\,p < 0.01$.

migrating to the city to work can help them get higher salaries. It is helpful to reduce vulnerability to relative poverty. Vulnerability to relative poverty decreases by 2.9% when the years of education increase by 1 year. Vulnerability to relative poverty decreases by 2.5% when health level increases by 1 unit. Working experience has little impact on vulnerability to relative poverty decreases. Vulnerability to relative poverty decreases by 0.1% when working experience increases by 1 year.

Second, we use the panel quantile model to analyze the complete situation of the impact of human capital on vulnerability to relative poverty. According to most related studies, we select five fractiles of 0.1, 0.25, 0.5, 0.75, and 0.9 for panel quantile regression. The regression results are shown in columns 2–5 of Table 2, giving a complete situation of the impact of human capital on vulnerability to relative poverty. First, from the 10th to the 90th fractile, labor force migration, education, and health all have significant negative impacts on vulnerability to relative poverty. Moreover, labor force migration has the greatest negative impact on vulnerability to relative poverty among them from the 10th to the 90th fractile. The negative impact of labor force migration gradually decreases with the increase of fractile. Labor force migration has the greatest impact on the vulnerability to relative poverty of rural households, which has a low vulnerability to relative poverty. Vulnerability to relative poverty of rural household that has a low vulnerability to relative poverty decreases by 30.6% when the proportion of

Table 3: Impact of human capital on vulnerability to relative poverty by regions.

	PaneL	QR_10	QR_25	QR_50	QR_75	QR_90
			Panel A: east region			
Mig	−0.316***	−0.326***	−0.323***	−0.316***	−0.309***	−0.306***
	(0.007)	(0.029)	(0.023)	(0.023)	(0.041)	(0.049)
Health	−0.026***	−0.024**	−0.025***	−0.026***	−0.028*	−0.029
	(0.003)	(0.012)	(0.009)	(0.009)	(0.017)	(0.020)
Workexp	−0.001**	−0.001**	−0.001**	−0.001**	−0.001	−0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)
Edu	−0.027***	−0.027***	−0.027***	−0.027***	−0.027***	−0.027**
	(0.002)	(0.006)	(0.005)	(0.005)	(0.009)	(0.011)
Observations	3,956	3,956	3,956	3,956	3,956	3,956
			Panel B: central region			
Mig	−0.301***	−0.312***	−0.309***	−0.302***	−0.293***	−0.290***
	(0.007)	(0.069)	(0.056)	(0.040)	(0.057)	(0.069)
Health	−0.029***	0.030	0.030	−0.029*	0.029	0.028
	(0.003)	(0.027)	(0.022)	(0.015)	(0.022)	(0.027)
Workexp	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.000)	(0.004)	(0.004)	(0.002)	(0.004)	(0.004)
Edu	−0.031***	−0.031**	−0.031***	−0.031***	−0.030**	−0.030**
	(0.002)	(0.015)	(0.012)	(0.008)	(0.012)	(0.015)
Observations	3,336	3,336	3,336	3,336	3,336	3,336
			Panel C: west region			
Mig	−0.265***	−0.279***	−0.275***	−0.265***	−0.254***	−0.250***
	(0.007)	(0.030)	(0.025)	(0.014)	(0.014)	(0.018)
Health	−0.021***	−0.023**	−0.022***	−0.021***	−0.020***	−0.020***
	(0.002)	(0.010)	(0.008)	(0.005)	(0.005)	(0.006)
Workexp	−0.001*	−0.001*	−0.001*	−0.001*	−0.001*	−0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Edu	−0.028***	−0.030***	−0.029***	−0.028***	−0.027***	−0.027***
	(0.001)	(0.005)	(0.004)	(0.002)	(0.003)	(0.003)
Observations	4,179	4,179	4,179	4,179	4,179	4,179
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note. Numbers in the parentheses represent robust standard error. Significance level: $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$. PANEL means the two-way fixed effected model. QR means the panel quantile regression model. QR_10 means the regression results of panel quantile regression model in 10 percentile. QR_25 means the regression results of panel quantile regression model in 25 percentile. QR_50 means the regression results of panel quantile regression model in 50 percentile. QR_75 means the regression results of panel quantile regression model in 75 percentile. QR_90 means the regression results of panel quantile regression model in 90 percentile.

the labor force migrating to cities increases by 1%. At different fractiles of vulnerability to relative poverty, the impact of education and health on vulnerability to relative poverty fluctuates little, and coefficients are basically stable around the estimated value of the two-way fixed-effect model.

4.2. Heterogeneity Analysis

4.2.1. The Impact of Human Capital on Vulnerability to Relative Poverty by Regions. The two-way fixed-effects model regression results are shown in column 1 of Table 3. No matter in the east, central, or west region, labor force migration, health, education, and work experience all significantly reduce vulnerability to relative poverty. Only in east and west regions has working experience a significant negative effect on vulnerability to relative poverty. But the effect is small. Labor force migration has the biggest negative effect on vulnerability to relative poverty in the east region. When the proportion of labor force migration increases by 1%, vulnerability to relative poverty decreases by 31.6%. Health has the greatest negative impact on vulnerability to relative poverty in the central region. When health level increases by 1%, vulnerability to relative poverty decreases by 2.9%. Education has the greatest negative impact on vulnerability to relative poverty in the central region. When years of education increase by 1 year, vulnerability to relative poverty decreases by 3.1%.

Panel quantile regression results are shown in columns 2–6 in Table 3, which provide a complete situation of the impact of human capital on vulnerability to relative poverty in different regions. From the 10th to the 90th fractile, labor force migration has a significant negative impact on vulnerability to relative poverty in eastern, central, and western regions. The impact of labor force migration gradually decreases with the increase of fractile. Labor force migration has the biggest negative impact on rural households that has a low vulnerability to relative poverty in eastern, central, and

Table 4: Impact of human capital on vulnerability to relative poverty by poverty status.

	Panel	QR_10	QR_25	QR_50	QR_75	QR_90
			Panel A: poor households			
Mig	−0.211***	−0.220***	−0.219***	−0.211***	−0.203***	−0.202***
	(0.013)	(0.025)	(0.022)	(0.013)	(0.014)	(0.017)
Health	−0.019***	−0.018***	−0.018***	−0.019***	−0.020***	−0.020***
	(0.004)	(0.007)	(0.006)	(0.003)	(0.004)	(0.005)
Workexp	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Edu	−0.020***	−0.021***	−0.021***	−0.020***	−0.020***	−0.019***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.002)	(0.003)
Observations	2,518	2,518	2,518	2,518	2,518	2,518
			Panel B: nonpoor households			
Mig	−0.310***	−0.315***	−0.314***	−0.310***	−0.306***	−0.305***
	(0.005)	(0.053)	(0.045)	(0.024)	(0.015)	(0.021)
Health	−0.027***	−0.026	−0.027	−0.027***	−0.028***	−0.028***
	(0.002)	(0.020)	(0.017)	(0.009)	(0.006)	(0.008)
Workexp	−0.001**	−0.001***	−0.001**	−0.001	−0.001	−0.001
	(0.000)	(0.000)	(0.000)	(0.002)	(0.001)	(0.001)
Edu	−0.030***	−0.031***	−0.031***	−0.030***	−0.029***	−0.029***
	(0.001)	(0.011)	(0.009)	(0.005)	(0.003)	(0.004)
Observations	8,953	8,953	8,953	8,953	8,953	8,953
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note. Numbers in the parentheses represent robust standard error. Significance level: $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$. PANEL means the two-way fixed effected model. QR means the panel quantile regression model. QR_10 means the regression results of panel quantile regression model in 10 percentile. QR_25 means the regression results of panel quantile regression model in 25 percentile. QR_50 means the regression results of panel quantile regression model in 50 percentile. QR_75 means the regression results of panel quantile regression model in 75 percentile. QR_90 means the regression results of panel quantile regression model in 90 percentile.

western regions. From the 10th to the 90th fractile, the negative impact of education in eastern, central, and western regions fluctuates little, and the regression coefficients are stable around the estimated value of the two-way fixed-effects model. The impact of health on vulnerability to relative poverty in eastern and western regions is complete at different fractiles. In the eastern region, health has a significant negative impact from the 10th to the 75th fractile. The negative impact increases slowly with the increase of fractile. In the western region, health has a significant negative impact from the 10th to the 90th fractile, and the negative impact decreases slowly with the increase of fractile. In the central region, only has health level a negative impact in the 50th fractile.

4.2.2. The Impact of Human Capital on Vulnerability to Relative Poverty by Poverty Status. The two-way fixed-effects model regression results are shown in column 1 of Table 4. No matter rural household is in poor status or nonpoor status, labor force migration, health, and education all significantly reduce vulnerability to relative poverty. Only has work experience a negative effect on vulnerability to relative poverty of nonpoor households. But the effect is little. Labor force migration, health, and education have a greater effect on the vulnerability to relative poverty of nonpoor households than poor households. Vulnerability to relative poverty of poor households decreases by 21.1%, and that of nonpoor households decreases by 31.0% when the proportion of the labor force migrating to cities increases by 1%. Vulnerability to relative poverty of poor households decreases by 1.9%, and that of nonpoor households decreases by 2.7% when health level increases by 1 unit. Vulnerability to relative poverty of poor households decreases by 2.0%, and that of nonpoor households decreases by 3.0% when years of education increase by 1 year.

Panel quantile regression results are shown in columns 2–6 in Table 4, which provide a complete situation of the impact of human capital on vulnerability to relative poverty of households in different poverty statuses. From the 10th to the 90th fractile, the negative impact of labor force migration on vulnerability to relative poverty of poor farmers decreased gradually from −0.220 to −0.202 with the increase of fractile. But, from the 10th to the 75th fractile, the negative impact of labor force migration on vulnerability to relative poverty of nonpoor farmers decreased gradually from −0.315 to−0.306 with the increase of fractile. From the 75th to the 90th fractile, the negative impact increases from −0.306 to −0.315. For poor households, the negative impact on health increases slowly with the increase of fractile. For nonpoor households, only has health a significant negative impact from the 50th fractile to the 75th fractile. The negative influence of education fluctuates little both on poor and nonpoor households. The regression coefficients are stable around the estimated value of the two-way fixed-effects model.

Table 5: Endogeneity analysis.

	Fe	IV-FE	IV exogenesis test	
HCindex	−0.521***	−0.460***		−0.527***
	(0.008)	(0.023)		(0.008)
Village_HCindex			−0.442***	−0.064***
			(0.029)	(0.023)
Observations	11,471	11,471	11,471	11,471
Controls	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Davidson-MacKinnon p value		0.001***		
First stage F-stat		706.34		
First stage T value		26.58***		

Note. Numbers in the parentheses represent robust standard error. Significance level: $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

4.3. Endogeneity Analysis. We use an instrumental variable to solve potential endogeneity problems in the regression model. Based on the ideas of Rozelle [33], we adopt the human capital index of the village where rural household lives as an instrument variable. The human capital of villages is inevitably related to the human capital of rural households living in, and it does not directly affect the vulnerability to relative poverty of individual rural households. Theoretically speaking, the establishment of this logic requires that instrument variables meet the two conditions of relevance and exclusivity. Table 5 shows the 2SLS estimation result. The Davidson–MacKinnon endogeneity test result rejects the null hypothesis that there is no endogeneity problem in the formula (6) at the 1% level of significance, indicating that rural households' human capital index is endogenous. In the first stage regression, the Kleibergen-Paap rk Wald F-statistic is 706.34, which is far beyond the critical value of 16.38 at the 10% level of error, indicating that there is no weak instrument variable problem. In addition, the t value of the instrument variable is 26.58, passing the 1% level of a significance test, indicating that there is a strong correlation between the rural household's human capital index and the instrument variable. Column 2 shows the estimated result in the second stage regression. The coefficient of the human capital index is –0.460 at the 1% level of significance. Vulnerability to relative poverty decreases by 46.0% when the human capital of rural household index increases by one unit. Compared with the result in column 1, the influence direction and significance of the human capital index are basically consistent with an estimation of the two-way fixed-effects model. The estimated result of 2SLS indicates that the impact of human capital on vulnerability to relative poverty is overestimated due to the existence of endogenous problems.

The assumption of the exclusivity of the instrument variable cannot be tested directly because the instrument variable is just identified. Referring to the approach of Ashraf [34], we use an alternative test as follows. We use the instrument variable to replace the key explanatory variable and regress. The result is shown in column 3. Then we put the human capital index and the instrument variable in the model at the same time and regress. The result is shown in column 4. In column 3, where only is instrument variable controlled, the village human capital index of the village significantly reduces vulnerability to relative poverty at the 1% level of significance. In column 4, where both the human capital index of household and the instrument variable are controlled, human capital significantly reduces vulnerability to relative poverty t the 1% level of significance. The impact of the human capital of households on vulnerability to relative poverty decreases from −0.442 to −0.064. This auxiliary test supports the exclusivity hypothesis of the instrument variable in this paper

Table 6: Moderating effect of social capital.

	Panel
Household_HCindex*	−0.487***
Household_SCindex	(0.061)
Household_HCindex	−0.378***
	(0.020)
Household_SCindex	−0.164***
	(0.025)
Controls	Yes
Household FE	Yes
Year FE	Yes

Note. Numbers in the parentheses represent robust standard error. Significance level: $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Table 7: Robustness check.

	Relative poverty line, 40% of median income		Relative poverty line, 60% of median income	
HCindex		−0.529***		−0.449***
		(0.007)		(0.008)
Mig	−0.297***		−0.255***	
	(0.004)		(0.005)	
Health	−0.024***		−0.023***	
	(0.002)		(0.002)	
Workexp	−0.001*		−0.001***	
	(0.000)		(0.000)	
Edu	−0.029***		−0.025***	
	(0.001)		(0.001)	
Observations	11,471	11,471	11,471	11,471
Controls	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

from one side: human capital of village reduces vulnerability to relative poverty of household by increasing human capital of household, but it does not directly affect vulnerability to relative poverty of household.

4.4. Moderating Effect of Social Capital. Some scholars point out that whether human capital can play a role in poverty depends on its social environment. Social capital such as social networks, social trust, and social status can play a certain role in the development of farmers. We also adopt the entropy method to calculate the social capital index of rural households. We put both the human capital index and the social capital index and their interaction terms into the estimation model to explore the moderating effect of social capital on the relationship between human capital and vulnerability to relative poverty. The sign of the interaction coefficient and its significance is worth paying attention to. The regression results are shown in Table 6. The results show that the interaction coefficient is negative at the 1% level of significance, indicating that social capital strengthens the negative effect of human capital on vulnerability to relative poverty.

4.5. Robustness. We use strategies to test robustness as follows. The relative poverty line in the baseline regression is 50% of median income. We changed the relative poverty judgment standard and adopted 40% and 60% of the median income as the relative poverty line respectively. The regression results are shown in Table 7. The change in relative poverty standard does not change the conclusion of this paper. The empirical results in baseline regression are robust.

5. Conclusions

Drawing on three-wave panel data from China Family Panel Studies (CFPS) of 2014, 2016, and 2018, we measure rural households' vulnerability to relative poverty by using the three-stage feasible generalized least squares (FGLS) model. Then we analyze the impact of human capital on rural households' vulnerability to relative poverty by using the two-way fixed-effects model and panel quantile model. The descriptive results show that rural households' vulnerability to relative poverty in China is descending over time. Rural households in the western region are most vulnerable to relative poverty.

The empirical results indicate that labor force migration, health level, years of education, and work experience have a significant negative impact on vulnerability to relative poverty. Labor force migration has the greatest impact on farmers' vulnerability to relative poverty. The influence of different dimensions of human capital on vulnerability to relative poverty varies. With the increase of fractile, the impact of labor force migration gradually decreases, but the impact of years of education and health level fluctuated little. The results of heterogeneity analysis show that no matter in the east, central, or west region, labor force migration, health level, years of education, and work experience all significantly reduce vulnerability to relative poverty. Only in east and west regions has working experience a significant negative effect on vulnerability to relative poverty. But the effect is small. Labor force migration has the biggest negative effect on vulnerability to relative poverty in the east region. Both health and years of education have the greatest negative impact on vulnerability to relative poverty in the central region. Regardless of whether the rural household is in poor status or nonpoor status, labor force migration, health level, and years of education all significantly reduce vulnerability to relative poverty. Only has work experience a negative effect on vulnerability to relative poverty of nonpoor households. But the effect is little. Labor force migration, health level, and years of education have a greater effect on the vulnerability to relative poverty of nonpoor households than poor households.

Conclusions above have policy implications as follows. First, although China has achieved initial success in poverty alleviation, major changes have taken place in the structure of social poverty, with people in relatively poverty status becoming the main group. Under the current antipoverty background, China's poverty alleviation work will change from eliminating absolute poverty to alleviating relative poverty. Most rural households' vulnerability to relative poverty are still very high. Therefore, the government should consider the vulnerability to relative poverty when assess rural household's poverty.

The government should continue to promote policies such as industrial targeted poverty alleviation and transfer employment targeted poverty alleviation to provide more job opportunities for rural households. The government should also enhance the human capital accumulation of rural households. For example, more skills training courses should be held to improve the vocational skills of farmers. The government should guide farmers form their own awareness of poverty alleviation. The government will continue to improve the new rural cooperative medical care insurance and expand the coverage of insurance to ensure the health of farmers.

Data Availability

The CFPS data used to support the findings of this study have been deposited in http://www.isss.pku.edu.cn/cfps.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

J.S. contributed to the following aspects: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, and supervision. G.R. contributed to the following aspects: validation, writing—original draft preparation, writing—review and editing, and project administration. All

authors have read and agreed to the final version of the manuscript.

References

[1] A. T. Q. Pham and P. Mukhopadhaya, "Multidimensionl poverty and the role of social capital in poverty alleviation among ethnic groups in rural Vietnam: a multilevel analysis," *Social Indicators Research*, vol. 159, no. 1, pp. 281–317, 2022.

[2] H. Xiao, X. Zheng, and L. Xie, "Promoting pro-poor growth through infrastructure investment: evidence from the Targeted Poverty Alleviation program in China," *China Economic Review*, vol. 71, Article ID 101729, 2022.

[3] Y. Shen and S. Alkire, "Exploring China's potential child poverty," *China and World Economy*, vol. 30, no. 1, pp. 82–105, 2022.

[4] G. Wan, X. Hu, and W. Liu, "China's poverty reduction miracle and relative poverty: focusing on the roles of growth and inequality," *China Economic Review*, vol. 68, Article ID 101643, 2021.

[5] L. Zhang, Y. Yan, W. Xu, J. Sun, and Y. Zhang, "Carbon emission calculation and influencing factor Analysis based on industrial big data in the "double carbon" era," *Computational Intelligence and Neuroscience*, vol. 2022, Article ID 2815940, 12 pages, 2022.

[6] Y. Mare, Y. Gecho, and M. Mada, "Assessment of multidimensional rural poverty in Burji and Konso area, Southern Ethiopia," *International Review of Economics*, vol. 69, pp. 1–21, 2022.

[7] Y. Shen and S. Li, "Eliminating poverty through development: the dynamic evolution of multidimensional poverty in rural China," *Economic and Political Studies*, vol. 10, pp. 1–20, 2022.

[8] X. Li, Q. Gao, and J. Tang, "Who are identified as poor in rural China's targeted poverty alleviation strategy? Applying the multi-dimensional capability approach," *Journal of Chinese Political Science*, vol. 27, pp. 1–26, 2022.

[9] L. Shi, Y. Wang, Y. Liu, and Y. Li, "The poverty evolution of typical countries along the Belt and Road and implications from China's poverty reduction experiences," *Journal of Geographical Sciences*, vol. 32, no. 3, pp. 458–476, 2022.

[10] D. Zhou, K. Cai, and S. Zhong, "A statistical measurement of poverty reduction effectiveness: using China as an example," *Social Indicators Research*, vol. 153, no. 1, pp. 39–64, 2021.

[11] X. Qi, S. Ye, Y. Xu, and J. Chen, "Uneven dynamics and regional disparity of multidimensional poverty in China," *Social Indicators Research*, vol. 159, no. 1, pp. 169–189, 2022.

[12] World Bank, *World Development Report 2000/2001: Attacking poverty*, Washington,D.C.: World Bank, 2001.

[13] Y. Zhang, W. Wang, and Y. Feng, "Impact of different models of rural land consolidation on rural household poverty vulnerability," *Land Use Policy*, vol. 114, Article ID 105963, 2022.

[14] T. W. Schultz, "Investment in human capital," *The American Economic Review*, vol. 51, no. 1, pp. 1–17, 1961.

[15] P. M. Romer and M. Romer, "Endogenous technological change," *Journal of Political Economy*, vol. 98, no. 5, Part 2, pp. S71–S102, 1990.

[16] M. Collin and D. N. Weil, "The effect of increasing human capital investment on economic growth and poverty: a simulation exercise," *Journal of Human Capital*, vol. 14, no. 1, pp. 43–83, 2020.

[17] A. Sen, *Poverty and Famines: An Essay on Entitlement and Deprivation*, Oxford University Press, Oxford, UK, 1982.

[18] S. Bawono, "Human capital, technology, and economic growth: a case study of Indonesia," *Journal of Asian Finance, Eco-nomics and Business*, vol. 08, 2021.

[19] P. Brown and D. James, "Educational expansion, poverty reduction and social mobility: reframing the debate," *International Journal of Educational Research*, vol. 100, Article ID 101537, 2020.

[20] M. Filandri, S. Pasqua, and E. Struffolino, "Being working poor or feeling working poor? The role of work intensity and job stability for subjective poverty," *Social Indicators Research*, vol. 147, no. 3, pp. 781–803, 2020.

[21] Y. Guo and J. Wang, "Poverty alleviation through labor transfer in rural China: evidence from Hualong County," *Habitat International*, vol. 116, Article ID 102402, 2021.

[22] R. Wedgwood, "Education and poverty reduction in Tanzania," *International Journal of Educational Development*, vol. 27, no. 4, pp. 383–396, 2007.

[23] F. R. Moeis, T. Dartanto, J. P. Moeis, and M. Ikhsan, "A longitudinal study of agriculture households in Indonesia: the effect of land and labor mobility on welfare and poverty dynamics," *World Development Perspectives*, vol. 20, Article ID 100261, 2020.

[24] Y. Shen, "Human capital and rural residents' poverty dynamic changes, Rural Poverty, Growth, and Inequality in China," *Rural Poverty, Growth, and Inequality in China*, Springer, Singapore, pp. 165–183, 2022.

[25] K. Bird, B. Chabé-Ferret, and A. Simons, "Linking human capabilities with livelihood strategies to speed poverty reduction: evi-dence from Rwanda," *World Development*, vol. 151, p. 105728, 2022.

[26] O. Gloede, L. Menkhoff, and H. Waibel, "Shocks, individual risk attitude, and vulnerability to poverty among rural households in Thailand and Vietnam," *World Development*, vol. 71, pp. 54–78, 2015.

[27] K. S. Imai, R. Gaiha, and G. Thapa, "Does non-farm sector employment reduce rural poverty and vulnerability? Evidence from Vietnam and India," *Journal of Asian Economics*, vol. 36, pp. 47–61, 2015.

[28] J. Chen, S. Rong, and M. Song, "Poverty vulnerability and poverty causes in rural China," *Social Indicators Research*, vol. 153, no. 1, pp. 65–91, 2021.

[29] S. Chaudhuri, J. Jalan, and A. Suryahadi, *Assessing Household Vulnerability to Poverty from Cross-Sectional Data: A Methodology and Estimates from Indonesia*, pp. 1–25, Columbia University, New York, 2002.

[30] T. Ameniya, "The maximum likelihood estimator and the nonlinear three-stage least squares estimator in the general non-linear simultaneous equation model," *Econometrica*, vol. 45, no. 4, pp. 955–968, 1977.

[31] Y. Zhang and G. Wan, "An empirical analysis of household vulnerability in rural China," *Journal of the Asia Pacific Economy*, vol. 11, no. 2, pp. 196–212, 2006.

[32] M. Ravallion and S. Chen, "Weakly relative poverty," *The Review of Economics and Statistics*, vol. 93, no. 4, pp. 1251–1261, 2011.

[33] S. Rozelle, J. E. Taylor, and A. DeBrauw, "Migration, remittances, and agricultural productivity in China," *The American Economic Review*, vol. 89, no. 2, pp. 287–291, 1999.

[34] Q. Ashraf and O. Galor, "The "out of africa" hypothesis, human genetic diversity, and comparative economic development," *The American Economic Review*, vol. 103, no. 1, pp. 1–46, 2013.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9823083, 1 page
https://doi.org/10.1155/2023/9823083

Retraction

Retracted: An Empirical Study on the Influencing Factors of the Returning Intention of Overseas Talents

Discrete Dynamics in Nature and Society

Received 3 October 2023; Accepted 3 October 2023; Published 4 October 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] L. Liu and F. Tian, "An Empirical Study on the Influencing Factors of the Returning Intention of Overseas Talents," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2778287, 7 pages, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2778287, 7 pages
https://doi.org/10.1155/2022/2778287

Research Article

An Empirical Study on the Influencing Factors of the Returning Intention of Overseas Talents

Liu Liu[1] and Fan Tian[2]

[1]*Department of Public Administration, Chinese Communist Party School of Nanjing, New Era Development Research Institute of Nanjing, Nanjing 210046, China*
[2]*Institute of Social Development, Chinese Academy of Macroeconomic Research, Beijing 100044, China*

Correspondence should be addressed to Fan Tian; tianfan0419@sina.com

Received 17 February 2022; Accepted 22 March 2022; Published 14 May 2022

Academic Editor: Lele Qin

Many scholars have carried out a large number of studies on the factors influencing the intention of returning overseas talents based on different theories. This study integrates two theoretical perspectives at macro and individual levels, puts forward a new theoretical framework for analyzing the intention of returning overseas talents, and constructs a theoretical model including the intention of returning overseas talents, talent ecological environment of the host country, prospect expectation of home country, talent growth expectation, and perceived opportunity. Based on 302 survey samples, we used correlation analysis, confirmatory factor analysis, structural equation, and other methods, and the results show that four variables, including talent ecological environment of the host country, prospect expectation of home country, talent growth expectation, and perceived opportunity, have a significant impact on the intention of returning overseas talents. The research also found that talent growth expectation and perceived opportunity had mediating effects, and the prospect expectation and perceived opportunity of origin had moderating effects, which provides a new research idea for the research on the factors influencing the return intention of overseas talents.

1. Introduction

With the changing globalization trend, the situation of the transnational flow of talents is also changing. For developing countries, it is crucial for the next stage of development that how to attract the talents working overseas back, which is receiving more and more attention.

Theories to explain the transnational flow of human capital include two directions. One is from the macro level, and the representative theory is the push-pull theory. The theory holds that various positive factors in the places of immigration will produce pull, while various negative factors will produce the force of push. The combined action of the force of push and pull produces the flow of human capital [1]. Studies based on the push-pull theory mainly analyze the influences of various external environmental factors on the transnational flow of human capital from the macro level. In addition, such studies generally do not involve an individual microscopic investigation. Early studies have pointed out that the international differences in individual remuneration are an important reason for brain drain. Compared with low-skilled workers, talents are more sensitive to economic factors [2]. The long-term backward economic level will also lead to a vicious cycle; that is, a low economic level leads to low salary level, which leads to brain drain and further affects the economic development [3]. Environmental factors are also important factors leading to brain drain. When the environments of working, education, policies, and living in the source country are unfavorable for talents to make the most of themselves, they will initiatively choose to develop themselves in countries or regions that can provide stronger support and better conditions [4].

The other direction is from the individual level, and representative theories include field theory, ERG, and theory. According to the field theory, the behavior of individuals is not only determined by their own abilities and qualities but also affected by the surrounding environments. The motivation behavior of individuals in transnational

mobility is jointly determined by the "psychological life space" composed of the "psychological field" and "environmental field." ERG theory points out that the three core needs of individual existence, relatedness, and growth jointly promote the transnational flow of talents, among which growth is the core demand of career development [5]. These studies mainly focus on the individual level to analyze individual psychological activities and perception of the macro environment. In addition, the perspective of this kind of study focuses on the retaining of talents for the region, and the objects are mainly individuals of transregional flowing. Studies show that regional environment and talent growth expectations can play a significant role in promoting regional talent agglomeration. Other studies show that the talent ecological environment and talent growth region of the host country can significantly promote the willingness of expatriates to stay abroad [6].

Based on the integration of previous theories, this paper will form a new theoretical perspective, which will analyze the influence of talent ecological environment of the host country and prospect expectation of the home country from the macro level as well as talents' growth expectation and perceived opportunity from the individual level on overseas talents return intention under the combined effect of the force of push and pull. It is expected that the conclusions of this study can not only fill in the theoretical gaps of previous studies to a certain extent but also provide new ideas for future studies.

2. Research Design

2.1. Research Hypothesis Development

2.1.1. Talent Ecological Environment of Host Country and Returning Intention. Talent ecological environment refers to the external environment that can meet people's needs directly or indirectly. According to the research ideas of McElroy [7], this study defines the extension of talent ecological environment as four aspects: economy, life, culture, and policies. The economic scale and strength of different countries are important factors affecting the international flow of talents, and higher remuneration is the main demand affecting the transregional flow of talents [8]. The living environment is an important reference for talents to consider whether to stay for a long time, and the living infrastructure represented by recreational facilities is a necessary factor to attract highly educated talents who have advantages of technic and education. As these talents grow older and become parents, the importance of education gets more and more important [9]. Openness and inclusiveness have significant influences on the transregional flow and aggregation of talents. There is a significant positive correlation between the spatial distribution of highly educated talents and the inclusive and open social atmosphere of the city [10]. Personnel policy will have a positive influence on the flow and aggregation of talents, and good policies in the destination country are one of the driving forces of the flow of talents [11]. Based on these four aspects, one hypothesis is put forward in this paper:

Hypothesis 1. The talent ecological environment of the host country has a negative influence on the returning intention of overseas talents.

2.1.2. Talent Ecological Environment and Talents' Growth Expectation. Talents' growth expectation refers to the psychological evaluation of talents' growth after judging their environment based on the information and experiences they own. The talent ecological environment of the host country has a direct influence on the cultivation and development of talents. The constant improved economic development level, continuous improved living service facilities, good talent policies, and a cultural environment with strong inclusiveness and a good atmosphere of innovation can offer good learning and growing environment for talents and provide more opportunities, which positively affect the psychological expectation of talent growth [6]. Based on this, the hypothesis in this paper is proposed as follows.

Hypothesis 2. The talent ecological environment of the host country has a positive influence on talents' growth expectation.

2.1.3. Talents' Growth Expectation and Returning Intention. Talent is a relative concept. Compared with general human resources, talents have a stronger desire to realize their own value and a better pursuit of career development [6]. Similarly, talents' growth is a dynamic process. If the environment cannot meet their needs for career development, the possibility of turnover will be significantly increased [12]. Studies have shown that career development plays a leading role among those factors affecting talent flow decision-making [13]. When a region can provide wider space for development, material life of higher level, and more convenient access to information than other regions, its attraction ability will be significantly improved [14]. Especially for overseas talents, it costs high for them to leave their home to a new environment for work and study. Therefore, they have a better pursuit of career development, and they are more willing to accept new tasks and new challenges with reselecting the place of development [6]. As the external environment changes, the growth expectation of the overseas talents will be constantly adjusted driven by their growing demand. When overseas talents think their current growth expectation is high, the chances to make return decisions will be reduced. On the contrary, when they think the expectation is low, the chances will be increased. Based on this, the hypothesis is proposed.

Hypothesis 3. Talents' growth expectation has a negative influence on overseas talents returning intention.

2.1.4. Expectation of Native Country Prospect and Returning Intention. According to the push-pull theory, the expectation of native country prospects and the talent ecological environment of the host country is a pair of corresponding variables. The return of overseas talents is the result of the joint action of both native and host countries, and the

development level of the native country has a very important influence on overseas talents' decision whether to return or not. From the perspective of economics, an individual's decision is the action about the future made on the basis of current situations. In order to get the maximum utility, an individual will predict the future values of various variables affecting individual utility and take corresponding actions [15]. Overseas talents will make the decision whether to return according to their judgment on the development prospect of their native country. If they are optimistic about the development prospect of their home country, they are more likely to choose to return; otherwise, if they are not optimistic about it, they are less likely to choose to return. Based on this, in this paper, the fourth hypothesis is proposed.

Hypothesis 4. The expectation of native country prospect has a positive influence on returning intention.

2.1.5. Perceived Opportunity and Returning Intention. Theoretically, making the decision of whether to change jobs or not can be expressed as a function of the difficulties of changing jobs they perceived [16], in which the perception of external job opportunities is very important, mainly referring to perceiving the ease of finding an alternative job. It also means the ability to find a new job that matches the current one [17]. When employees make decisions of changing jobs, they will make a comparison at two levels. The first one is to directly compare all other choices and evaluate the results that may be brought by changing job. The second is to compare from the perspective of opportunity cost. If the former is higher, with satisfaction declining, the employee will finally take action to change the current situation [18]. Perceived opportunity in this study mainly refers to overseas talents perceiving the ease of returning to their native country for employment. Similarly, based on the push-pull theory, when overseas talents choose whether to return, they will evaluate and compare the two situations of continuing to work abroad and returning according to the expected development situation in the two countries and then make choices. External opportunities will psychologically prompt employees to choose leaving or transregional departure [19], which is also applicable to overseas talents, and when they think they can find a more promising job in the domestic market, there will be greater uncertainty in their career choice, and they may be attracted by the domestic opportunities. On the contrary, when they feel that there are few opportunities in the domestic market, they are more inclined to continue working abroad to avoid all kinds of uncertainty. Based on this, the hypothesis is proposed.

Hypothesis 5. Perceived opportunity has a positive influence on the returning intention of overseas talents.

2.1.6. Expectation of Native Country Prospect and Perceiving Opportunity. Employment is an important indicator to evaluate the development level of a region. The higher the level of development and the more vigorous a region is, the better the prospect of its employment market will be [20]. Similarly, the higher the talent's expectation of the development prospects of a region, the higher their expectation of its employment prospects will be. As a group of talents more excellent than general human resources [21], they will also have a higher judgment on their own employment opportunities when they have a higher judgment on the employment prospects of a region. Overseas talents with a higher level of education and more courage to challenge themselves have a stronger identification of their talent attributes [22]. When they are optimistic about the development prospect of our country, they will be more optimistic about their career prospects returning back, while when they are not optimistic about it, they will also accordingly show a negative attitude towards their career prospect. Based on this, the hypothesis is proposed:

Hypothesis 6. The expectation of native country prospect has a positive influence on perceived opportunity.

2.1.7. The Mediating Effect of Talents' Growth Expectation and Perceived Opportunity. In this paper, it is believed that the expectation of overseas talents on the talent ecological environment of the host country and the prospect of the native country will lead to the change of talents' growth expectation and perceived opportunities and then have different influences on their returning intention. On the one hand, if overseas talents are satisfied with the talent ecological environment of the host country, they will be more optimistic about their career development prospect in the host country [21], which will have a negative influence on their returning intention. On the other hand, if they have a high expectation of the development prospect of their native country, they will also have a better judgment of the expected benefits of their return [22], which will have a positive influence on their returning intention. Based on this, the hypothesis is proposed:

Hypothesis 7

(a) Talents' growth expectation has a mediating effect on the negative relationship between talent ecological environment of host country and overseas talents' returning intention

(b) Talents' growth expectation has a mediating effect on the positive relationship between expectation of native country prospect and overseas talents' returning intention

2.1.8. The Adjustment Effects of the Expectation of Native Country Prospect and Perceived Opportunity. Hom et al. found that labor market conditions have an adjustment effect on the relationship between being discontented with work and voluntary turnover [23]. When the labor market is tight, it could hinder their individual development to leave the job and even make them unable to find an alternative job.

Therefore, in this case, being discontented with work has a relatively weak influence on voluntary turnover. Youngblood et al. and Gerhart (1987) found that the effect of job satisfaction on turnover was stronger when the unemployment rate was low [24]. Wheeler et al. found through empirical research that perceiving opportunity has an adjustment effect on the relationship between employees' job satisfaction and turnover intention [17]. When overseas talents have a poor judgment on their overseas career development, there will be a certain degree of returning intention, which is affected by perceived opportunity: if overseas talents' perception of development opportunity of returning is higher, they will find it more beneficial for their own career growth, which will lead a higher tendency of returning. Similarly, it is also reasonable to believe that overseas talents will have a higher tendency to return when they are not satisfied with the talent ecological environment of the host country as well as a higher expectation of the prospect of the native country. Figure 1 shows the correlativity. Based on this, the hypothesis is proposed.

Hypothesis 8

(a) Perceived opportunity has an adjustment effect on the positive relationship between the talents' growth expectation and the returning intention of overseas talents

(b) The expectation of native country prospect has an adjustment effect on the negative relationship between the talent ecological environment of the host country and the returning intention of overseas talents

2.2. Design of Questionnaire

2.2.1. Talent Ecological Environment of Host Country Scale and Expectation of Native Country Prospect Scale. The scale of the talent ecological environment of the host country has been borrowed the scale of the talent ecological environment of the host country which is revised by Wang et al. and compiled by Yang [6]. On the scale, there are 4 items with "Good momentum of economic development in this region" as a representative topic. The Cronbach's α of the scale in this study is 0.823. The scale of expectation of native country prospect is also designed on the basis of the ideas of Wang et al. [6] and Yang [14]. There are 4 items in this scale with "I think China's economic maintains a good momentum of development" as a representative topic. The Cronbach's α of this scale is 0.823 in this study.

2.2.2. Overseas Talents Returning Intention Scale. The scale of overseas talents returning intention is designed based on the ideas of Yang, which has 4 items with topics such as "I will resolutely leave here if I can find a suitable job in China" [25]. The Cronbach's α scale in this study is 0.796.

2.2.3. Talents' Growth Expectation Scale. The talents' growth expectation scale adopts the 6-item scale used by Wang, with representative topics such as "Working her, I have many opportunities for growth and development" [6]. The Cronbach's α of the scale in this study is 0.875.

2.2.4. Perceived Opportunity Scale. The perceived opportunity scale has borrowed the perceived opportunity scale compiled by Weng [9]. There are 4 items with representative topics such as "There are many other opportunities for me to choose if I'm back to China." The Cronbach'α of the scale in this study is 0.837 (as shown in Table 1).

The 5-division Likert scale is used in all questions in this study, and the options from 1 to 5 are "very inconsistent," "not very consistent," "uncertain," "relatively consistent," and "very consistent," respectively.

2.3. Distributing and Collecting Questionnaires. In this study, overseas talents who had worked abroad for more than two years are the investigation sample, and 324 questionnaires were distributed and collected. 302 valid questionnaires were obtained after getting rid of the questionnaires with repeated values and obvious logical errors, and thus, an effective rate of 93.2% is obtained. In this investigation, the male accounted for 53.4%, with the female 46.6%. For age distribution, 49.3% of them were 21–30 years old, 27.8% were 31–40 years old, and 22.9% aged 41 or over. In terms of educational background, 13.3% of them have bachelor's degree, 66.4% have master's degree, and 20.3% have doctor's degree.

3. Empirical Analysis

3.1. Confirmatory Factor Analysis. SPSS 25.0 software was used for correlation analysis. A confirmatory factor analysis was conducted to test the discriminant validity of the variables (host country talent ecological environment, talents' growth peak, overseas talent return intention, home country prospect expectation, and perceived opportunity). As shown in Table 2, the data fitting effect of the five-factor model is the best (CFI = 0.929, TLI = 0.908, RMSEA = 0.061, SRMR = 0.052), which indicates a good discriminative validity of the five variables in the study.

3.2. Correlation Analysis. AMOS 19.0 was used for correlation analysis. The results show that there is a high correlation between talent ecological environment, talents' growth expectation, and talents' settling intention in the host country. Also, there is a high correlation between the returning intention of overseas talents, the expectation of their native country prospect, and the perception of opportunities while there is an obvious negative correlation between the settling intention and the returning intention of overseas talents, which is consistent with the hypotheses of this paper (Table 3).

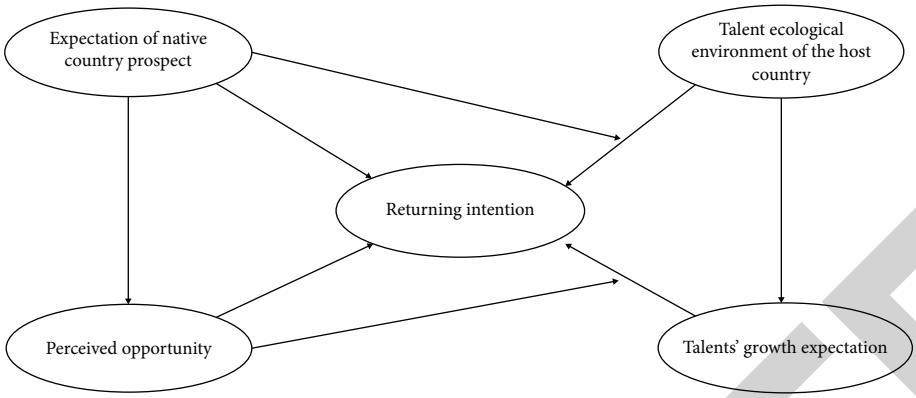


Figure 1: Correlativity model diagram.

Table 1: Perceived opportunity scale.

Scale	Options	Cronbach'α
Willingness to return overseas talents	If I find a suitable job opportunity in China, I will leave my current place immediately I'm thinking of coming back to China I had little thought of coming back to China I tried to find new job opportunities in China	0.796
Talent ecological environment of host country	I am very optimistic about the economic situation in this region I really like the living conditions in this area I really like the cultural atmosphere of this area I am very pleased with the talent policy of the district	0.823
Prospective home country	I am very optimistic about China's economic situation I really like the living environment in China I really like the cultural atmosphere in China I think China's talent policy is very attractive to me	0.823
Talent growth expectation	Working here offers me many opportunities for growth and development My job offers quite a lot of practical opportunities I can feel a sense of accomplishment and belong in my work My job is full of challenges My job has a smooth promotion channel and a lot of room for advancement I got a raise at work	0.875
Perceived opportunities	It will not be hard for me to leave here and go back to China and find another one I feel there are many opportunities for me to develop in China With my current skills and qualifications, it would be easy to find a satisfying job back in China Back in China, I had plenty of other job opportunities to choose from	0.837

Table 2: Confirmatory factor analysis.

Model	$\triangle\chi^2$ ($\triangle$df)	CFI	TLI	RMSEA	SRMR
5-factor model (HE; GP; OI; AP; PO)	—	0.929	0.908	0.061	0.052
4-factor model (HE + GP; OI; AP; PO)	89.3 (1)	0.854	0.817	0.072	0.069
3-factor model (HE + GP; OI; AP + PO)	122.4 (2)	0.732	0.894	0.085	0.101
2-factor model (HE + GP; OI + AP + PO)	143.2 (4)	0.643	0.602	0.129	0.137
Single-factor model (HE + GP + OI + AP + PO)	547.9 (5)	0.505	0.474	0.197	0.199

Note. HE = Host country talent ecological environment, GP = talents' growth prediction, OI = overseas talents' returning intention, AP = anticipative prospect of native country prospect, and PO = perceived opportunity.

3.3. Path Coefficient Analysis. The test results of the structural equation model are sorted out and then shown in Table 4. The talent ecological environment of the host country has a significant influence on the returning intention of the overseas talents (−0.227, 1% level of significance), while it has a significant positive influence on the talent growth expectations (0.289, 1% level of significance). However, talent growth expectation has a significant negative influence on the returning intention of the overseas talents (−0.309, 1% level of significance). All the above had

Table 3: Correlation analysis.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) HE	1							
(2) GP	0.201***	1						
(3) OI	−0.114*	−0.103*	1					
(4) AP	0.021	−0.067	0.238***	1				
(5) PO	0.032	−0.053	0.189***	0.205**	1			
(6) Gen	0.056	0.029	0.021	0.045	0.037	1		
(7) Age	−0.098*	0.043	0.067	0.089	0.043	0.019	1	
(8) Edu	−0.112	0.047	0.076	0.076	0.044	0.071	0.132	1

Note. *** and ***stand for significant levels of 10%, 5%, and 1%, respectively.

Table 4: Model effect analysis.

Path	Coefficient	S.E.	P
HE ⟶ OI	0.277	0.167	<0.01
HE ⟶ GP	0.289	0.144	<0.01
GP ⟶ OI	0.309	0.149	<0.01
HE ⟶ GP ⟶ OI	0.089	0.152	<0.05
HE ∗ AP ⟶ OI	−0.119	0.108	<0.05
AP ⟶ OI	0.459	0.094	<0.01
AP ⟶ PO	0.477	0.109	<0.01
PO ⟶ OI	0.514	0.062	<0.01
AP ⟶ PO ⟶ OI	0.245	0.083	<0.01
GP ∗ PO ⟶ OI	−0.128	0.089	<0.01

been verified in Hypothesis 1, Hypothesis 2, and Hypothesis 3. The expectation of native country prospect has a significant positive influence on the returning intention of overseas talents (0.459, 1% level of significance), and it has a significant positive influence on perceiving opportunities (0.477, 1% level of significance), which also has a significant positive influence on the returning intention of overseas talents (0.514, 1% level of significance). Therefore, Hypothesis 4, Hypothesis 5, and Hypothesis 6 are verified.

Talent growth expectation has a mediating effect on the relationship between the talent ecological environment of the host country talent and the returning intention of overseas talents (−0.089, 5% level of significance), and because of the significant direct effect of the talent ecological environment of the host country on overseas talents returning intention, it is a partial mediating effect, of which the total response value is 0.366. The perceived opportunity has a mediating influence on the relationship between the expectation of native country prospect and the returning of overseas talents (−0.245, 1% level of significance) and causes a direct effect of the prospect expectation of native country on the intention of returning overseas talents is significant, and its total response value is 0.704. Both Hypothesis 7 (a) and (b) are verified.

Perceived opportunities have an adjustment effect on the negative relationship between the talent growth expectation and the returning intention of the overseas talents (−0.119, 5% level of significance), and the expectation of the native country has an adjustment on the negative relationship between the talent ecological environment in the host country and the returning intention of the overseas talents (−0.128, 1% level of significance). Both Hypothesis 8 (a) and (b) are verified.

4. Discussions and Conclusions

In this study, a new theoretical model is established after combining previous theories. An empirical analysis is conducted by taking Chinese overseas talents who have worked abroad for a certain time as a research sample. And conclusions show that the talent ecological environment of the host country and talent growth expectation have negative influences on the returning intention of the overseas talents, and the expectation of native country prospects and perceived opportunities have a positive influence on the returning intention of overseas talents. Meanwhile, talent's growth expectation and perceived opportunities have mediating effects on the influence process.

All the conclusions have further verified the research conclusions of Everett (1966), Bhagwati & Hamada (1974), Cao (2016), and Wang (2021).

On the basis of verifying previous research conclusions, further finding in this study shows that the influences of the expectation of native country prospect and perceiving opportunities on the returning intention of overseas talents are stronger than that of talent ecological environment of the host country and talent growth expectation, which indicates that the situation of a native country is more important than that of the host country in attracting overseas talents back. At the same time, perceived opportunities and the expectation of native country prospect have an adjustment effect on the negative relationship between talent growth expectation and the returning intention of overseas talents and the negative relationship between talent ecological environment of the host country and the returning intention of overseas talents, which shows that for those who speak highly of their native country, talent ecological environment of host country and talent growth expectation have a greater effect on their returning intention.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 5634702, 14 pages
https://doi.org/10.1155/2022/5634702

Research Article

Measuring the Total-Factor Green Efficiency in China's Industrial Sectors: A Parametric Approach

Zhenghuan Wang

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China

Correspondence should be addressed to Zhenghuan Wang; 11113120@bjtu.edu.cn

Received 25 February 2022; Accepted 25 March 2022; Published 9 May 2022

Academic Editor: Lele Qin

At present, China's industrial economy is facing a severe problem of green transformation, so the measurement of total-factor green efficiency has become one of the research hot spots. Combining Shephard's distance function and metafrontier model, this study constructs a parametric total-factor green efficiency model in consideration of technology heterogeneity. Stochastic metafrontier analysis, which controls individual effects, is used to estimate metafrontier green efficiency. This study calculates the green efficiency of Chinese industrial sectors. Results show that there are significant differences in metafrontier green efficiency between high- and low-emission groups, and the efficiency level of the low-emission group is systematically higher than that of the high-emission group. Compared with pooled green efficiency and existing studies without considering technology heterogeneity, the metafrontier green efficiency is more intuitive and realistic. In order to achieve green industrial growth, this study suggests that the government should implement heterogeneous energy conservation and emission reduction policies for high- and low-emission groups, especially to encourage carbon-intensive industries to improve the use of existing group technologies, and to promote technology diffusion and spillover between high- and low-emission groups. Based on the reliable measurement of green efficiency, green productivity might be reliably explored as well in the future.

1. Introduction

In the past four decades of reform and opening up, China has made remarkable achievements in economic development. At the same time, the industrial economy has also achieved unprecedented development. China has not only become the "world factory" covering the whole industrial chain but also increased its industrial added-value production by nearly 60 times compared with 1978, with an average annual growth rate of 14.5% [1]. China's economic growth miracle has dramatically improved the welfare of its people and eliminated absolute poverty across the country by 2020. However, decades of rapid growth have also brought enormous environmental pressure, resulting in the frequent haze, extreme weather, and environmental degradation across the country in recent years, which is largely due to the traditional extensive mode of growth. This type of growth is characterized by "high input, high consumption, and high emissions" and is also the main culprit of various environmental and climate change problems. For this reason, since the 11th Five-Year Plan [2], energy conservation and emission reduction have become a mandatory target of the government's national economic plan and have been well implemented. At present, energy conservation and emission reduction have become the international consensus to deal with global warming. At the 75th Session of the United Nations General Assembly recently, the Chinese government stated that China will strive to achieve the carbon emission peak by 2030 and achieve carbon neutrality by 2060. On the other hand, economic growth has its inherent regularity. Since 2012, China's economic growth has been under great downward pressure and entered the "new normal" of medium-high growth [3]. Therefore, how to ensure the sound and steady growth of China's economy and solving the problems of environment and climate change has become one of the core issues of China's sustainable economic growth in the new era.

Under this background, green growth has become a new economic growth model that attracts much attention [4]. Although there is no universally recognized and unified definition, its basic connotation is to achieve sustainable economic growth with minimum resource consumption and minimum environmental cost [5]. In other words, green growth is an environmentally inclusive growth model that ensures environmental friendliness while achieving economic growth. It is an alternative to the "pollution first, treatment later" model and a feasible solution to environmental and climate change issues. Studies have shown that industrial activities are the main source of environmental and climate change problems, and the green development of China's economy largely depends on the green transformation of the industrial economy.

There are two main lines of research on measuring green growth. One is to construct a comprehensive evaluation indicator system, and the other is to construct relevant indexes of green growth under the input-output framework [5]. This study adopts the second research route, in which green growth is often expressed by green total-factor productivity or total-factor green efficiency. Chambers et al. [6] proposed an environmental regulation behavior analysis model based on directional distance function (DDF), which can asymmetrically deal with outputs and/or inputs. However, the directional distance function requires that the inputs or outputs vary in the same proportion (radial) and that input- and output-based choices (angular) are required for efficiency measurement. In order to overcome the above two defects, Chuang et al. [7]; Oh et al. [8]; and Du et al. [9] combined DDF to construct Malmquist-Luenberger total-factor productivity index by taking undesirable output as an output variable to measure the green total-factor productivity that takes environmental factors into account. However, this method is carried out in a nonparametric framework and has two main shortcomings: (i) mathematical programming is nonlinear except in the case of constant return to scale; (ii) the model is deterministic, and statistical inference cannot be made unless bootstrapping is used [10].

On the other hand, Fare et al. [11] introduced a hyperbolic distance function to measure production performance through the ability to expand output and shrink input in a balanced way. In this case, the traditional radial distance function, which expands output or contracts input, is a special case of the hyperbolic distance function. Fare et al. [12] used the linear programming technique to construct a parametric (quadratic) directional distance function to assess the ability of firms to improve environmental efficiency by simultaneously increasing good output and reducing bad output, but this model is still affected by the second shortcoming of the nonparametric approach described above. Cuesta et al. [13] developed a stochastic hyperbolic distance function model, which utilized the transcendental logarithmic production function proposed by Christensen et al. [14]. Zhang and Ye [15] extended the hyperbolic distance function module of Cuesta et al. [13] to include the use of an elastic time-varying framework to capture neutral technical changes using technology (t) rather than time dummy variables. Duman and Kasman [16] applied the enhanced hyperbolic distance function proposed by Cuesta et al. [13] to investigate the environmental efficiency of EU members and candidate countries and analyzed its convergence. However, the hyperbolic distance function still needs to expand and decrease the good and bad outputs in equal proportion. Zhou et al. [17] proposed the carbon emission distance function under the DEA framework, which can investigate the maximum emission reduction potential of carbon emissions under the condition that other inputs and technologies remain unchanged, so as to flexibly measure carbon emission efficiency or green efficiency more. Lin and Du [18] proposed the green efficiency based on the carbon emission distance function under the SFA framework and investigated the green efficiency and productivity of each province in China. The SFA framework for green efficiency measurement gained many attention because it could provide statistical inference while the DEA framework generally does not. For example, Tan et al. [19] estimated the green efficiency of 36 industrial subsectors in China from 2001 to 2015. Lv et al. [20] used the SFA framework to evaluate the green productivity of 30 provinces in China from 1997 to 2017.

A common assumption in the above studies is that all DMUs share the same production technology, which may lead to biased measurement results because there may be inherent differences between different technology groups. Hayami and Ruttan [21] first proposed the concept of metafrontier to solve the problem of noncomparability of production performance of different groups. Battese and Rao [22] developed the stochastic metafrontier method (SMFA) by combining the coproduction concept with the SFA framework, but the method had problems with the data generation process (DGP). Battese et al. [23] proposed a different definition of the metafrontier function to solve the above DGP problem. They also proposed a two-step standard estimation procedure, that is, the first step uses SFA to estimate the group frontier, and the second step uses linear or quadratic programming techniques to estimate the metafrontier. O 'Donnell et al. [24] further extended this method to the distance function and the DEA model. Based on the development of the metafrontier function and due to the advantage of providing statistical inference of SFA, Lin and Du [25] used the SMFA method to measure the total-factor energy efficiency of 30 regions in China from 1997 to 2010. Along this line, Lin and Du [18] used the fixed-effects SMFA model to estimate the total-factor carbon emission efficiency and Malmquist carbon emission performance of 30 provinces in China during 2000–2010. Bai et al. [26] used the SMFA to measure the environmental performance and carbon emission reduction potential of 39 industrial sectors in China from 2005 to 2011. Zheng et al. [27] estimated the total-factor water efficiency of 30 provinces in China from 2001 to 2016 using the SFMA. All the above studies adopted the two-step method proposed by Battese et al. [23] and O 'Donnell et al. [24]. However, Huang et al. [28] pointed out that the statistical properties of the metafrontier estimated by the second step of the above two-step mixed approach are not clear, because the estimated results obtained from

programming techniques may be "contaminated" by random disturbances. They then proposed a two-step stochastic frontier approach that uses SFA estimation in both the first and second steps to address the limitations mentioned above. The two-step stochastic frontier approach attracted many attention and was applied in a wide range of efficiency studies. For example, Safiullah and Shamsuddin [29] applied the two-step stochastic frontier approach to measure the Islamic banks' cost efficiency and Alem et al. [30] evaluated Norwegian dairy farms' technical efficiency using this approach. In the field of energy and environmental studies, Lu et al. [31] used the two-step stochastic frontier approach to assess the environmental efficiency of China's 273 cities from 2002 to 2016. Zhang et al. [32] estimated the energy efficiency of Chinese cities from 2005 to 2015 using the two-step stochastic frontier approach. However, these studies seldom considered individual heterogeneity, which might cause biased results [18].

Therefore, this study aims to provide a new parametric framework of total-factor green efficiency, based on the carbon emission distance function proposed by Zhou et al. [17] and Lin and Du [18] and the two-step stochastic frontier approach proposed by Huang et al. [28]. The new method can deal with both individual heterogeneity and technology heterogeneity, which has been seldom carried out in literature, especially in the measurement of green efficiency. Moreover, there are numerous studies assessing the energy or green efficiency in China from the province perspective while those from the industry perspective are very limited. Thus, using this method, this study calculates the total-factor metafrontier green efficiency of China's 34 industrial sectors from 2000 to 2016, and the results show that the green efficiency is more reasonable and accurate after considering the technology heterogeneity and individual heterogeneity.

This study is arranged as follows: in section 2, the method of total-factor green efficiency considering technology heterogeneity is given, and the data source and parametric estimation are given. Section 3 is the analysis of the green efficiency of the Chinese industry. Section 4 is the conclusion.

2. Research Methodology

2.1. Method. Zhou [17] proposed the Shephard emission distance function under the DEA framework. This function measures the largest reduction of bad output (carbon emissions) given good output. Lin and Du [18] parameterized this function and proposed a parametric measurement framework of total-factor green efficiency. Based on Lin and Du [18], this study will construct the total-factor green efficiency in consideration of technology heterogeneity among different groups of industrial sectors. Under the concept of metafrontier, there are two different kinds of environmental technologies: one is group technology, which is heterogeneous among different groups; the other is the metafrontier technology, which is the envelope function of different group technologies.

An environmental technology that produces good output (Y) and bad output of carbon dioxide (C) is considered by putting in capital (K) and labor (L). The reason why energy input is not considered here is that China's industrial energy consumption structure is relatively stable, which has a very high correlation with carbon emissions and thus affects the effect of econometric analysis [18]. In this study, China's industrial sectors are divided into groups, and the group environmental technology is defined by the following:

$$P^j = \left\{\left(K^j, L^j, Y^j, C^j\right): \left(K^j, L^j\right) \text{ can produce } \left(Y^j, C^j\right)\right\}, \quad (1)$$

where $j = 1, 2, \ldots, J$ denotes sectors, and P^j stands for the group environmental technology.

Accordingly, the metafrontier environmental technology is defined by the following:

$$P^* = \{(K, L, Y, C): (K, L) \text{ can produce } (Y, C)\}, \quad (2)$$

where P^* stands and the metafrontier environmental technology.

Referring to Zhou et al. [17] and Lin and Du [18], the Shephard emission distance function corresponding to group environmental technology and metafrontier environmental technology is given by the following:

$$\begin{aligned} D_C^j\left(K^j, L^j, Y^j, C^j\right) &= \sup\left\{\theta \middle| \left(K^j, L^j, Y^j, \frac{C^j}{\theta}\right) \in P^j\right\}, \\ D_C^*(K, L, Y, C) &= \sup\left\{\theta \middle| \left(K, L, Y, \frac{C}{\theta}\right) \in P^*\right\}, \end{aligned} \quad (3)$$

where $\theta \geq 1$ reflects the maximum reduction potential of carbon emissions given by the capital stock, labor, and technology. The group green efficiency (GGE) is defined by the following:

$$GGE = \frac{1}{D_C^j\left(K^j, L^j, Y^j, {}^j_C\right)}. \quad (4)$$

The metafrontier green efficiency (MGE) is defined by the following:

$$MGE = \frac{1}{D_C^*(K, L, Y, C)}. \quad (5)$$

Since the metafrontier is an envelope function of the group frontiers, it can be obtained as follows:

$$D_C^*(K, L, Y, C) \geq D_C^j(K, L, Y, C). \quad (6)$$

In other words, we get the following:

$$MGE \leq GGE. \quad (7)$$

O 'Donnell et al. [24] constructed a metafrontier ratio (MTR) to capture the potential gap between group frontier and metafrontier as follows:

$$\begin{aligned} MTR &= \frac{D_C^*(K, L, Y, C)}{D_C^j(K, L, Y, C)} \\ &= \frac{MGE}{GGE}. \end{aligned} \quad (8)$$

Thus, the metafrontier green efficiency can be regarded as the product of group green efficiency and metafrontier ratio as follows:

$$MGE = GGE \times PGE. \tag{9}$$

Equation (9) reveals that for any decision-making unit, its green efficiency relative to the metafrontier consists of two parts: one is within the group, namely, group green efficiency (GGE), and the other is between groups, namely, metafrontier ratio (MTR). Accordingly, there are two basic ways to improve green efficiency. One is to approach the leaders of green efficiency within the group by tapping their own potential, such as management, innovation, and energy-saving investment. The other is to improve the group's overall potential green efficiency by improving the economic environment and conditions, such as infrastructure investment, environmental regulation, and technology diffusion. The above discussion shows that under the concept of metafrontier, the improvement of green efficiency requires not only the contribution of a single individual but also the joint efforts of its group.

Following Huang et al. [28] and Wang [33], this study first describes the carbon emission distance function in the translogarithmic function because of its flexibility, ease of calculation, and homogeneity [18, 34]. In order to control individual effects, we adopt the fixed-effects SFA method proposed by Greene [35]. The group emission distance function is then given by the following:

$$\begin{aligned}\ln D_{it}^{j} = {} & \alpha_i + \alpha_k \ln K_{it}^{j} + \alpha_l \ln L_{it}^{j} + \alpha_t t + 0.5\alpha_{kk}\left(\ln K_{it}^{j}\right)^2 \\ & + 0.5\alpha_{ll}\left(\ln L_{it}^{j}\right)^2 + 0.5\alpha_{tt}t^2 \\ & + \alpha_{kl} \ln K_{it}^{j} \ln L_{it}^{j} + \alpha_{tk} t \ln K_{it}^{j} + \alpha_{tl} t \ln L_{it}^{j} \\ & + \beta_y \ln Y_{it}^{j} + 0.5\beta_{yy}\left(\ln Y_{it}^{j}\right)^2 \\ & + \beta_c \ln C_{it}^{j} + 0.5\beta_{cc}\left(\ln C_{it}^{j}\right)^2 + \beta_{yc} \ln Y_{it}^{j} \ln C_{it}^{j} \\ & + \gamma_{ky} \ln K_{it}^{j} \ln Y_{it}^{j} + \gamma_{ly} \ln L_{it}^{j} \ln Y_{it}^{j} + \gamma_{ty} t \ln Y_{it}^{j} \\ & + \delta_{kc} \ln K_{it}^{j} \ln C_{it}^{j} + \delta_{lc} \ln L_{it}^{j} \ln C_{it}^{j} \\ & + \delta_{tco_2} t \ln C_{it}^{j} + \varepsilon_{it}^{j},\end{aligned} \tag{10}$$

where α_i measures the individual effects; D_{it}^{j} is the distance function of industry i at time t; t is also a technical variable; and ε_{it}^{j} is a random term and satisfies $\varepsilon_{it}^{j} \sim N(0, \sigma_{\varepsilon j}^2)$. For the convenience of expression, equation (10) is rewritten as follows:

$$\ln D_{it}^{j} = TL\left(K^j, L^j, t, Y^j, C^j\right) + \varepsilon_{it}^{j}. \tag{11}$$

Since the carbon emission distance function is linearly homogeneous to carbon emission, it can be obtained as follows:

$$\ln D_{C,it}^{j}\left(K_{it}^{j}, L_{it}^{j}, t, Y_{it}^{j}, C_{it}^{j}\right) = \ln C_{it}^{j} + \ln D_{H,it}^{j}\left(K_{it}^{j}, L_{it}^{j}, t, Y_{it}^{j}, 1\right). \tag{12}$$

Table 1: China's industrial sectors and group codes.

Code	Sectors
H01	Coal mining and washing
H02	Oil and natural gas extracting
H03	Ferrous metal mining
H04	Nonmetal mining
H05	Paper industry
H06	Oil processing and coking
H07	Chemical materials and products
H08	Nonmetallic mineral products
H09	Ferrous metal smelting and pressing
H10	Nonferrous metal pressing
H11	Electricity production
H12	Gas production
L13	Nonferrous metal mining
L14	Food processing
L15	Food manufacturing
L16	Beverage manufacturing
L17	Tobacco manufacturing
L18	Textile industry
L19	Leather manufacturing
L20	Timber and wood processing
L21	Furniture manufacturing
L22	Printing and intermediary replication
L23	Culture, education, and sport activities
L24	Medicine manufacturing
L25	Chemical fiber manufacturing
L26	Rubber and plastic manufacturing
L27	Metal product manufacturing
L28	General-purpose manufacturing
L29	Special-purpose manufacturing
L30	Transport equipment manufacturing
L31	Electrical machinery and equipment
L32	Communication equipment manufacturing
L33	Measuring instrument manufacturing
L34	Water production

Note: H and L denote high-emission and low-emission groups, respectively.

After rearranging, we get the following:

$$\begin{aligned}-\ln C_{it}^{j} = {} & \alpha_i + \alpha_k \ln K_{it}^{j} + \alpha_l \ln L_{it}^{j} + \alpha_t t + 0.5\alpha_{kk}\left(\ln K_{it}^{j}\right)^2 \\ & + 0.5\alpha_{ll}\left(\ln L_{it}^{j}\right)^2 \\ & + 0.5\alpha_{tt}t^2 + \alpha_{kl} \ln K_{it}^{j} \ln L_{it}^{j} + \alpha_{tk} t \ln K_{it}^{j} \\ & + \alpha_{tl} t \ln L_{it}^{j} + \beta_y \ln Y_{it}^{j} + 0.5\beta_{yy}\left(\ln Y_{it}^{j}\right)^2 \\ & + \gamma_{ky} \ln K_{it}^{j} \ln Y_{it}^{j} \\ & + \gamma_{ly} \ln L_{it}^{j} \ln Y_{it}^{j} + \gamma_{ty} t \ln Y_{it}^{j} + \varepsilon_{it}^{j} - u_{it}^{j},\end{aligned} \tag{13}$$

where $u_{it}^{j} = \ln D_{C,it}^{j}(K_{it}^{j}, L_{it}^{j}, t, Y_{it}^{j}, C_{it}^{j}) > 0$ is defined as the inefficiency term in stochastic frontier analysis and satisfies $u_{it}^{j} \sim N^{+}(0, \sigma_u^{2j})$.

Then, the group green efficiency can be estimated as follows:

$$\widehat{GGE}_{it} = E\left\{\exp\left(-u_{it}^{j}\right) | \hat{\varepsilon}_{it}^{j}\right\}. \tag{14}$$

Table 2: Statistical description of main variables.

Variable	Unit	High-emission group			Low-emission group		
		Observations	Mean	Standard deviation	Observations	Mean	Standard deviation
Y	10^8 yuan	204	1419.15	1580.14	374	2426.98	3737.28
K	10^8 yuan	204	15648.84	23092.15	374	5401.28	6579.41
L	10^4 persons	204	297.49	237.93	374	346.02	337.35
E	PJ	204	5849.65	9835.75	374	323.48	304.07
C	10^4 tons	204	40414.37	77756.41	374	1316.99	1339.65
CI	Ton/10^4 yuan	204	23.83	34.68	374	1.00	0.86

Table 3: Estimated results of different stochastic frontier functions.

Model	(1) High-emission group		(2) Low-emission group		(3) Metafrontier		(4) Pooled	
Methods	MLE		MLE		QMLE		MLE	
lnK	−2.717∗∗∗	(0.713)	3.308∗∗∗	(0.737)	3.275∗∗∗	(0.025)	0.815∗∗	(0.413)
lnL	0.402	(0.914)	−1.020 ∗	(0.616)	−0.988∗∗∗	(0.023)	−1.492∗∗∗	(0.462)
lnY	1.473 ∗	(0.767)	−0.728	(0.726)	−0.896∗∗∗	(0.027)	−0.409	(0.399)
t	0.191#	(0.127)	−0.529∗∗∗	(0.092)	−0.511∗∗∗	(0.002)	−0.144∗∗	(0.057)
lnK2	−0.216∗∗	(0.106)	−0.295∗∗	(0.118)	−0.318∗∗∗	(0.007)	−0.108#	(0.066)
lnL2	−0.232	(0.269)	−0.098	(0.103)	−0.093∗∗∗	(0.003)	0.079	(0.087)
lnY2	−0.174#	(0.118)	0.195∗∗∗	(0.069)	0.200∗∗∗	(0.003)	0.031	(0.054)
t2	0.008∗∗∗	(0.003)	−0.002	(0.002)	−0.002∗∗∗	(0.000)	0.006∗∗∗	(0.001)
lnKL	0.628∗∗∗	(0.218)	0.409∗∗	(0.186)	0.430∗∗∗	(0.006)	0.117	(0.113)
lnKY	0.400∗∗∗	(0.153)	−0.242∗∗	(0.102)	−0.208∗∗∗	(0.008)	−0.037	(0.070)
lnLY	−0.452	(0.392)	−0.125	(0.128)	−0.156∗∗∗	(0.006)	−0.014	(0.097)
tlnK	0.023	(0.029)	0.094∗∗∗	(0.024)	0.096∗∗∗	(0.001)	0.024#	(0.014)
tlnL	−0.052	(0.045)	−0.062∗∗∗	(0.018)	−0.061∗∗∗	(0.000)	−0.034∗∗∗	(0.012)
tlnY	−0.036#	(0.025)	0.026 ∗	(0.014)	0.022∗∗∗	(0.001)	0.013 ∗	(0.008)
σ_u								
lnCI	0.843∗∗∗	(0.264)	2.905#	(1.799)	2.583∗∗∗	(0.121)	0.392∗∗∗	(0.065)
_Cons	−5.460∗∗∗	(0.939)	−6.340∗∗∗	(2.174)	−6.229∗∗∗	(0.104)	−2.526∗∗∗	(0.174)
σ_v								
_Cons	−3.872∗∗∗	(0.356)	−3.572∗∗∗	(0.084)	−14.387∗∗∗	(0.518)	−4.675∗∗∗	(0.317)
σ_u	0.678∗∗∗	(0.195)	0.942∗∗∗	(0.345)	1.839 ∗	(1.089)	0.137∗∗∗	(0.039)
σ_v	0.005∗∗∗	(0.000)	0.001∗∗∗	(0.000)	0.008∗∗∗	(0.001)	0.002∗∗∗	(0.000)
Likelihood	51.93		129.43		917.36		91.40	
LR test			179.92 (P−value = 0.000)					
Observations	578		204		374		578	

Note: (1) #, ∗, ∗∗, and ∗∗∗ represent statistical significance of 15%, 10%, 5%, and 1%, respectively. (2) The numbers in brackets are standard deviations.

The second step is to estimate the metafrontier ratio (MTR). Referring to Huang et al. [28], it can be derived that:

$$-\ln\left(TL_{it}^{j}\right) = -\ln\left(TL_{it}^{*}\right) - u_{it}^{j*}, \tag{15}$$

$$\begin{aligned} -\ln\left(Y_{it}^{j}\right) &= -\ln\left(TL_{it}^{j}\right) + \varepsilon_{it}^{j}, \\ &= -\ln\left(\hat{TL}_{it}^{j}\right) + \hat{\varepsilon}_{it}^{j}. \end{aligned} \tag{16}$$

Equation (15) is substituted into equation (17) to get the following:

$$-\ln\left(\hat{TL}_{it}^{j}\right) = \ln\left(TL_{it}^{*}\right) + \varepsilon_{it}^{j*}, \tag{17}$$

where $\varepsilon_{it}^{j*} = v_{it}^{j*} - u_{it}^{j*}$ and $v_{it}^{j*} = \varepsilon_{it}^{j} - \hat{\varepsilon}_{it}^{j}$.

Referring to Huang et al. [28], the non-negative inefficiency term can be assumed as i.i.d. $u_{it}^{j*} \sim N(\mu, \sigma_{uj*}^2)$; v_t^{ij*} can also reasonably be assumed to be an asymptotically normal distribution with zero mean, but it may not be an independent normal distribution because of the inclusion of ε_t^{ij}. To solve this problem, a quasi-maximum likelihood estimator (QMLE) can be used. Therefore, MTR can be predicted as follows:

$$\hat{MTR}_{it} = E\left\{\exp\left(-u_{it}^{j*}\right)|\hat{\varepsilon}_{it}^{j*}\right\}. \tag{18}$$

Finally, the metafrontier green efficiency (MGE) can be calculated according to equation (9) given equations (14) and (18).

2.2. Data. The sample period of this study is 2000–2016. During this period, the National Industry Classification Standard (NSIC) was revised twice (2002 and 2011). In order to ensure the consistency of statistical coverage, we finally select 34 industrial sectors with good continuity of industry connotation for empirical analysis, as shown in Table 1. The capital stock and labor data of China's industrial sectors

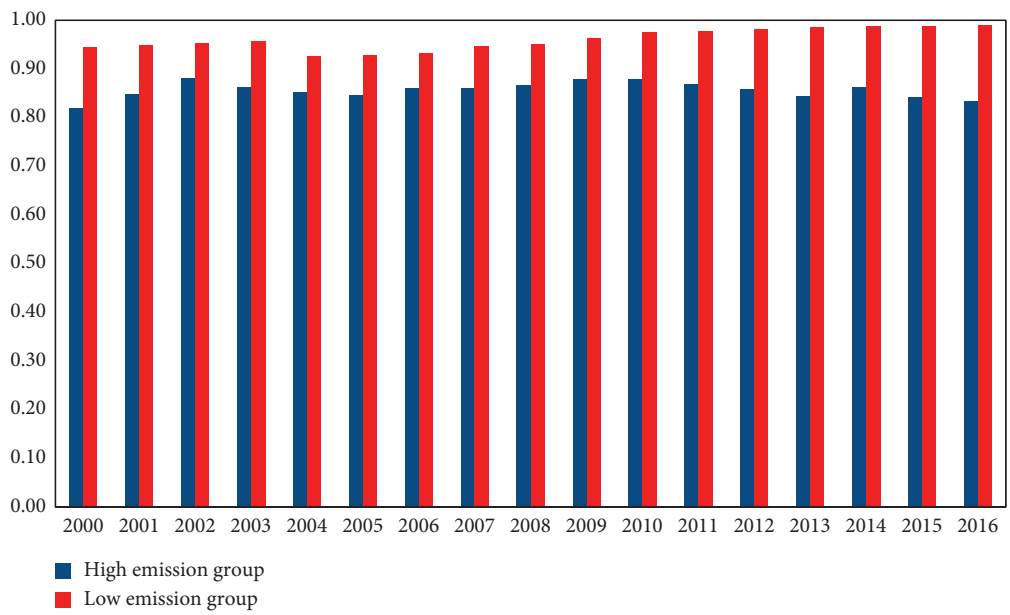


Figure 1: Trends in group green efficiency of different groups.

Table 4: Group green efficiency of China's industrial sectors.

Code	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
H01	0.823	0.849	0.866	0.804	0.932	0.929	0.920	0.913	0.926	0.798	0.861	0.820	0.795	0.789	0.950	0.941	0.931	0.873
H02	0.602	0.720	0.822	0.794	0.853	0.908	0.896	0.934	0.865	0.917	0.883	0.930	0.898	0.839	0.893	0.803	0.861	0.848
H03	0.912	0.920	0.941	0.935	0.895	0.906	0.910	0.923	0.909	0.936	0.809	0.909	0.925	0.902	0.905	0.922	0.919	0.911
H04	0.951	0.952	0.952	0.923	0.895	0.808	0.806	0.806	0.858	0.870	0.914	0.932	0.900	0.943	0.941	0.935	0.921	0.900
H05	0.832	0.870	0.865	0.891	0.835	0.839	0.867	0.889	0.882	0.885	0.932	0.928	0.945	0.955	0.962	0.962	0.957	0.900
H06	0.898	0.939	0.938	0.888	0.823	0.878	0.891	0.839	0.825	0.870	0.812	0.705	0.692	0.650	0.653	0.537	0.560	0.788
H07	0.877	0.909	0.904	0.908	0.850	0.829	0.839	0.863	0.898	0.911	0.937	0.914	0.917	0.920	0.912	0.874	0.881	0.891
H08	0.820	0.844	0.867	0.809	0.675	0.684	0.767	0.825	0.864	0.882	0.917	0.870	0.868	0.911	0.917	0.912	0.910	0.844
H09	0.892	0.906	0.923	0.910	0.911	0.844	0.844	0.824	0.845	0.794	0.816	0.779	0.752	0.747	0.722	0.726	0.659	0.817
H10	0.891	0.929	0.918	0.921	0.910	0.900	0.876	0.882	0.896	0.906	0.933	0.929	0.933	0.942	0.936	0.933	0.930	0.916
H11	0.727	0.818	0.850	0.862	0.829	0.847	0.832	0.829	0.849	0.831	0.786	0.736	0.697	0.601	0.584	0.600	0.541	0.754
H12	0.615	0.531	0.725	0.699	0.823	0.771	0.875	0.791	0.789	0.943	0.949	0.958	0.966	0.916	0.958	0.953	0.922	0.834
L13	0.940	0.944	0.934	0.917	0.838	0.855	0.839	0.920	0.944	0.958	0.974	0.967	0.973	0.980	0.981	0.982	0.987	0.937
L14	0.897	0.898	0.903	0.930	0.757	0.779	0.806	0.782	0.783	0.867	0.941	0.956	0.964	0.970	0.965	0.957	0.956	0.889
L15	0.807	0.841	0.877	0.911	0.803	0.819	0.816	0.864	0.859	0.880	0.933	0.936	0.958	0.961	0.967	0.970	0.964	0.892
L16	0.947	0.953	0.950	0.947	0.774	0.774	0.810	0.840	0.852	0.897	0.968	0.971	0.973	0.974	0.975	0.978	0.980	0.916
L17	0.991	0.992	0.992	0.993	0.996	0.996	0.997	0.998	0.999	0.999	0.999	0.999	0.999	0.999	1.000	1.000	1.000	0.997
L18	0.931	0.935	0.936	0.935	0.874	0.887	0.913	0.930	0.942	0.953	0.963	0.960	0.972	0.979	0.987	0.988	0.989	0.946
L19	0.969	0.978	0.980	0.982	0.970	0.975	0.952	0.966	0.974	0.980	0.988	0.990	0.989	0.992	0.994	0.995	0.995	0.981
L20	0.905	0.931	0.932	0.917	0.810	0.831	0.874	0.915	0.926	0.940	0.965	0.965	0.972	0.981	0.987	0.989	0.994	0.931
L21	0.955	0.965	0.967	0.967	0.991	0.991	0.982	0.984	0.984	0.987	0.990	0.992	0.994	0.995	0.996	0.996	0.997	0.984
L22	0.973	0.979	0.980	0.980	0.989	0.990	0.985	0.988	0.988	0.991	0.992	0.995	0.996	0.996	0.995	0.995	0.996	0.989
L23	0.987	0.988	0.989	0.990	0.987	0.990	0.984	0.988	0.990	0.992	0.993	0.996	0.986	0.988	0.987	0.989	0.988	0.989
L24	0.977	0.982	0.982	0.983	0.973	0.976	0.973	0.974	0.976	0.984	0.986	0.986	0.987	0.990	0.993	0.994	0.995	0.983
L25	0.892	0.834	0.839	0.912	0.896	0.885	0.922	0.940	0.949	0.963	0.968	0.957	0.958	0.966	0.976	0.976	0.973	0.930
L26	0.964	0.971	0.976	0.976	0.959	0.958	0.950	0.962	0.963	0.973	0.980	0.983	0.987	0.990	0.993	0.994	0.995	0.975
L27	0.918	0.931	0.938	0.953	0.961	0.965	0.953	0.960	0.963	0.972	0.981	0.985	0.979	0.981	0.988	0.989	0.990	0.965
L28	0.943	0.951	0.953	0.964	0.957	0.944	0.941	0.946	0.947	0.954	0.967	0.940	0.980	0.986	0.988	0.988	0.989	0.961
L29	0.900	0.921	0.944	0.942	0.958	0.962	0.961	0.969	0.975	0.979	0.979	0.986	0.991	0.992	0.992	0.994	0.995	0.967
L30	0.959	0.971	0.976	0.986	0.985	0.983	0.983	0.987	0.987	0.990	0.992	0.993	0.993	0.994	0.996	0.997	0.998	0.987
L31	0.992	0.994	0.994	0.995	0.993	0.994	0.992	0.994	0.995	0.996	0.997	0.997	0.998	0.998	0.999	0.999	0.999	0.996
L32	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999
L33	0.989	0.991	0.991	0.992	0.996	0.997	0.997	0.997	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1.000	1.000	0.997
L34	0.931	0.938	0.923	0.896	0.894	0.884	0.874	0.935	0.935	0.946	0.906	0.962	0.934	0.965	0.980	0.975	0.977	0.933
High	0.820	0.849	0.881	0.862	0.853	0.845	0.860	0.860	0.867	0.879	0.879	0.867	0.857	0.843	0.861	0.842	0.833	0.856
Low	0.944	0.949	0.952	0.958	0.926	0.929	0.932	0.947	0.951	0.964	0.975	0.978	0.981	0.985	0.988	0.988	0.989	0.961
All	0.900	0.914	0.927	0.924	0.900	0.899	0.907	0.916	0.922	0.934	0.941	0.939	0.937	0.935	0.943	0.937	0.934	0.924

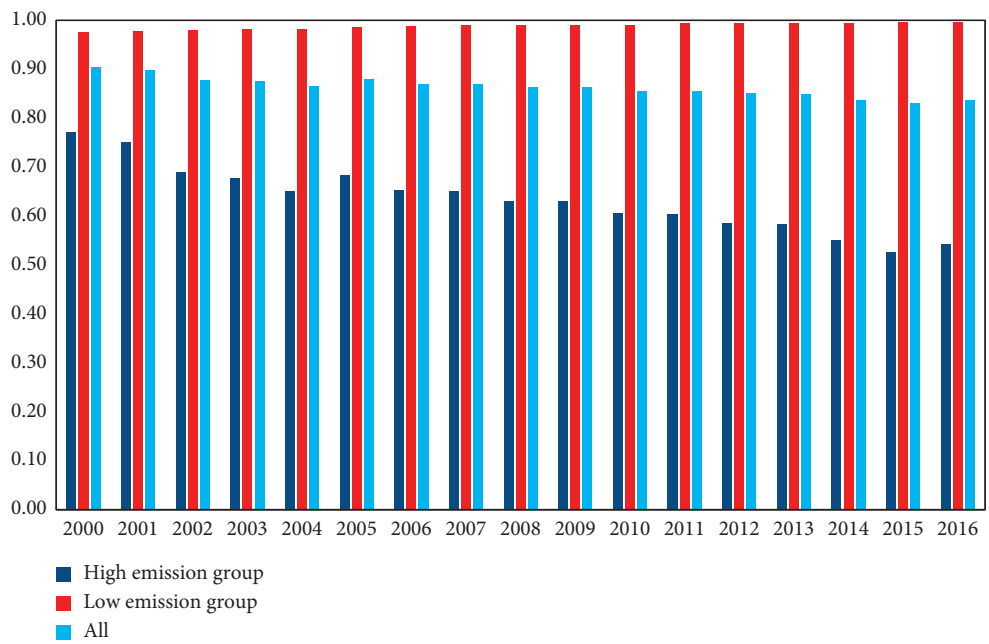


Figure 2: Trends in metafrontier ratio of different groups.

from 2000 to 2008 are quoted by Chen [36]. The data from 2009 to 2016 are extrapolated according to Chen's method, and the original data required are from China Statistical Yearbook and China Industry Statistical Yearbook. All nominal values are deflated at 1990 constant price. Referring to Shan et al. [37], the carbon emissions are calculated by the following:

$$C_{ij} = AD_{ij} \times NCV_j \times CC_j \times O_{ij} \times \frac{44}{12}, \tag{19}$$

where C_{ij} represents the carbon emissions; AD_{ij} represents energy consumption; NCV_j is the net caloric value; CC_j is carbon content; and O_{ij} stands for the oxidation rate. It should be noted that the first two variables on the right-hand side of equation (19) measure the standard quantity of energy consumption. Since this study directly uses the final energy consumption of industrial sectors provided by China Energy Statistical Yearbook, there is no need to repeat the calculation. The coefficients of carbon content (CC_j) and oxidation rate (O_{ij}) are referred to Shan et al. [37].

Industrial sectors need to be grouped to reflect technology heterogeneity. We calculate carbon emission intensity first and then rank the sectors in terms of the annual average levels between 2000 and 2016. Together with the classification of light and heavy industries, the industries with more than 4 tons per10000 yuan are classified as the high-emission group, while those with less than 4 tons per 10000 yuan are classified as the low-emission group. The high- and low-emission groups consist of 12 and 22 industrial sectors, respectively. Table 2 presents the statistical description of variables in the high- and low-emission groups, respectively. Notice that the average carbon intensity of two groups (CI) is quite different, which to a certain extent supports the rationality of the use of carbon intensity as a grouping variable.

2.3. Estimation. Table 3 reports the estimation results of four different stochastic frontiers, in which models (1), (2), and (4) adopt the MLE estimation, and model (3) adopts the QMLE estimation. Models (1) and (2) are group estimates, model (3) is a metafrontier estimate, and model (4) is a pooled estimate. Here, the logarithmic likelihood ratio (LR) is used to test whether group heterogeneity is statistically significant, i.e., $\lambda = -2\{\ln[L(H_0) - L(H_1)]\}$, ln[L(H)0)] represents the likelihood ratio value of the null hypothesis that all groups face the same frontier; Ln [L(H_1)] represents the likelihood ratio value of the alternative hypothesis, that is, the sum of the logarithmic likelihood values of the high-emission group and the low-emission group. As shown in Table 3, the logarithmic likelihood ratio test rejects the null hypothesis, indicating that the high- and low-group frontiers are statistically heterogeneous. In addition, the standard deviations of inefficiency (σ_u) and random disturbance (σ_v) in models (1)–(4) have a statistical significance of 1%–10%, indicating that the two-step stochastic metafrontier method is appropriate. In particular, lnCI, which measures inefficiency variables, was positive in each model. This is consistent with theoretical expectations, indicating the reliability of the model.

3. Results and Discussion

3.1. Group Green Efficiency. With estimation results in Table 3, we calculate the group green efficiency of 12 sectors in the high-emission group and 22 sectors in the low-emission group. Figure 1 shows the trend of average group green efficiency of high- and low-emission groups. As defined, they are not comparable between groups. So, we analyze their individual trends here. In the high-emission group, the group green efficiency experienced a fluctuating process, with an increase during 2000 and 2002 but a decrease during

Table 5: Metafrontier ratio of China's industrial sectors.

Code	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
H01	0.742	0.772	0.791	0.783	0.801	0.831	0.839	0.878	0.882	0.947	0.929	0.981	0.997	0.983	0.954	0.914	0.886	0.877
H02	0.987	0.715	0.529	0.414	0.363	0.344	0.289	0.241	0.244	0.220	0.192	0.170	0.166	0.156	0.133	0.142	0.126	0.319
H03	0.894	0.999	0.643	0.629	0.475	0.409	0.427	0.398	0.377	0.403	0.336	0.334	0.351	0.359	0.359	0.358	0.394	0.479
H04	0.347	0.355	0.366	0.442	0.561	0.999	0.743	0.826	0.734	0.757	0.748	0.714	0.683	0.666	0.628	0.692	0.817	0.652
H05	0.997	0.987	0.984	0.962	0.913	0.956	0.924	0.901	0.842	0.804	0.768	0.775	0.745	0.714	0.685	0.670	0.662	0.841
H06	0.994	0.930	0.948	0.867	0.728	0.601	0.544	0.563	0.526	0.463	0.467	0.462	0.451	0.445	0.436	0.443	0.452	0.607
H07	0.995	0.982	0.952	0.885	0.770	0.812	0.820	0.734	0.641	0.671	0.611	0.606	0.611	0.588	0.544	0.545	0.475	0.720
H08	0.995	0.865	0.832	0.816	0.810	0.798	0.755	0.690	0.639	0.656	0.602	0.609	0.630	0.560	0.507	0.492	0.455	0.689
H09	0.890	0.894	0.799	0.851	0.828	0.921	0.981	0.984	0.897	0.936	0.840	0.740	0.694	0.609	0.530	0.456	0.425	0.781
H10	0.997	0.991	0.959	0.972	0.928	0.938	0.933	0.907	0.857	0.867	0.844	0.807	0.797	0.750	0.729	0.710	0.680	0.863
H11	0.271	0.293	0.304	0.307	0.403	0.298	0.305	0.313	0.283	0.261	0.238	0.216	0.190	0.168	0.151	0.146	0.137	0.252
H12	0.140	0.240	0.177	0.213	0.233	0.298	0.268	0.384	0.635	0.571	0.706	0.838	0.705	0.998	0.944	0.757	0.998	0.536
L13	0.943	0.941	0.935	0.931	0.933	0.942	0.950	0.955	0.967	0.975	0.979	0.981	0.985	0.987	0.993	0.995	0.999	0.964
L14	0.970	0.969	0.971	0.974	0.974	0.978	0.980	0.982	0.981	0.989	0.989	0.994	0.996	0.998	0.997	0.998	0.997	0.985
L15	0.968	0.969	0.976	0.973	0.975	0.980	0.983	0.986	0.985	0.988	0.987	0.990	0.991	0.989	0.990	0.998	0.998	0.984
L16	0.986	0.986	0.989	0.990	0.987	0.990	0.991	0.994	0.994	0.995	0.994	0.995	0.995	0.995	0.994	0.997	0.998	0.992
L17	0.999	0.999	0.998	0.998	0.999	0.999	0.998	0.997	0.997	0.999	0.999	0.998	0.999	0.998	0.999	1.000	1.000	0.999
L18	0.991	0.991	0.991	0.992	0.987	0.991	0.992	0.992	0.991	0.992	0.992	0.996	0.998	0.997	0.995	0.997	0.998	0.993
L19	0.996	0.999	0.997	0.999	0.987	0.993	0.993	0.995	0.994	0.995	0.995	0.998	0.998	0.996	0.992	0.990	0.990	0.994
L20	0.958	0.965	0.965	0.961	0.963	0.971	0.974	0.979	0.981	0.985	0.988	0.995	0.997	0.998	0.999	0.997	0.996	0.981
L21	0.959	0.964	0.967	0.972	0.978	0.985	0.989	0.994	0.990	0.991	0.991	0.995	0.999	0.999	0.998	0.998	0.996	0.986
L22	0.980	0.994	0.993	0.997	0.996	0.999	0.999	0.999	0.996	0.995	0.993	0.992	0.994	0.991	0.991	0.991	0.990	0.994
L23	0.995	0.998	0.999	0.997	0.987	0.991	0.990	0.993	0.994	0.994	0.993	0.996	0.997	0.996	0.999	0.998	0.995	0.995
L24	0.975	0.978	0.983	0.985	0.988	0.993	0.992	0.993	0.992	0.993	0.992	0.992	0.993	0.994	0.995	0.999	0.999	0.990
L25	0.997	0.977	0.980	0.978	0.983	0.993	0.994	0.995	0.990	0.985	0.982	0.990	0.990	0.987	0.988	0.992	0.998	0.988
L26	0.989	0.988	0.991	0.992	0.991	0.992	0.992	0.993	0.991	0.992	0.991	0.996	0.996	0.997	0.996	0.998	0.999	0.993
L27	0.970	0.974	0.975	0.973	0.969	0.974	0.976	0.980	0.978	0.982	0.982	0.988	0.994	0.993	0.999	0.991	0.992	0.982
L28	0.969	0.973	0.976	0.981	0.981	0.985	0.987	0.989	0.989	0.991	0.992	0.995	0.998	0.997	0.997	0.999	0.998	0.988
L29	0.960	0.963	0.968	0.974	0.974	0.979	0.982	0.984	0.985	0.988	0.989	0.994	0.997	0.997	0.998	0.998	0.998	0.984
L30	0.978	0.982	0.986	0.988	0.988	0.993	0.994	0.995	0.994	0.996	0.993	0.995	0.996	0.995	0.993	0.998	0.999	0.992
L31	0.992	0.994	0.995	0.997	0.995	0.997	0.997	0.997	0.996	0.997	0.996	0.998	0.999	0.998	0.998	0.999	1.000	0.997
L32	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	1.000	0.999	1.000	1.000	1.000	1.000	1.000	1.000	0.999
L33	0.969	0.970	0.971	0.988	0.988	0.994	0.996	0.998	0.998	0.996	0.998	0.999	0.999	0.999	0.999	0.999	1.000	0.992
L34	0.925	0.938	0.958	0.966	0.978	0.970	0.988	0.994	0.988	0.989	0.984	0.987	0.986	0.979	0.974	0.988	0.999	0.976
High	0.771	0.752	0.690	0.678	0.651	0.684	0.652	0.652	0.630	0.630	0.607	0.604	0.585	0.583	0.550	0.527	0.542	0.635
Low	0.976	0.978	0.980	0.982	0.982	0.986	0.988	0.990	0.990	0.991	0.991	0.994	0.995	0.994	0.995	0.996	0.997	0.989
All	0.903	0.898	0.878	0.875	0.865	0.879	0.870	0.871	0.863	0.864	0.855	0.856	0.850	0.849	0.838	0.831	0.837	0.864

Table 6: Comparison between group green efficiency and metafrontier ratio.

Group	Top and bottom industries	Grouped green efficiency		Common frontier ratio	
High-emission group	Top three	Nonferrous metal pressing H10	0.916	Coal mining and washing H01	0.877
		Ferrous metal mining H03	0.911	Nonferrous metal pressing H10	0.863
		Nonmetal mining H04	0.900	Paper industry H05	0.841
	Bottom three	Electricity production H11	0.754	Electricity production H11	0.252
		Oil processing and coking H06	0.788	Oil and natural gas extracting H02	0.319
		Ferrous metal smelting and pressing H09	0.817	Ferrous metal mining H03	0.479
Low-emission group	Top three	Communication manufacturing L32	0.999	Communication equipment manufacturing L32	0.999
		Tobacco manufacturing L17	0.997	Tobacco manufacturing L17	0.999
		Measuring instrument manufacturing 33	0.997	Electrical machinery and equipment L31	0.997
	Bottom three	Food processing L14	0.889	Nonferrous metal mining L13	0.964
		Food manufacturing L15	0.892	Water production L34	0.976
		Beverage manufacturing L16	0.916	Timber and wood processing L20	0.981

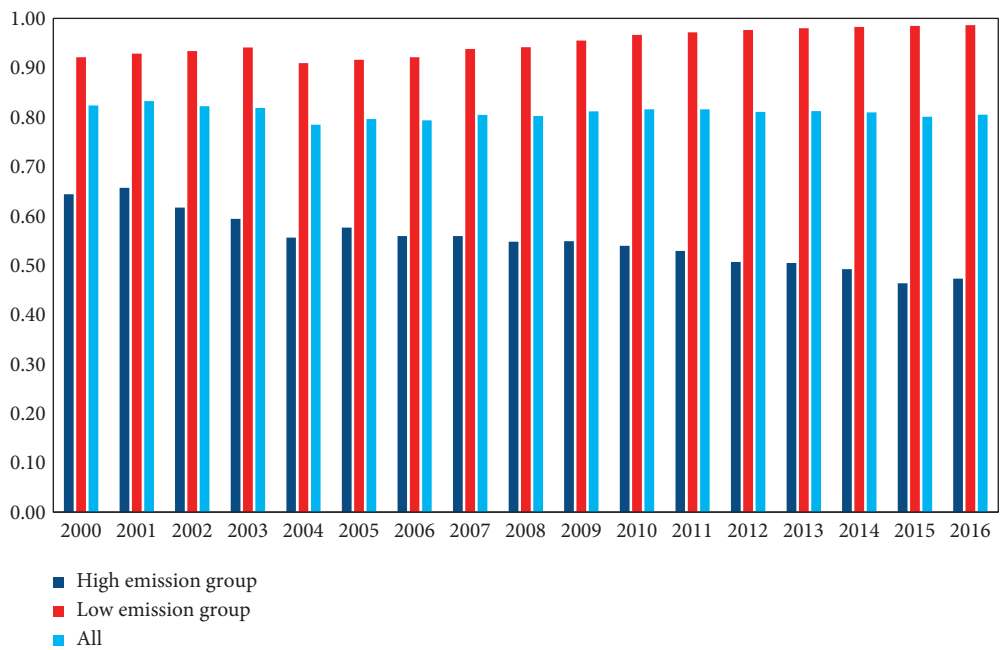


Figure 3: Trends in the metafrontier green efficiency of different groups.

2003 and 2005. This is because the heavy industrialization process occurred during this period, resulting in a large amount of energy consumption and pollution discharge. The energy conservation and emission reduction have become a mandatory target of the government's 11th Five-Year Plan, so the group green efficiency has undergone an improvement since 2006. However, the group green efficiency of the high-emission group deteriorated from 2011 to 2013, which may be related to the four-trillion stimulus measures taken in response to the global financial crisis. Large-scale investment flowed to the heavy industry, resulting in the deterioration of group green efficiency of the high-emission group. At the same time, it may also be related to the transition of China's economic growth rate, because during this period China entered the "new normal" stage characterized by medium-high speed. The traditional model of supporting high-speed growth could not be sustained, while the new growth mode was being shaped. In 2014, the group green efficiency showed a temporary improvement but then entered the decline range, because the long-term heavy industrialization and high investment in response to the financial crisis accumulated a large amount of excess capacity. The deterioration of economic efficiency led to the deterioration of group green efficiency. Comparatively, the low-emission group witnessed an increase-decrease-increase trend, which is relatively smooth.

Table 4 reports the group green efficiency of China's industrial sectors. Since there is no comparability between high- and low-emission groups, we investigate sectoral performance within each group. On the one hand, in the high-emission group, H10 has the highest green efficiency, with an average value of 0.916. Meanwhile, H11 has the lowest group green efficiency of 0.754. In the low-emission group, the top three sectors are L32, L17, and L33, with average group green efficiency of 0.999, 0.997, and 0.997, respectively. The bottom three are L14, L15, and L16, with average group green efficiency of 0.889, 0.892, and 0.916, respectively.

3.2. Metafrontier Ratio. The metafrontier ratio measures the gap between group frontier and metafrontier. It is the key indicator to transform the noncomparable group green efficiency into comparable metafrontier green efficiency. Figure 2 shows the trend of the metafrontier ratio of the high- and low-emission groups from 2000 to 2016. In the high-emission group, except for a transient increase in 2005 and 2016, the rest years show a continuous decline. In the low-emission group, with the exception of a few years (2004, 2008, 2010, and 2013), the metafrontier has been growing on. This means that the low-emission group is gradually shrinking the gap to the metafrontier. From the perspective of comparison, the metafrontier of the low-emission group is systematically higher than that of the high-emission group. That is to say, the low-emission group is closer to the metafrontier. This conclusion is consistent with the reality that the low-emission group or light industry is generally considered to be more efficient in carbon emission. In other words, carbon-intensive sectors need to make more effective use of technology spillover mechanisms, such as stricter regulations and technology diffusion reservoirs, to shrink the technology gap to the metafrontier.

Table 5 shows the metafrontier ratios of China's industrial sectors. Since the metafrontier ratios of the different groups are comparable, we can analyze them from a global view of point. Comparisons can be made from the perspective of the entire industrial sector. In terms of individual sectors, the three industries with the highest metafrontier ratios are L32, L17, and L31, with values of 0.9993, 0.9985, and 0.9968, respectively. We observe that they belong to the

Table 7: Metafrontier green efficiency of China's industrial sectors.

Code	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
H01	0.610	0.656	0.685	0.630	0.746	0.772	0.772	0.802	0.817	0.756	0.800	0.805	0.792	0.776	0.907	0.860	0.825	0.765
H02	0.594	0.515	0.435	0.329	0.309	0.313	0.259	0.226	0.211	0.202	0.169	0.158	0.149	0.131	0.118	0.114	0.108	0.255
H03	0.815	0.919	0.605	0.588	0.426	0.370	0.388	0.367	0.343	0.377	0.272	0.303	0.324	0.324	0.325	0.330	0.362	0.438
H04	0.330	0.338	0.348	0.408	0.502	0.807	0.599	0.666	0.630	0.658	0.683	0.665	0.614	0.628	0.591	0.647	0.753	0.580
H05	0.830	0.858	0.851	0.857	0.763	0.802	0.801	0.801	0.743	0.712	0.716	0.719	0.704	0.681	0.659	0.644	0.633	0.751
H06	0.892	0.873	0.889	0.770	0.599	0.528	0.485	0.472	0.434	0.403	0.379	0.326	0.312	0.289	0.285	0.238	0.253	0.496
H07	0.873	0.893	0.861	0.804	0.655	0.673	0.688	0.634	0.575	0.611	0.573	0.553	0.560	0.542	0.496	0.476	0.419	0.640
H08	0.816	0.731	0.722	0.660	0.546	0.546	0.579	0.569	0.552	0.579	0.552	0.530	0.547	0.510	0.465	0.449	0.414	0.574
H09	0.794	0.809	0.737	0.774	0.755	0.778	0.829	0.811	0.757	0.743	0.686	0.576	0.522	0.455	0.383	0.331	0.280	0.648
H10	0.888	0.920	0.880	0.895	0.845	0.844	0.817	0.800	0.768	0.786	0.788	0.750	0.743	0.706	0.683	0.662	0.633	0.789
H11	0.197	0.240	0.259	0.264	0.334	0.252	0.254	0.259	0.240	0.216	0.187	0.159	0.132	0.101	0.088	0.087	0.074	0.197
H12	0.086	0.127	0.128	0.149	0.192	0.230	0.235	0.304	0.501	0.539	0.669	0.803	0.681	0.914	0.904	0.722	0.920	0.477
L13	0.886	0.889	0.873	0.854	0.782	0.806	0.797	0.879	0.912	0.934	0.953	0.948	0.959	0.967	0.974	0.977	0.985	0.904
L14	0.870	0.871	0.877	0.906	0.738	0.762	0.790	0.768	0.769	0.857	0.931	0.950	0.961	0.968	0.962	0.955	0.953	0.876
L15	0.781	0.815	0.855	0.886	0.783	0.803	0.802	0.852	0.846	0.869	0.921	0.926	0.949	0.951	0.957	0.969	0.962	0.878
L16	0.934	0.940	0.939	0.937	0.764	0.766	0.803	0.834	0.846	0.893	0.962	0.966	0.969	0.969	0.969	0.976	0.977	0.909
L17	0.990	0.991	0.990	0.991	0.995	0.995	0.995	0.995	0.995	0.998	0.998	0.997	0.998	0.997	0.999	0.999	0.999	0.996
L18	0.922	0.927	0.928	0.927	0.863	0.879	0.905	0.923	0.934	0.946	0.955	0.956	0.970	0.975	0.982	0.985	0.988	0.939
L19	0.965	0.977	0.977	0.981	0.957	0.968	0.944	0.961	0.968	0.975	0.984	0.988	0.987	0.988	0.986	0.985	0.985	0.975
L20	0.867	0.898	0.899	0.881	0.781	0.807	0.851	0.897	0.908	0.925	0.953	0.960	0.969	0.978	0.986	0.987	0.989	0.914
L21	0.916	0.931	0.936	0.940	0.969	0.976	0.970	0.978	0.974	0.978	0.981	0.987	0.993	0.994	0.994	0.995	0.993	0.971
L22	0.954	0.973	0.972	0.978	0.985	0.989	0.984	0.987	0.984	0.986	0.986	0.987	0.990	0.986	0.986	0.987	0.986	0.982
L23	0.981	0.987	0.988	0.986	0.974	0.981	0.974	0.980	0.984	0.986	0.986	0.993	0.983	0.984	0.986	0.986	0.983	0.984
L24	0.953	0.961	0.965	0.969	0.961	0.969	0.966	0.967	0.968	0.977	0.978	0.978	0.980	0.985	0.988	0.992	0.993	0.974
L25	0.890	0.815	0.823	0.891	0.881	0.879	0.917	0.936	0.939	0.948	0.951	0.947	0.949	0.953	0.964	0.968	0.971	0.919
L26	0.954	0.960	0.967	0.968	0.950	0.951	0.943	0.955	0.953	0.965	0.971	0.978	0.983	0.987	0.989	0.992	0.994	0.968
L27	0.890	0.907	0.914	0.928	0.931	0.940	0.930	0.940	0.942	0.954	0.963	0.973	0.973	0.974	0.986	0.980	0.982	0.947
L28	0.913	0.925	0.930	0.946	0.939	0.930	0.928	0.936	0.937	0.945	0.959	0.935	0.977	0.983	0.985	0.987	0.987	0.950
L29	0.864	0.887	0.914	0.918	0.933	0.941	0.944	0.954	0.961	0.967	0.969	0.980	0.988	0.989	0.991	0.992	0.993	0.952
L30	0.938	0.954	0.963	0.975	0.973	0.976	0.978	0.983	0.982	0.986	0.986	0.988	0.989	0.989	0.989	0.995	0.997	0.979
L31	0.984	0.988	0.989	0.992	0.988	0.990	0.988	0.991	0.991	0.993	0.993	0.996	0.997	0.997	0.997	0.998	0.999	0.993
L32	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000	0.999
L33	0.959	0.962	0.962	0.980	0.985	0.991	0.993	0.996	0.996	0.994	0.996	0.998	0.998	0.999	0.999	0.999	0.999	0.988
L34	0.861	0.879	0.885	0.866	0.875	0.858	0.864	0.929	0.923	0.935	0.892	0.950	0.921	0.944	0.954	0.963	0.976	0.910
High	0.644	0.657	0.617	0.594	0.556	0.576	0.559	0.559	0.548	0.548	0.540	0.529	0.507	0.505	0.492	0.463	0.473	0.551
Low	0.921	0.929	0.934	0.941	0.909	0.916	0.921	0.938	0.941	0.955	0.967	0.972	0.977	0.980	0.983	0.985	0.986	0.950
All	0.823	0.833	0.822	0.818	0.785	0.796	0.793	0.804	0.802	0.812	0.816	0.816	0.811	0.812	0.810	0.801	0.805	0.809

low-emission group. The three industries with the lowest metafrontier ratios are H11, H02, and H03, which belong to the high-emission group.

We also observe that group green efficiency and metafrontier ratio are not always consistent. As shown in Table 6, H03 in the high-emission group appears in the top three for highest green efficiency and the bottom three for lowest metafrontier ratio. More generally, there is a big discrepancy between the top and bottom sectors in terms of group green efficiency and metafrontier ratio. In fact, this shows the difference between group technologies and metatechnology, which implies different possibilities for efficiency catch-up. That is, sectors with low group green efficiency may get a free ride on technology spillover and environmental regulation of the group to improve the metafrontier ratio. On the other hand, some sectors with higher group green efficiency may deviate from the metafrontier if they do not effectively utilize technology spillover. In short, in order to improve the overall green efficiency, it is necessary not only to improve its own group green efficiency but also to promote the technological progress of this group and make comprehensive use of the technology spillover.

3.3. Metafrontier Green Efficiency. As discussed above, the metafrontier green efficiency is comparable from a global view of point. In Figure 3, the overall metafrontier green efficiency suffered a general declining trend from 2000 to 2004, a rising trend during 2005–2011, and a slightly declining trend after 2012. This periodic shift is in line with those studies that considered the technology heterogeneity, e.g., Li and Lin [38]; Cheng et al. [39]; and Cheng and Jin [40]. However, this periodic shift is not very in line with those studies that either did not consider technology heterogeneity or did not consider individual heterogeneity, e.g., Sun and Huang [41]; Ouyang et al. [42]; and Luo et al. [43]. Moreover, the high-emission group witnessed a general declining trend of metafrontier

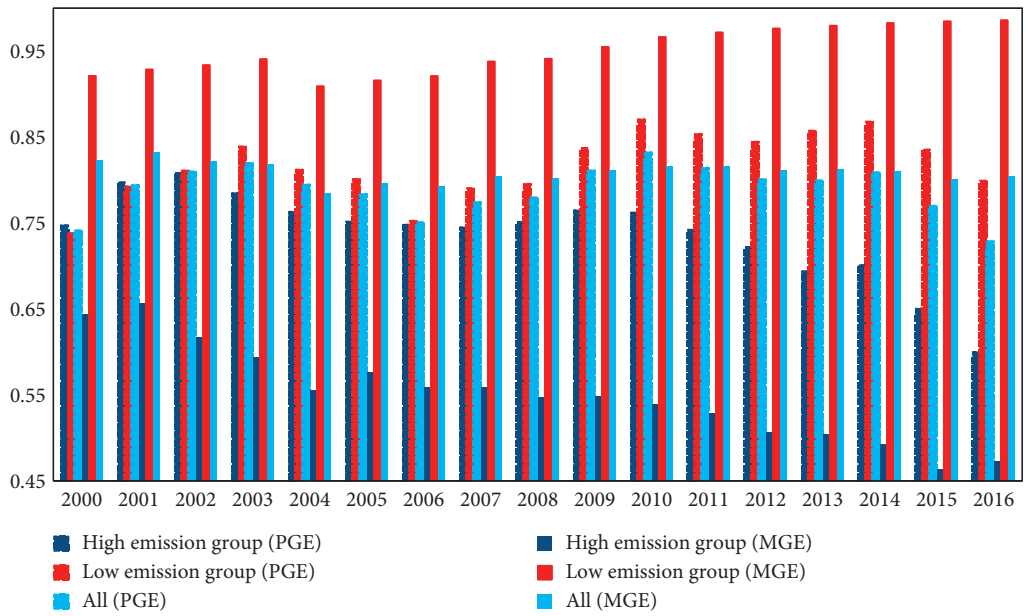


Figure 4: Comparison of metafrontier and pooled green efficiency in different groups.

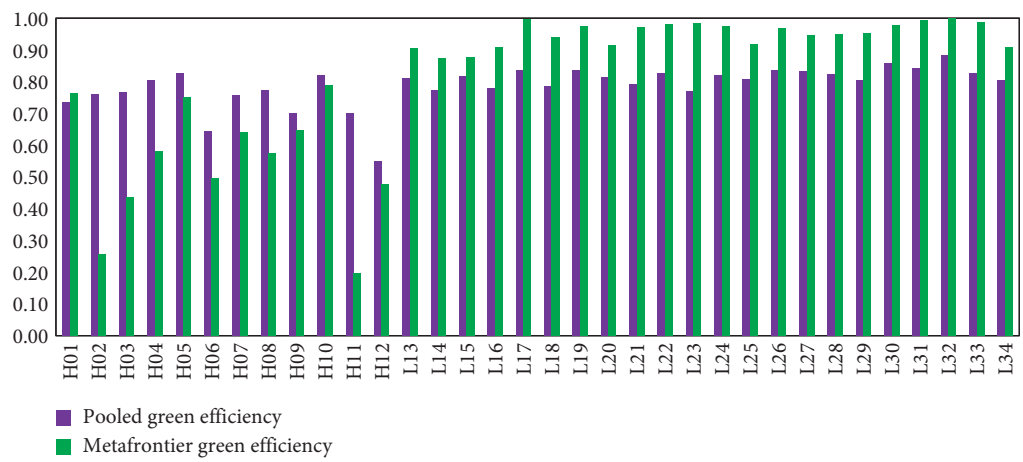


Figure 5: Comparison of metafrontier and pooled green efficiency in different sectors.

green efficiency while the low-emission group experienced an increasing trend. These results are in line with the existing literature, e.g., Li and Lin [38]; Kang et al. [44]; and Liu et al. [45].

Table 7 reports the metafrontier green efficiency of China's industrial sectors. Among different industrial sectors, the top three sectors of metafrontier green efficiency are L32 (Communication equipment manufacturing), L17 (Tobacco manufacturing), and L31 (Electrical machinery and equipment), with values of 0.9988, 0.9955, and 0.9925, respectively. The bottom three sectors of metafrontier green efficiency are H11 (Electricity production), H02 (Oil and natural gas extracting), and H03 (Ferrous metal mining), with values of 0.197, 0.255, and 0.438, respectively. This is consistent with the metafrontier ratio, because the metafrontier ratio has more difference than group green efficiency between the high- and low-emission groups. Therefore, the metafrontier ratio has a greater weight than group green efficiency in the calculation of metafrontier green efficiency. From the perspective of the industry distribution of best and worst metafrontier green efficiency, the calculation results in this study are reliable and follow the practical observations. Comparatively, those studies that did not consider technology heterogeneity and/or individual heterogeneity might suffer bias. For example, in Li and Cheng [46], the top three sectors of green efficiency include Communication equipment manufacturing (L32), Oil processing and coking (H06), and Leather manufacturing (L19). However, the Oil processing and coking (H06) is known as the high-emission and low green efficiency sector [38]. Printing and intermediary replication (L22) and Paper industry (H05) are the bottom two sectors in their study,

Table 8: Comparison of rankings of metafrontier and pooled green efficiency.

Sectors	MGE	MGE rank	PGE	PGE rank	Difference of rank
H01	0.765	24	0.736	30	6
H02	0.255	33	0.762	28	−5
H03	0.438	32	0.766	27	−5
H04	0.580	28	0.805	19	−9
H05	0.751	25	0.828	8	−17
H06	0.496	30	0.645	33	3
H07	0.640	27	0.759	29	2
H08	0.574	29	0.773	25	−4
H09	0.648	26	0.702	31	5
H10	0.789	23	0.819	13	−10
H11	0.197	34	0.699	32	−2
H12	0.477	31	0.548	34	3
L13	0.904	20	0.810	16	−4
L14	0.876	22	0.774	24	2
L15	0.878	21	0.816	14	−7
L16	0.909	19	0.779	23	4
L17	0.996	2	0.835	6	4
L18	0.939	15	0.787	22	7
L19	0.975	8	0.837	5	−3
L20	0.914	17	0.813	15	−2
L21	0.971	10	0.791	21	11
L22	0.982	6	0.826	10	4
L23	0.984	5	0.769	26	21
L24	0.974	9	0.822	12	3
L25	0.919	16	0.809	17	1
L26	0.968	11	0.837	4	−7
L27	0.947	14	0.834	7	−7
L28	0.950	13	0.825	11	−2
L29	0.952	12	0.806	18	6
L30	0.979	7	0.859	2	−5
L31	0.993	3	0.841	3	0
L32	0.999	1	0.883	1	0
L33	0.988	4	0.828	9	5
L34	0.910	18	0.804	20	2

Note: ranking differences are calculated with reference to metafrontier green efficiency.

which is also anti-intuitive because none of them belong to the six high-emission industries recognized by the Chinese government [47].

3.4. Comparison between Metafrontier and Pooled Green Efficiency. Figure 4 shows the average pooled green efficiency and metafrontier green efficiency from 2000 to 2016. For the high-emission group, the pooled green efficiency is obviously higher than the metafrontier green efficiency, while for the low-emission group the pooled green efficiency is systematically lower than the metafrontier green efficiency. Nevertheless, from the global perspective, the average pooled green efficiency is very close to the metafrontier green efficiency. These results indicate that the pooled green efficiency overestimates the efficiency level of the high-emission group and underestimates the efficiency level of the low-emission group when technological heterogeneity is not considered.

Figure 5 provides a further comparison at the sector level. Consistent with the situation of the high- and low-emission groups in Figure 4, in the high-emission group, the pooled green efficiency of each sector (except H01) is systematically higher than the metafrontier green efficiency, which is consistent with Figure 4. In the low-emission group, the metafrontier green efficiency of each sector is systematically higher than the pooled green efficiency, which is also consistent with Figure 4.

Finally, we provide Table 8 to compare the rankings of sectors between the metafrontier green efficiency and the pooled green efficiency. As shown, the rankings of metafrontier green efficiency among sectors and those of the pooled green efficiency are quite different. There are only two sectors that have the same ranking, i.e., L31 and L32, both of which belong to the top three sectors of green efficiency. The biggest ranking difference appears in H05, which ranks 25th in the metafrontier green efficiency while ranks 8th in pooled green efficiency ranked. Since H05 ranks 11th in terms of carbon intensity (from high to low), we believe that the ranking of metafrontier green efficiency is more reliable than that of pooled green efficiency. Overall, there are 13 sectors with ranking differences within 3 while more than 60% of sectors have ranking differences greater than 3. Compared with existing studies that did not consider technology heterogeneity and/or individual heterogeneity (e.g., [45, 46]), we find that their rankings of green efficiency are quite different from ours. Take the six high-emission sectors as an example, they are ranked the 34th (Electricity production, H11), 30th (Oil processing and coking, H06), 29th (Nonmetallic mineral products, H08), 27th (Chemical materials and products, H07), 26th (Ferrous metal smelting and pressing, H09), and 23rd (Nonferrous metal pressing, H10). In other words, all of them belong to the bottom group of sectors in terms of green efficiency. However, in Li and Cheng [46], only Chemical materials and products (H07) and Nonmetallic mineral products (H08) belong to the bottom group while Ferrous metal smelting and pressing (H09) belong to the middle group and Non-ferrous metal pressing (H10) and Oil processing and coking (H06) even belong to the top group. This indicates that technology heterogeneity should be considered to get a better understanding of individual sectors' green efficiency performance.

4. Conclusions

In this study, we propose a new parametric measurement framework for total-factor green efficiency by combining the Shephard distance function [18] and the two-step stochastic frontier approach [28]. The new approach can not only flexibly evaluate green efficiency but also deal with both technology heterogeneity and individual heterogeneity. Using the comprehensive approach, we measure the metafrontier green efficiency of 34 industrial sectors in China.

It is found that the metafrontier green efficiency in China's industrial sectors has experienced a fluctuating change, with an overall trend of decline-increase-decline. At the same time, the metafrontier green efficiency levels of the high- and low-emission groups are significantly different. Moreover, the efficiency level of the low-emission group is systematically higher than that of the high-emission group.

Compared with pooled green efficiency without considering technology heterogeneity, the metafrontier green efficiency is more intuitive and realistic both at the group average level and at the sector level. Moreover, compared with those studies that did not consider technology heterogeneity and/or individual heterogeneity, this study produces more reliable green efficiency of industrial sectors, which also follows the common economic sense. The results indicate that, in order to achieve green growth, the government needs to implement heterogeneous energy conservation and emission reduction policies for high- and low-emission groups. In particular, carbon-intensive industries should be encouraged to effectively improve the utilization of existing group technologies and to promote technology diffusion and spillover between groups.

Overall, the new approach proposed in this study produces a reliable measurement of green efficiency, which is supported by various comparisons. Nevertheless, there are some limitations of this study. For example, the high-emission and low-emission groups are equally divided on the basis of carbon intensity. In the future, a new grouping criterion that asymmetrically divides the industrial sectors into groups may be found with additional information. Besides, this study only considers the metafrontier green efficiency. In the future, green productivity based on the reliable measurement of green efficiency can be explored.

Data Availability

The data that support the findings of this study are openly available in China Statistical Yearbook and China Industry Statistical Yearbook.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Nbsc (National Bureau of Statistics of China), "Available online," 2022, https://data.stats.gov.cn/english/.

[2] Cpgprc, "(The central people's government of the people's Republic of China). Suggestions of the CPC central committee on formulating the eleventh five-year plan," 2005, http://www.gov.cn/ztzl/2005-10/19/content_79386.htm Available online:.

[3] G. Xu and W. Wang, "China's energy consumption in construction and building sectors: an outlook to 2100," *Energy*, vol. 195, Article ID 117045, 2020.

[4] S. D'Alessandro, A. Cieplinski, T. Distefano, and K. Dittmer, "Feasible alternatives to green growth," *Nature Sustainability*, vol. 3, no. 4, pp. 329–335, 2020.

[5] M. Capasso, T. Hansen, J. Heiberg, A. Klitkou, and M. Steen, "Green growth - a synthesis of scientific findings," *Technological Forecasting and Social Change*, vol. 146, pp. 390–402, 2019.

[6] R. G. Chambers, R. Fāure, and S. Grosskopf, "Productivity growth in apec countries," *Pacific Economic Review*, vol. 1, no. 3, pp. 181–190, 1996.

[7] Y. H. Chung, R. Färe, and S. Grosskopf, "Productivity and undesirable outputs: a directional distance function approach," *Journal of Environmental Management*, vol. 51, no. 3, pp. 229–240, 1997.

[8] D. h. Oh and A. Heshmati, "A sequential Malmquist-Luenberger productivity index: environmentally sensitive productivity growth considering the progressive nature of technology," *Energy Economics*, vol. 32, no. 6, pp. 1345–1355, 2010.

[9] J. Du, Y. Duan, and J. Xu, "The infeasible problem of Malmquist-Luenberger index and its application on China's environmental total factor productivity," *Annals of Operations Research*, vol. 278, no. 1-2, pp. 235–253, 2019.

[10] L. Simar and P. W. Wilson, "Estimation and inference in two-stage, semi-parametric models of production Processes [J]," *Journal of Econometrics*, vol. 137, pp. 31–64, 2004.

[11] R. Fare, S. Grosskopf, and C. A. K. Lovell, *The Measurement of Production Efficiency*, Kluwerer-nijhoff Publishing, Boston, 1985.

[12] R. Färe, S. Grosskopf, D.-W. Noh, and W. Weber, "Characteristics of a polluting technology: theory and practice," *Journal of Econometrics*, vol. 126, no. 2, pp. 469–492, 2005.

[13] R. A. Cuesta, C. K. Lovell, and J. L. Zofío, "Environmental efficiency measurement with translog distance functions: a parametric approach," *Ecological Economics*, vol. 68, no. 8-9, pp. 2232–2242, 2009.

[14] L. R. Christensen, D. W. Jorgenson, and L. J. Lau, "Transcendental logarithmic production frontiers," *The Review of Economics and Statistics*, vol. 55, no. 1, pp. 28–45, 1973.

[15] Z. Zhang and J. Ye, "Decomposition of environmental total factor productivity growth using hyperbolic distance functions: a panel data analysis for China," *Energy Economics*, vol. 47, pp. 87–97, 2015.

[16] Y. S. Duman and A. Kasman, "Environmental technical efficiency in EU member and candidate countries: a parametric hyperbolic distance function approach," *Energy*, vol. 147, pp. 297–307, 2018.

[17] P. Zhou, B. W. Ang, and J. Y. Han, "Total factor carbon emission performance: a Malmquist index analysis," *Energy Economics*, vol. 32, no. 1, pp. 194–201, 2010.

[18] B. Lin and K. Du, "Modeling the dynamics of carbon emission performance in China: a parametric Malmquist index approach," *Energy Economics*, vol. 49, pp. 550–557, 2015.

[19] X. Tan, Y. Choi, B. Wang, and X. Huang, "Does China's carbon regulatory policy improve total factor carbon efficiency? A fixed-effect panel stochastic Frontier analysis," *Technological Forecasting and Social Change*, vol. 160, Article ID 120222, 2020.

[20] Y. Lv, J. Liu, J. Cheng, and V. Andreoni, "The persistent and transient total factor carbon emission performance and its economic determinants: evidence from China's province-level panel data," *Journal of Cleaner Production*, vol. 316, Article ID 128198, 2021.

[21] Y. Hayami and V. W. Ruttan, "Agricultural productivity differences among countries," *The American Economic Review*, vol. 60, no. 5, pp. 895–911, 1970.

[22] G. E. Battese and D. S. P. Rao, "Technology gap, efficiency, stochastic metafrontier function," *International Journal of Business and Economics*, vol. 1, no. 2, p. 87, 2002.

[23] G. E. Battese, D. S. P. Rao, and C. J. O'Donnell, "A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies," *Journal of Productivity Analysis*, vol. 21, no. 1, pp. 91–103, 2004.

[24] C. J. O'Donnell, D. S. P. Rao, and G. E. Battese, "Metafrontier frameworks for the study of firm-level efficiencies and

technology ratios," *Empirical Economics*, vol. 34, no. 2, pp. 231–255, 2008.

[25] B. Lin and K. Du, "Measuring energy efficiency under heterogeneous technologies using a latent class stochastic Frontier approach: an application to Chinese energy economy," *Energy*, vol. 76, pp. 884–890, 2014.

[26] Y. Bai, X. Deng, Q. Zhang, and Z Wang, "Measuring environmental performance of industrial sub-sectors in China: a stochastic metafrontier approach," *Physics and Chemistry of the Earth, Parts A/B/C*, vol. 101, pp. 3–12, 2017.

[27] J. Zheng, H. Zhang, and Z. Xing, "Re-examining regional total-factor water efficiency and its determinants in China: a parametric distance function approach," *Water*, vol. 10, no. 10, p. 1286, 2018.

[28] C. J. Huang, T.-H. Huang, and N.-H. Liu, "A new approach to estimating the metafrontier production function based on a stochastic Frontier framework," *Journal of Productivity Analysis*, vol. 42, no. 3, pp. 241–254, 2014.

[29] M. Safiullah and A. Shamsuddin, "Risk-adjusted efficiency and corporate governance: evidence from Islamic and conventional banks," *Journal of Corporate Finance*, vol. 55, pp. 105–140, 2019.

[30] H. Alem, G. Lien, J. B. Hardaker, and A. Guttormsen, "Regional differences in technical efficiency and technological gap of Norwegian dairy farms: a stochastic meta-frontier model," *Applied Economics*, vol. 51, no. 4, pp. 409–421, 2019.

[31] J. Lu, B. Li, H. Li, and X. Zhang, "Characteristics, exchange experience, and environmental efficiency of mayors: evidence from 273 prefecture-level cities in China," *Journal of Environmental Management*, vol. 255, Article ID 109916, 2020.

[32] H. Zhang, L. W. Fan, and P. Zhou, "Handling heterogeneity in Frontier modeling of city-level energy efficiency: the case of China," *Applied Energy*, vol. 279, Article ID 115846, 2020.

[33] Z. Wang, "Measuring China's industrial total-factor energy efficiency by a fixed-effects two-step stochastic metafrontier model," *Economic Computation & Economic Cybernetics Studies & Research*, vol. 54, no. 1, 2020.

[34] T. Coelli and S. Perelman, "A comparison of parametric and non-parametric distance functions: with application to European railways," *European Journal of Operational Research*, vol. 117, no. 2, pp. 326–339, 1999.

[35] W. Greene, "Fixed and random effects in stochastic frontier models," *Journal of Productivity Analysis*, vol. 23, no. 1, pp. 7–32, 2005.

[36] S. Y. Chen, "Reconstruction of sub-industrial statistical data in China (1980-2008)," *China Economic Quarterly*, vol. 10, no. 3, pp. 735–776, 2011, (in Chinese).

[37] Y. Shan, D. Guan, H. Zheng et al., "China CO2 emission accounts 1997-2015," *Scientific Data*, vol. 5, no. 1, Article ID 170201, 2018.

[38] J. Li and B. Lin, "Ecological total-factor energy efficiency of China's heavy and light industries: which performs better?" *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 83–94, 2017.

[39] Z. Cheng, L. Li, J. Liu, and H. Zhang, "Total-factor carbon emission efficiency of China's provincial industrial sector and its dynamic evolution," *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 330–339, 2018.

[40] Z. Cheng and W. Jin, "Agglomeration economy and the growth of green total-factor productivity in Chinese Industry," *Socio-Economic Planning Sciences*, 2020, In Press, Article ID 101003.

[41] W. Sun and C. Huang, "How does urbanization affect carbon emission efficiency? Evidence from China," *Journal of Cleaner Production*, vol. 272, Article ID 122828, 2020.

[42] X. Ouyang, J. Chen, and K. Du, "Energy efficiency performance of the industrial sector: from the perspective of technological gap in different regions in China," *Energy*, vol. 214, 2021.

[43] Y. Luo, Z. Lu, S. Muhammad, and H. Yang, "The heterogeneous effects of different technological innovations on eco-efficiency: evidence from 30 China's provinces," *Ecological Indicators*, vol. 127, Article ID 107802, 2021.

[44] Y.-Q. Kang, B.-C. Xie, J. Wang, and Y.-N. Wang, "Environmental assessment and investment strategy for China's manufacturing industry: a non-radial DEA based analysis," *Journal of Cleaner Production*, vol. 175, pp. 501–511, 2018.

[45] S. Liu, X. Jia, and J. Dang, "Research on the measurement and influencing factors of industrial green total factor productivity in China," *Ecological Economy*, vol. 36, no. 11, pp. 46–53, 2020.

[46] J. Li and Z. Cheng, "Study on total-factor carbon emission efficiency of China's manufacturing industry when considering technology heterogeneity," *Journal of Cleaner Production*, vol. 260, Article ID 121021, 2020.

[47] G. Du, C. Sun, X. Ouyang, and C. Zhang, "A decomposition analysis of energy-related CO2 emissions in Chinese six high-energy intensive industries," *Journal of Cleaner Production*, vol. 184, pp. 1102–1112, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7799695, 8 pages
https://doi.org/10.1155/2022/7799695

Research Article

Crisis Analysis and Prevention and Control of Financial Leverage Imbalance in Shareholder Equity Pledge Based on the DANP Model

Fang Fang

School of Accounting, Jiangxi University of Finance and Economics, Nanchang, China

Correspondence should be addressed to Fang Fang; fangfang@jxufe.edu.cn

Received 1 March 2022; Accepted 5 April 2022; Published 5 May 2022

Academic Editor: Lele Qin

Research Background. The process of economic globalization is accelerating, and the financial risks that listed companies need to face are more complicated. *Research Purpose*. In order to clarify the impact of shareholder equity pledge on financial leverage imbalance crisis, research on the analysis and prevention of financial leverage imbalance crisis of shareholder equity pledge based on the DANP model is carried out. *Research Method and Process*. The DANP financial leverage imbalance early warning model is introduced to analyze the impact of shareholder equity pledge on financial leverage imbalance crisis by combining the financial leverage effect and potential risks of shareholder equity pledge, optimize the financial leverage imbalance early warning evaluation index system, preprocess the early warning evaluation indicators, determine the constant weight of each evaluation index, and obtain the final financial leverage imbalance crisis early warning evaluation value based on the determined constant weight. *Research Results*. The DANP model can accurately analyze the financial leverage imbalance crisis in the case of shareholder equity pledges, clarify the company's financial status in the case of shareholder equity pledges, propose to standardize equity pledge behavior, improve the company's internal control system in response to the crisis of shareholder equity pledge financial leverage imbalances, and improve the three prevention and control measures of the independent director system to enhance the ability of enterprises to resist the crisis of financial leverage imbalance.

1. Introduction

The financial market environment is complex and changeable, information technology is developing rapidly, and there is great uncertainty in the operation of enterprises. It is not uncommon for enterprises to go bankrupt due to financial risks [1]. Enterprises can find financial risks as early as possible and avoid and diversify risks in time to maintain the sustainable development of the enterprise. In enterprise risk management, financial leverage imbalance crisis early warning occupies an important position. Enterprise financial leverage imbalance crisis early warning is an important topic that is highly valued in the academic field. Efficient financial leverage imbalance crisis early warning methods have important early warning and supervision functions. The financial leverage imbalance crisis early warning method can clarify the cause of the corporate financial crisis and facilitate timely measures and countermeasures to resolve the financial crisis.

The pledge of major shareholders' equity brings huge risks to the capital market. The risk of shareholder equity pledge mainly includes the risk of control transfer caused by the fluctuation of the company's stock price, the risk of excessive investment, and the risk of related party transactions. After the pledge of corporate shareholders' equity, the company's internal environment and performance decline will cause stock prices to fall and shareholders' inability to repay loans will change the company's control. After the pledge of shareholder equity, the company's scale continues to expand [2] and the company's frequent foreign investment will cause the company to form risks due to excessive investment. After the shareholder's equity pledge,

shareholders transfer the interests of the listed company through related transactions and other forms. The equity pledge risk will increase the business risk of the enterprise.

Corporate stakeholders such as investors, creditors, and managers attach great importance to corporate financial health. The correctness of corporate investment decisions can avoid corporate investment risks and maintain corporate funds in a safe and stable state. Investors use the risk warning results to correctly implement investment decisions [3], which can ensure the safety of corporate funds. Managers clarify the root causes of the financial crisis in strategic decision-making and can choose projects with lower risks and higher returns. In the production and operation process of managers, rational adjustment of capital structure can timely reverse the risks faced by enterprises due to financial crisis. An efficient financial crisis early warning model has extremely important practical value and theoretical significance.

Researchers at home and abroad have studied the risk of shareholder equity pledge and financial leverage. Xia and Khang studied the influence of investment heat and financial leverage on the excess return rate of stocks [4], taking full account of the influence of the excess return rate of stocks on financial leverage and investment heat influence, and clarifying the relationship between the three; Li and Xin studied the sensitivity of controlling shareholder's equity pledge to executive compensation performance [5], fully considering the impact of shareholder equity pledge on corporate executive compensation and performance; Liao et al. study the controlling shareholder's equity pledge and the dividend policy of listed companies [6] and clarify the relationship between the listed company's dividend policy and the shareholder's equity pledge; Lin and Wei studied analyzed the equity pledge of controlling shareholders, the nature of equity, and corporate performance and found that the controlling shareholders of private listed companies were more inclined to equity pledge than the controlling shareholders of state-owned listed companies [7], and it was clear that the shareholding ratio of shareholders was negatively correlated with equity pledge; Walthoff–Borm et al. have fully studied the relationship between equity crowdfunding, shareholder structure, and company performance [8], clarifying that company performance is affected by equity crowdfunding and shareholder structure. Although the above method analyzes the financial leverage imbalance crisis of shareholder equity pledge, the research method is not effective due to the unreasonable construction of the index system and the incomplete analysis of the financial leverage effect.

The DANP (network hierarchy analysis) model is based on the analytic hierarchy process (AHP) model with high analytical effectiveness and has been applied to the financial field; it is of great significance to apply it to the financial leverage imbalance crisis analysis. The DANP model has the advantages of a systematic analysis method, practical decision-making, being simple, and having less quantitative data information, which can effectively evaluate the system evaluation without structural characteristics and the multiobjective, multiquasi side, and multiperiod system. The structure is simple and clear, and it can solve the practical problems that cannot be solved by optimization technology.

Therefore, to solve these problems, this paper analyzes the imbalance crisis of shareholders' equity pledge and financial leverage. The Danp model is introduced to optimize the index system and model.

2. Research Methods

2.1. Financial Leverage. The effect of financial leverage is the change in earnings per common stock caused by the fluctuation of corporate earnings before interest and taxes due to corporate fixed debt. When the capital structure is fixed, interest expenses need to be paid, that is, the debt financing cost is fixed. When the preinterest and tax profit is increased, the debt interest on the preinterest and tax profit of each unit will be reduced [9], the distribution to shareholders after tax deduction will be increased, and shareholders will get additional financial leverage benefits and financial risks of financial leverage. At this point, the leverage effect is positive and negative, respectively.

The effect of financial leverage will form a positive effect and a negative effect; that is, both returns and risks exist simultaneously [10]. The DFL indicator is selected as a measure of financial leverage income and risk indicators. DFL refers to the financial leverage coefficient, which is obtained from the change rate of the company's profit before interest and tax and the change rate of each share's return. Table 1 shows the calculation process of the DFL value when the enterprise finances ordinary liabilities.

According to Table 1, the available financial leverage formula is as follows:

$$\mathrm{DFL} = \frac{\Delta EPS/EPS}{\Delta \mathrm{EBIT}/\mathrm{EBIT}}. \tag{1}$$

The formula of ΔEPS for earnings per share is as follows:

$$\begin{aligned}\Delta EPS &= \frac{(\mathrm{EBIT}' - U)(1-E)}{N} - \frac{(\mathrm{EBIT} - U)(1-E)}{N} \\ &= \frac{(1-E)\Delta \mathrm{EBIT}}{N}.\end{aligned} \tag{2}$$

Then, we have the following:

$$\frac{\Delta EPS}{EPS} = \frac{\Delta \mathrm{EBIT}}{\mathrm{EBIT} - U}. \tag{3}$$

Substituting the previous formula into formula (1), the following formula can be obtained:

$$\mathrm{DFL} = \frac{\mathrm{EBIT}}{\mathrm{EBIT} - U}. \tag{4}$$

In the above-mentioned formula, DFL and EPS, respectively, represent the financial leverage factor and earnings per share; EBIT and U represent the preinterest and tax profit and debt interest, respectively; and E and N represent the income tax rate and the number of ordinary shares issued.

Table 1: DFL value calculation process.

	Base period	Reporting period
EBIT	EBIT	EBIR'
Debt interest	U	U
Income tax rate	E	E
Profit after interest and tax	(EBIT-U) (1-E)	(EBIT'-U) (1-E)
Earnings per share	(EBIT-U) (1-E)/ N	(EBIT'-U) (1-E)/ N

The above analysis shows that the following conditions are required to obtain the financial leverage factor: (1) the total assets of the enterprise, the total debt interest paid, the debt interest rate, and the capital structure are all fixed; (2) the corporate income tax rate has not changed, and income tax is levied at a fixed rate, but not converted into non-payment of income tax; (3) there is no change in the number of ordinary shares issued by the company, and there is no preference stock.

Under the above assumptions, the financial leverage coefficient can be used to clarify the changes in corporate profits, which is convenient for analyzing the crisis of financial leverage imbalance in shareholder equity pledge.

2.2. Potential Risks of Shareholder Equity Pledge. The listed company entity is an independent legal person, and the independent legal person is separated from each shareholder. Shareholder pledge of equity indicates that the parent company has a financing gap. A shareholder equity pledge is a financing method when there is no effective financing channel and shareholders are already short of funds. Under the situation of shrinking market liquidity, shareholders can easily choose equity pledge financing. The main risks of shareholder equity pledge are as follows: In the case of pledge default, when the stock price is too low, the pledgee may sell and retain the pledged equity. At this time, the equity pledge shareholder may lose control of the company; shareholders have financial leverage risk [11], and shareholder pledges are likely to be unpayable due to financial deterioration. The research results of Wang Xiongyuan and others showed that the decline in the value of shareholder pledged equity will have the risk of control transfer and pressure to cover positions; when the constraint state and specific conditions are fixed, the shareholder pledge of equity can fully consider the benefits and costs and formulate self-interested financial behaviors against equity pledge risks. The pledge of shareholders' equity may cause deviations from the actual development needs of listed companies and fail to bring expected benefits to the company; the pledge of shareholder's equity will consume a lot of resources and affect the stability of the company's capital chain; market investors do not favor shareholder equity pledge investment projects. Raising the company's share price has not brought a positive impact.

The pledge of shareholder equity can easily cause a crisis of corporate financial leverage imbalance. In the case of shareholder equity pledges, when shareholders' investment preferences change, radical subjective ideas will increase corporate debt pressure and increase corporate capital flow risks. A shareholder pledge would send a negative signal to the market, which will affect the company's financing environment and increase the crisis of the company's financial leverage imbalance.

2.3. DANP Financial Leverage Imbalance Early Warning Model

2.3.1. Early Warning Evaluation Index System for Financial Leverage Imbalance. The profit quality is selected as the evaluation index of the financial leverage imbalance crisis, which is reflected in continuity, solvency, capability, and stability. Profitability continuity can reflect whether a company can maintain sustainable development; profitability stability can reflect the degree of corporate profit volatility; profitability can reflect the level of cash obtained by the company, and debt solvency can reflect the operating efficiency of the main business of the enterprise [12]. The higher the value of the evaluation index, the better the performance of the enterprise. The impact of shareholder equity pledge on the financial operation of the enterprise is the main reason for the imbalance of financial leverage.

The uncertainty of the enterprise when facing risks can reflect the operation of the enterprise. The organizational ability and adaptability of the enterprise cannot operate stably when the indicators are behind [13], which causes the crisis of financial leverage imbalance. Combining the quality of corporate earnings to measure the crisis of corporate financial leverage imbalance, the established financial leverage imbalance crisis early warning evaluation index system is shown in Table 2.

2.3.2. Preprocessing of Early Warning Evaluation Index Values. The established financial leverage imbalance crisis early warning evaluation indicator system has large differences in various indicator dimensions, and each indicator needs to be normalized. The extreme value processing method in the linear normalization method is selected for dimensionless processing of each index data [14], so that all the index data are placed in the interval [0, 1].

Suppose the original data set is $U^{m\times n}$; the data set contains the number of rows and the dimensions are m and n, respectively, $D^{m\times n}$ represents the normalized data set, and $\max(\cdot)$ and $\min(\cdot)$ represent the maximum function and the minimum function, respectively. The extreme value normalization operation formula is as follows:

$$U^{m\times n} = \frac{D^{i\times j} - \min\left(D^{j}\right)}{\max\left(D^{j}\right) - \min\left(D^{j}\right)}. \tag{5}$$

Here, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

2.3.3. Determination of the Constant Weight. We use the network hierarchy analysis method (DANP) to determine the weight of each index in the evaluation index system; the process is as follows:

Table 2: Financial leverage imbalance crisis early warning evaluation index system.

Target layer	Criterion layer	Measure layer
Financial leverage imbalance crisis warning	Profitability continuity	Net profit growth rate
		Sustainable growth rate
		ROE growth rate
		Net cash flow growth rate
	Solvency	Asset load rate
		Earned interest multiple
		Current ratio
		Cash ratio
	Profit stability	Coefficient of variation of operating margin
		Coefficient of variation of profit rate of total assets
		Coefficient of variation of profit rate of net assets
		Coefficient of variation of main business profit
	Profitability	Working capital turnover rate
		Accounts receivable turnover rate
		Net cash content of net profit
		Cash content of operating income

(1) The expert questionnaire method is used to establish the direct influence matrix formula of each index and each dimension in the evaluation index system as follows:

$$E_t = \left(e_{ij}\right)_{m\times n}. \tag{6}$$

Here, e_{ij} represents the degree of influence of j index by i index.

(2) The formula for obtaining the average direct influence matrix is as follows:

$$B = \frac{1}{n}\sum_{t=1}^{n} E_t = \left(b_{ij}\right)_{m\times n}. \tag{7}$$

(3) The consistency test directly affects the matrix, and the consistency average gap ratio test formula is as follows:

$$p = \frac{1}{m(m-1)}\sum_{i=1}^{m}\sum_{i=1}^{n}\left|\frac{b_{ij}^{n} - b_{ij}^{n-1}}{b_{ij}^{n}}\right| \le 6\%. \tag{8}$$

b_{ij}^{n} represents the elements in the average influence matrix obtained when the number of experts is n.

(4) The normalization processing matrix B obtains the normalization result N as follows:

$$N = \frac{1}{k}\times B,$$
$$k = \max\left\{\sum_{i=1}^{m} b_{ij}, \quad \sum_{j=1}^{n} b_{ij},\right\}. \tag{9}$$

Here, k represents the normalization coefficient.

(5) solve the total influence matrix as follows:

$$T = N(I-N)^{-1}. \tag{10}$$

Here, I represents the identity matrix.

(6) The unweighted super matrix W^{α} is obtained by using the index total influence matrix T_C.

$$W^{\alpha} = \left(T_C^{\alpha}\right)' = \begin{array}{c} B_1 \\ \vdots \\ B_4 \\ c_{11} \\ \vdots \\ \vdots \\ c_{44} \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \\ \\ \\ \\ \begin{array}{cccc} B_1 & \cdots & B_4 & \\ c_{11} & \cdots & \cdots & c_{44} \end{array} \\ \begin{bmatrix} W^{11} & \cdots & W^{41} \\ \cdots & \cdots & \cdots \\ W^{14} & \cdots & W^{44} \end{bmatrix}_{16\times 16} \end{array}. \tag{11}$$

Here, B_i and T_C^{α}, respectively, represent the system dimension and the block normalization matrix of the total influence matrix and c_{ij} represents the i index in the i dimension of the system.

(7) The unweighted super matrix W^{α} and the total influence matrix are used to establish a weighted super matrix.

$$W = T_B^{\alpha} W^{\alpha}. \tag{12}$$

Here, T_B^{α} represents the normalized matrix of T_B.

(8) The self-multiplying weighted supermatrix is repeated until convergence, and the limit supermatrix $\lim_{n\longrightarrow\infty} W^n$ is obtained. The global constant weight vector w^g is a random column vector in the limit hypermatrix, and each index weight vector in the index system is obtained.

2.3.4. Obtaining Early Warning Evaluation Value. There is a positive relationship between corporate shareholder equity pledge and corporate financial leverage imbalance [15]. We use the construction of double-level penalty variables to determine the final result of the financial leverage imbalance crisis warning; the process is as follows:

(1) We set type equalization function and power function and use δ to represent the penalty coefficient; the value range is [0, 1], and the available penalty variable weight vector under the equalization function and power function is as follows:

$$D^{\delta}(x_1, x_2, x_3, x_4) = \sum_{i=1}^{4} x_i^{\delta}. \tag{13}$$

x_i represents the value of dimension B_i in the index system, and when the penalty coefficient is 1, the penalty variable weight vector is a constant weight vector.

(2) The results of using index penalty variable weight $w_{ij}^{\delta_i}(x_{i1}, x_{i2}, x_{i3}, x_{i4})$ to obtain dimension iB_i are as follows:

$$x_i^{\delta_i}(x_{i1}, x_{i2}, x_{i3}, x_{i4}) = \sum_{j=1}^{4i} w_{ij}^{\delta_i}(x_{i1}, x_{i2}, x_{i3}, x_{i4}) x_{ij}. \tag{14}$$

We use the dimensional penalty variable weight $w_{ij}^{\delta_i}(x_{i1}, x_{i2}, x_{i3}, x_{i4})$ to obtain the DANP early warning evaluation value as follows:

$$V^{\delta}\left(x_1^{\delta_1}, x_2^{\delta_2}, x_3^{\delta_3}, x_4^{\delta_4}\right) = \sum_{i=1}^{4} w_i^{\delta}(x_1, x_2, x_3, x_4) x_i^{\delta_i}. \tag{15}$$

(3) Comprehensive evaluation value: we set the evaluation annual limit to 3, and the comprehensive evaluation value formula of financial leverage imbalance crisis is as follows:

$$H = \sum_{K=1}^{3} w^{t-k} V_{t-k}^{\delta}\left(x_1^{\delta_1}, x_2^{\delta_2}, x_3^{\delta_3}, x_4^{\delta_4}\right). \tag{16}$$

Here, w^{t-k} represents the time series weight of the year $t-k$ and the comprehensive evaluation value of the financial leverage imbalance crisis is in the range of [0, 1].

3. Result Analysis and Discussion

A total of 95 listed companies with shareholder equity pledges provided by the Shanghai Securities News were selected, and listed companies with incomplete data were excluded to obtain a total of 87 superior companies. Thirty companies out of 87 listed companies were selected as test samples, and the remaining 57 listed companies were used as training samples. The listed company data comes from the Guotaian database.

The DANP model is used to calculate the weight of each indicator in the established financial leverage imbalance crisis rating indicator system. The calculation results are shown in Table 3.

The DANP model selects the median as the critical value and uses the accuracy of the model as the objective function to predict the crisis of financial leverage imbalance. The criteria for judging the financial leverage imbalance of listed companies using the DANP model are shown in Table 4.

It can be seen from Table 4 that the higher the financial crisis warning value, the lower the financial leverage imbalance crisis of the company due to shareholder equity pledge; when the warning value is higher than 0.6537, it indicates that the company has no financial leverage imbalance crisis and is in a safe state.

According to Table 3, the financial leverage imbalance crisis weights are determined using the DANP model to predict financial leverage imbalance crises for 87 listed companies with shareholder equity pledges. Compared with Table 4, the financial leverage imbalance crisis judgment criteria can be predicted as follows: among 87 listed companies, there are 12 companies with financial leverage imbalance crisis; 2 companies at the critical state of financial leverage imbalance crisis; and 73 companies without financial leverage imbalance crisis. The forecast results are consistent with the actual financial operation of listed companies, verifying the research and utilization of the DANP model in analyzing the effectiveness of the crisis of financial leverage imbalance in the pledge of shareholder equity.

The DANP model can accurately analyze the financial leverage imbalance crisis in the case of shareholder equity pledge, clarify the company's financial status in the case of shareholder equity pledge in real time, determine the cause of the financial leverage imbalance crisis based on the early warning results of different indicators in the established indicator system, and develop corresponding measures for specific indicators.

In view of the risk of financial leverage imbalance caused by shareholder equity pledge, the following preventive measures are proposed.

3.1. Standardizing Equity Pledge Behavior. Economic behaviors are heavily influenced by legal support and the market environment. The pledge of shareholder equity has been legalized, and the pledge of shareholder equity has strong convenience and is favored by many shareholders. The pledge of shareholder equity affects both the market environment and the financial changes of equity companies. In the operation of the pledge of shareholders' equity, the vital interests of investors and the financial risks of the company shall be fully considered, legal restrictions shall be considered, and the law shall be used to regulate shareholders' equity pledge behavior. The legal restraints for standardizing equity pledges are as follows.

3.1.1. Limited Equity Transactions. At present, there are no specific legal provisions restricting equity transactions in my country. The risk of control transfer is the main risk of

Table 3: Weight calculation results.

Criterion layer	Constant weight	Measure layer	Global constant weight	Local constant weight
Profitability continuity	0.3521	Net profit growth rate	0.0682	0.3215
		Sustainable growth rate	0.0582	0.1524
		ROE growth rate	0.0555	0.2355
		Net cash flow growth rate	0.0645	0.2906
Solvency	0.1526	Asset load rate	0.0583	0.1528
		Earned interest multiple	0.0616	0.2564
		Current ratio	0.0553	0.2314
		Cash ratio	0.0791	0.3594
Profit stability	0.2354	Coefficient of variation of operating margin	0.0755	0.3512
		Coefficient of variation of profit rate of total assets	0.0485	0.1254
		Coefficient of variation of profit rate of net assets	0.0582	0.2451
		Coefficient of variation of main business profit	0.0625	0.2783
Profitability	0.2599	Working capital turnover rate	0.0778	0.3524
		Accounts receivable turnover rate	0.0545	0.2159
		Net cash content of net profit	0.0592	0.1582
		Cash content of operating income	0.0631	0.2735

Table 4: Standards for judgment of financial leverage imbalance.

Financial status	Warning value
Leverage crisis	0–0.6483
Leverage crisis critical	0.6484–0.6536
Safety	0.6537–1

shareholder equity pledge. In the case of a high proportion of pledges, the risk of control transfer is more obvious. Using the law to restrict the pledge time period and pledge ratio and prohibit the high proportion of shareholder pledges, one can prevent and control the financial leverage imbalance crisis caused by the pledge of shareholder equity.

3.1.2. Supervising and Disclosing Information on Pledged Shareholder Equity. At present, relevant laws require that more than 5% of shareholders' equity pledges must be disclosed in a timely manner, and the disclosure content is not comprehensive. The controlling shareholder will influence the company due to their own financial status and pledge motivation. Improving laws and regulations will help the company make more detailed disclosures of shareholders' equity pledges and in the timely display of shareholders' solvency and personal financial status, and stakeholders can clarify the company's future direction and the purpose of equity pledges. Relevant control departments should timely strengthen the supervision and tracking of equity pledge of the high proportion of shareholders to avoid authenticity, sufficiency, and timeliness of the disclosed equity pledge information and avoid subsequent shareholder pledges that affect market stability and cause the company's financial leverage imbalance crisis.

With a sound supervision mechanism and complete information disclosure, market investors will be more clear about the company's operations after the shareholder's equity pledge, restrict shareholders to use equity pledge to cause the company's financial leverage imbalance crisis, protect the relevant interests of investors, ensure market stability, and prevent and control the financial leverage imbalance crisis caused by the pledge of shareholder equity.

3.2. Improving the Company's Internal Control System. Listed companies need a sound internal control system. The company's financial leverage imbalance crisis will be effectively prevented and controlled due to reasonable business decisions. A reasonable internal control system can avoid the encroachment of interests due to shareholder equity pledges and prevent the company's debt crisis. Listed companies not only need a sound internal control system but also improve the management efficiency of the internal control system, prevent and control corporate risks, fully consider the objective situation of the company, and avoid the company's financial leverage imbalance crisis. The superior company can formulate relevant internal control systems based on the pledge of corporate shareholders' equity to avoid risky projects due to equity pledges and prevent shareholders from encroaching on the company's interests. The company's internal audit agency is an important part of restraining shareholders' tunneling behavior. It should perform its internal audit functions in strict accordance with relevant procedures, reduce the risk of financial leverage imbalance caused by shareholder equity pledges, and protect the interests of listed company shareholders and related investors.

3.3. Improving the Independent Director System. The establishment of independent directors by the company can avoid the financial leverage imbalance crisis caused by the pledge of shareholders' equity. Independent directors can actively supervise the pledge of shareholders' equity. The independent board of directors currently accounts for about 30% of

the total number of board members in most of the superior companies. Many listed companies have the defects that independent directors are too superficial and have poor supervision.

Independent directors actively participate in the company's financial behavior and business decision-making, helping to safeguard the rights of small and medium shareholders, avoid irrational financial behaviors caused by the pledge of controlling shareholders' equity, and enhance the financial enthusiasm of the superior company. The independent director management system helps to play a huge role, enabling the company to maintain sustainable development through good operations.

The superior company should improve the independent director system through independent selection of independent directors, try to avoid management nominations, and select independent directors through recruitment; listed companies should improve the independent director mechanism through incentive mechanisms, which can encourage independent directors to work through incentives and economic remuneration; through the establishment of an evaluation system to adjust the allowances and remunerations of independent directors, independent directors should have the right to know information and have the right to vote and know the company's internal analysis data to have the right to realize supervision assistance and ensure the correctness and rationality of the company's operating procedures and business decisions.

4. Conclusion

Financial issues are the primary issue of corporate management, and maximizing returns is the main purpose of corporate capital optimization. We use the DANP model to analyze the crisis of financial leverage imbalance in shareholder equity pledge and propose relevant measures to prevent and control the crisis of financial leverage imbalance. Verification analysis shows that there are 12 companies with financial leverage imbalance crisis and 2 companies with crisis critical state. Therefore, this method effectively analyzes the influence of shareholder equity pledge on financial leverage imbalance, and through standardizing equity pledge behavior and improving the company's internal control system and independent director system, it effectively avoids the financial leverage imbalance crisis and major losses caused by shareholder equity pledge and realizes the sustainable development of enterprises. Due to time constraints, although the research method algorithm is simple, it takes a long time to run. Therefore, further research will be conducted in this aspect to improve the efficiency of the analysis method.

Data Availability

The data used in this study can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

This work was supported by University Humanities and Social Science Key Research Base Project of Jiangxi Province (No. JD16051, 2017.01) and Science and Technology Project of Jiangxi Province Department of Education (No. GJJ190270, 2020.01).

References

[1] X. Y. Xie and X. Y. Zhu, "Equity pledge and technological innovation investment of controlling shareholders in new third board Enterprises -- Based on the dual perspectives of financing mode and controlling shareholder behavior," *Research on Financial and Economic Issues*, vol. 5, pp. 68–75, 2020.

[2] C. Hong, H. Li, and L. L. Zhu, "Model construction and Key factors identification of knowledge collaboration in social Q&A platforms from the perspective of activity theory: an approach based on fuzzy DANP," *Information Studies:Theory & Application*, vol. 11, pp. 100–106, 2019.

[3] T. Xia, Y. C. Wen, and P. Yuan, "The path analysis on large shareholder's share pledge affecting firm value," *Journal of Shanxi Finance and Economics University*, vol. 8, pp. 93–108, 2018.

[4] X. L. Xia and M. Kang, "Research on the influence of investment enthusiasm and financial leverage on excess return rate of listed companie——empirical analysis based on the multi-factor asset pricing model of a-share market," *Price: Theory & Practice*, vol. 12, pp. 106–109+185, 2019.

[5] C. Q. Li and W. Xin, "Does the controlling shareholder equity pledge affect-executive pay-for-performance sensitivity?" *Economic Management Journal*, vol. 5, pp. 157–174, 2018.

[6] K. Liao, C. Y. Cui, and D. R. Xie, "Controlling shareholders' share pledging and dividends policy choice of listed companies," *Journal of Financial Research*, vol. 4, pp. 176–193, 2018.

[7] Y. Lin and L. B. Wei, "Research on controlling shareholder's equity Pledge, Equity nature and corporate performance," *Commercial Research*, vol. 2, no. 2, pp. 50–56, 2018.

[8] X. Walthoff-Borm, T. Vanacker, and V. Collewaert, "Equity crowdfunding, shareholder structures, and firm performance," *Corporate Governance: An International Review*, vol. 26, pp. 314–330, 2018.

[9] L. Pan, L. P. Zhang, and C. Y. Ouyang, "Stock rights pledge of controlling shareholders and trade credit financing ——an analysis based on internal control quality and audit quality," *The Theory and Practice of Finance and Economics*, vol. 4, pp. 80–87, 2018.

[10] D. S. Huang, Y. S. Huang, and J. N. Zhou, "Does controlling shareholder's share pledge affect the firm's decision on large stock dividends?" *Journal of Management Sciences in China*, vol. 12, pp. 22–40+98, 2018.

[11] F. Jiang, Y. Shen, X. Cai, and L. Jiang, "Corporate governance effects of multiple blockholders: a perspective from controlling shareholders' share pledge," *The Journal of World Economy*, vol. 2, pp. 74–98, 2020.

[12] C. Y. Xia and F. S. Jia, "Stock pledge of controlling shareholder and corporate crash risk," *Nankai Business Review*, vol. 5, pp. 165–177, 2019.

[13] C. Liu, Y. Zhang, and X. Z. Bao, "Dynamic crisis early warning of patent-backed loan for SMEs," *Science & Technology Progress and Policy*, vol. 15, pp. 138–143, 2018.

[14] M. Zhao and F. Yuan, "Controlling shareholder's share pledge, earnings management and audit decision—based on regression method in statistics," *Journal of Physics: Conference Series*, vol. 1616, Article ID 012045, 2020.

[15] Y. F. Wang and Y. Liu, "Share pledge of controlling Shareholders, Industry expertise of auditors and comparability of financial reports," *Journal of Nanjing Audit University*, vol. 6, pp. 39–49, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7310757, 8 pages
https://doi.org/10.1155/2022/7310757

Research Article

Application Research of Cross-Border Logistics Based on Cloud Distribution Model

Shengli Zang,[1] **Lihong Wang**,[1] **and Suqin Li**[2]

[1]*Hebei Vocational University of Industry and Technology, Tianjin, China*
[2]*Shijiazhuang Communications and Transport School, Shijiazhuang, Hebei, China*

Correspondence should be addressed to Lihong Wang; 13930112117@126.com

Received 2 March 2022; Accepted 7 April 2022; Published 2 May 2022

Academic Editor: Giulio E. Cantarella

Cross-border logistics is an important support for the rapid development of cross-border e-commerce. This paper expounds cross-border e-commerce and its development status and explores the problems existing in cross-border e-commerce logistics distribution, such as high cost, low level of information, e-commerce credit evaluation system being not perfect, and professional personnel shortage. Advanced cloud distribution mode is introduced into cross-border e-commerce logistics, and cloud logistics distribution network model is built using the precise center-of-gravity method. Based on the cloud distribution, the paper puts forward some suggestions for the development of cross-border logistics, such as optimizing the path to reduce transshipment links, optimizing the level of logistics informatization, improving the market supervision system and credit evaluation mechanism, and improving the talent training mechanism, in order to improve the stability and security of cross-border logistics distribution, reduce logistics costs, and improve service quality.

1. Introduction

In recent years, the increasingly convenient application of network technology in international trade motivates more and more consumer demands for cross-border consumption. At present, cross-border logistics has become an important link in the development of cross-border e-commerce in China, which is directly related to the overall benefit and investment cost of enterprises [1]. The types of cross-border logistics change along with the development of cross-border e-commerce, and currently there are four types of logistics: postal parcels, international business and domestic express, special line logistics, and overseas warehouses [2]. With the continuous improvement of logistics development level in China, cross-border e-commerce can no longer meet the needs of foreign consumers by relying solely on postal and express delivery. Reference [3] puts forward the limitations of logistics service transportation and introduces the fuzzy TOPSIS method to improve cross-border e-commerce logistics service, so as not to affect their shopping experience. Therefore, more and more cross-border e-commerce sellers regard it as the major logistics method in the future and plan and design it in order to obtain the optimal logistics system.

However, it is difficult for most of the current cross-border e-commerce logistics to meet the actual requirements. Although some logistics problems have been well solved and cross-border e-commerce logistics has been greatly improved, there are still many instability and insecurity problems such as holidays, weather, and many other factors because of which consumers often have to wait for a long time. For example, [4] analyzes logistics distribution and analyzes the realization of efficient transportation under the influence of product water management, yield loss, and adverse conditions in allusion to the short-term storage requirements of agricultural products based on the discrete time mathematical model. During logistics transportation, many problems such as parcel loss tend to occur which will directly cause consumer complaints; therefore, most cross-border e-commerce enterprises have gradually recognized the need to improve logistics distribution modes in order to further expand the cross-border e-commerce market. For this purpose, this research proposes the logistics cloud distribution development strategy under

cross-border e-commerce environment in combination with cloud distribution modes.

2. Review

2.1. Overview of Cross-Border e-Commerce. Cross-border e-commerce is an international trade behavior in cross-border transactions where trading entities from multiple countries conduct transactions, payments, and settlements between different countries and complete the transactions in cross-border logistics [5]. Based on existing research results, the basic elements of the e-commerce ecosystem are as shown in Figure 1. The e-commerce ecosystem can be divided into leading population, key population, parasitic population, etc. Due to the dual drive of the development of Internet technology and the diversification of customer needs, the internal and external parts of the system are characterized by competition, cooperation, and symbiosis.

On network transaction service platforms, there are e-commerce enterprises, financial institutions, logistics organizations, and consumers. E-commerce enterprises display their products through the Internet transaction service platform and continuously release and update product information [6] and thus obtain sales orders. The basic process is as shown in Figure 2.

Consumers check the products they need through the service platform, place purchase orders after finding the products, and make payment through the payment platform provided by financial institutions. After receiving the payment, the payment platform will provide payment information and, after verification, inform the cooperative logistics organizations to distribute goods to consumers according to the order information [7]. At the same time, the freight yard information is constantly updated on the network transaction service platform to facilitate e-commerce enterprises and consumers to track the products.

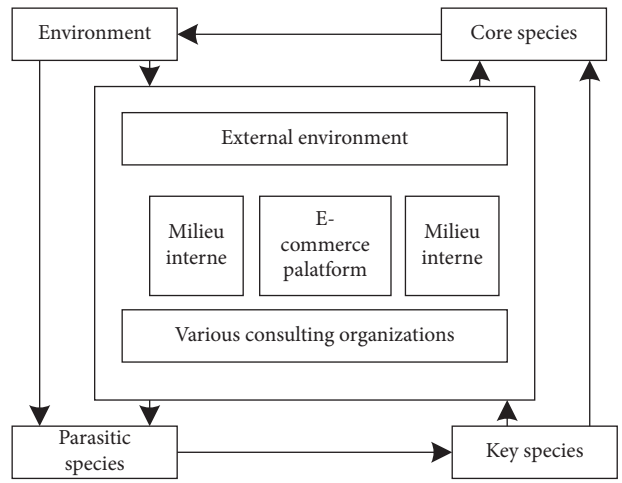


Figure 1: The e-commerce ecosystem structure diagram.

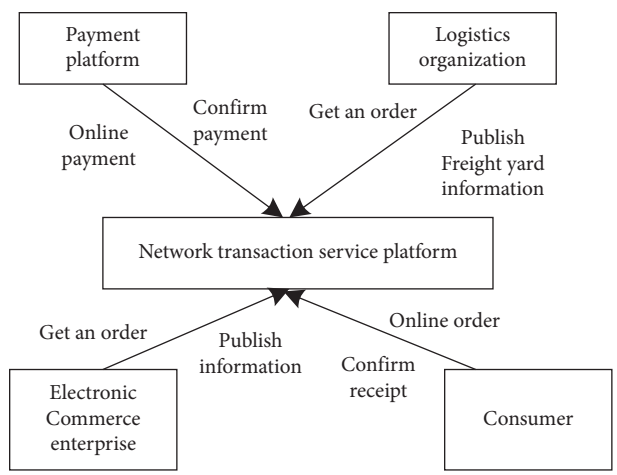


Figure 2: Cross-border e-commerce business flowchart.

2.2. Status Quo of Cross-Border e-Commerce Development. Cross-border e-commerce has emerged in developed economies such as North America and Western Europe and develops rapidly in emerging markets such as the Asia-Pacific region, Latin America, and Africa, which is consistent with the development level and development trend of e-commerce in China. In recent years, cross-border e-commerce has developed rapidly. More and more countries and companies begin to attach importance to cross-border e-commerce and rapidly expand all around the world. Globalization and the increasing frequency of international trade have promoted exchanges among countries and regions [8].

All around the world, traditional Internet enterprises, e-commerce enterprises, traditional international transportation enterprises, logistics enterprises, and financial institutions as well as traditional manufacturing industry, the retail industry, the food industry, and other traditional industries all actively dive in the wave of cross-border e-commerce. Although cross-border e-commerce has only a short history of development, it has become inevitable in terms of market prospect, market potential, market vitality, scale and number of participating enterprises, and market environment. At present, China has more than 5,000 platform enterprises and more than 250,000 foreign trade enterprises to carry out cross-border e-commerce business.

2.3. Problems Faced by Logistics Distribution under the Cross-Border e-Commerce Environment. At present, China's cross-border e-commerce enterprises are faced with problems such as insufficient capital, small scale, and inadequate warehousing and supply chain, details of which are as follows.

Logistics cost: at present, the well-known cross-border e-commerce platforms in China include DHgate.com, AliExpress, Globalsources, etc., all of which are engaged in e-commerce business. EMS, the largest express enterprise in China, has established a close relationship with them, thus forming a unified logistics network. DHL, FEDEX, UPS, and other frequently used international express companies [9] offer faster delivery but at a higher cost, so fewer consumers in foreign countries choose them. At present, the development of cross-border e-commerce logistics in China is greatly restricted. Taking DHL as an example, it takes 5 days

and corresponding money to ship 600 grams of goods from China to the US, while there is a corresponding extra charge for goods of more than 600 grams. If the seller reckons the freight in the cost of goods, the goods will lose their price advantage in the fierce market competition, thus adversely affecting the sales and development of the company. In addition, if the goods received by customers have quality defects, they must be returned or resent, which will lead to repeated logistics and thus increase transportation cost and reduce company profit [10].

Low logistics informatization level: in this information era, all walks of life should grasp the dynamic of the time. Therefore, only by improving the informatization degree of cross-border e-commerce can China's logistics service quality be effectively improved. However, the informatization construction of China's cross-border logistics system still faces many problems including imperfect communication channels, poor comprehensive sorting ability, and low informatization level.

Lack of the e-commerce enterprise credit evaluation system: because cross-border e-commerce involves many countries in the transaction process, it is difficult to accurately assess the credit of each other. Such asymmetry facilitates the selling of shoddy or fake commodities by some sellers in order to gain profits, thus damaging consumer benefits [11], while consumers with poor credit will deliberately damage products, return commodities, and make misleading evaluations, resulting in huge economic and credit losses of enterprises. Therefore, it is particularly urgent to establish a reputable international credit management system.

Lack of related professional talents: many multinational enterprises are relatively small and weak, and it is difficult for them to attract specialized multinational e-commerce talents. Meanwhile, many multinational enterprises lay insufficient stress on staff training and lack compound talents, and cross-border e-commerce transactions are also restricted.

3. The Theory of Cloud Logistics Distribution

The cloud logistics distribution mode is an information sharing platform established by applying cloud computing and other core technologies and it integrates a variety of technologies such as the Internet of Things and GPS technology. The combined application of various technologies can realize resource perception and location tracking [12]. Also, when relevant information is shred, the concept of cloud computing can be used for reference to realize joint service. Therefore, the cloud logistics platform can effectively coordinate and optimize distribution resources. The logistics distribution network under the cloud service mode is as shown in Figure 3.

The characteristics of the cloud logistics distribution mode are as follows.

First, it can meet personalized demands. The traditional distribution mode is one associated with production or commodities [13] and is restricted by factors such as resources, equipment, and user location. However, considering current distribution situation, there are cases of multiple

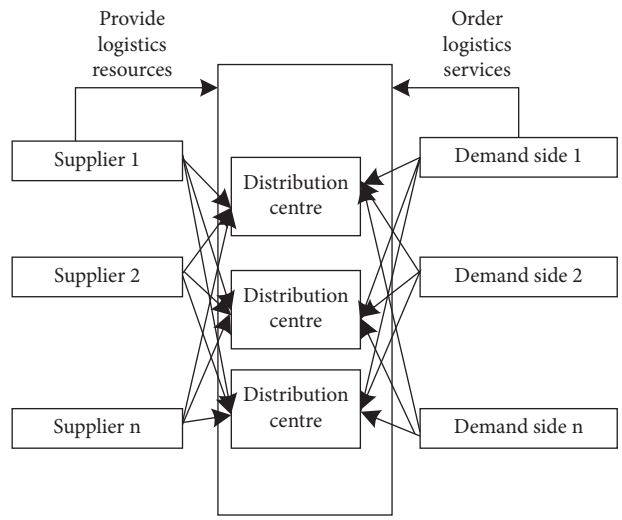


Figure 3: Distribution network under the cloud service mode.

batches and multiple varieties of cross-border commodities, which makes the personalized demands for logistics and distribution increasingly prominent. The cloud distribution mode can combine customer demands, integrate scattered resources in a virtual way, and uniformly process items so as to improve service quality and reduce distribution cost. Second, the distribution mode is dynamic, which is mainly shown in the following: It can dynamically reflect information and customer demand change can be learnt about in a timely manner; it can dynamically supply corresponding logistics resources [14], and cloud logistics distribution can set up resource values belonging to its own platform and dynamically allocate resources through coupling mapping; there is a dynamic relationship between distribution demanders and providers, and when there is a distribution demand, the platform can automatically search and match distribution service providers according to multiple constraints. Based on the abovementioned dynamic characteristics, it can better meet the personalized demands of customers. Third, it is a distribution mode with service collaboration and resource sharing. Compared with the traditional distribution mode, the distribution mode based on cloud computing technology can integrate resources and realize the real resource sharing because of the support of its database, model library, and so on. It is not a single service organization mainly because it requires the cooperation of multiple service principals to achieve the purpose of centralized resources and decentralized services. Fourth, it embodies intellectualization. The large amount of information contained in the logistics distribution mode enables it to fully consider the customer aggregation degree [15] and coordinate the logistics of all links so as to improve service quality and cut cost.

4. Design of the Cloud Logistics Distribution Network Model

According to geographical scope, logistics networks can be divided into four levels: international logistics networks, regional logistics networks, urban logistics networks, and

urban and rural logistics networks. The networks at different levels are interconnected and they organically constitute the modern cloud logistics network system. The transportation logistics network refers to the aggregation of logistics, business flow, information flow, capital flow, and the flow of related organizations and facilities between different countries or regions. The goal is to better serve cross-border e-commerce and international trade. Cross-border e-commerce is an international trade mode based on the development of international logistics networks. The unique advantages and value standards of cyberspace have a profound impact on cross-border e-commerce. Therefore, it has characteristics obviously different from traditional transactions. In a sense, cross-border e-commerce benefits from the rapid development of modern international logistics and can greatly cut logistics cost. Therefore, the characteristics of international logistics must be studied in depth. There are two types of methods, namely, qualitative analysis methods and quantitative analysis methods to study the characteristics of international logistics network. The qualitative analysis methods include the Delphi method, the analytic hierarchy process, the fuzzy comprehensive evaluation method, and the grey correlation method. The quantitative analysis methods consider the main factors affecting the location of logistics distribution centers such as transportation cost, storage cost, fixed cost, and maintenance cost, quantize these factors, and determine the optimal network layout.

The precise center-of-gravity method is a single-distribution-center network model which does not need to consider competition, hub flow distribution, and other factors and simply aims at the lowest freight. The net of the center-of-gravity method is in the same plane. All customer demand points are distributed in a plane with the center of gravity in its center. The requirement and location of each point represent the weight distribution of the object. The cloud logistics distribution center is the center of gravity of the object and is placed in the best position of logistics. The node position of the logistics network is determined through mathematical methods by imitating the center of gravity of objects, and the assumptions are as follows:

(i) The transportation cost is only related to the straight-line distance between the logistics distribution center and the distribution point, while urban traffic conditions are not considered. In contrast, urban traffic conditions have little impact on freight costs, so ignoring them will not have a great impact on the practicability of the model.

(ii) The location of the logistics distribution center is greatly related to the freight, which this model does not take into account nevertheless.

(iii) Assume that each demand point and its demand quantity are known and constant.

Assume that there are n customer demand points within a network and their coordinates are $(x_i, y_i)\,(i = 1, 2, \ldots, n)$, respectively, and that the coordinate of the logistics distribution center is (x, y). The network graph is as shown in Figure 4.

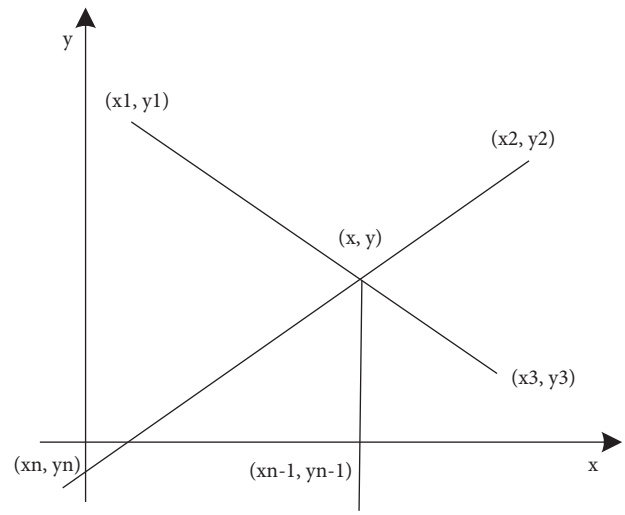


Figure 4: Graph of the precise center-of-gravity method.

Parameter setting is as follows:

(i) a_i: the freight of per unit volume within per unit distance of transportation from the logistics distribution center to demand point i

(ii) b_i: the transportation volume from the logistics distribution center to demand point i

(iii) d_i: the transportation distance from the logistics distribution center to demand point i

Objective function is as follows:

$$F = \sum_{i=1}^{n} a_i b_i d_i = \sum_{i=1}^{n} a_i b_i \sqrt{(x - x_i)^2 + (y - y_i)^2}. \tag{1}$$

Let

$$\frac{\partial F}{\partial x} = \sum_{i=1}^{n} \frac{a_i b_i (x - x_i)}{d_i} = 0, \tag{2}$$

$$\frac{\partial F}{\partial y} = \sum_{i=1}^{n} \frac{a_i b_i (y - y_i)}{d_i} = 0. \tag{3}$$

Then,

$$x* = \frac{\sum_{i=1}^{n} a_i b_i x_i / d_i}{\sum_{i=1}^{n} a_i b_i / d_i}, \tag{4}$$

$$y* = \frac{\sum_{i=1}^{n} a_i b_i y_i / d_i}{\sum_{i=1}^{n} a_i b_i / d_i}. \tag{5}$$

Because formulas (4) and (5) contain the distance item d_i, $x*$, $y*$, the coordinate of the shortest distance cannot be obtained directly. Generally, the geometric center point of all users is calculated first and then the center point is taken as the postulated point of the initial logistics distribution center before the iterative method is employed repeatedly to get the corresponding x, y of the minimum freight. The cloud

logistics distribution network model features that it is suitable for solving static problems and applies to the logistics situation of choosing-one-from-many. Its advantage is its great flexibility as the alternative points can be arbitrarily set. Subsequently, some heuristic methods and intelligent algorithms can be introduced to quickly solve the problem of dynamic logistics distribution. The model should be verified by example to prove the rationality and operability of the model.

5. Evaluation

5.1. Path Optimization to Shorten Transportation Process and Lower the Cost in the Meantime. Considering the actual situation, customs clearance will take a long time and the goods will not be delivered in time while the cloud logistics platform can provide efficient custom clearance services for current cross-border e-commerce, thus improving the efficiency of logistics. In order to realize the mode reform and innovation of cross-border e-commerce, it is necessary to strengthen the construction of cloud computing platforms [16], which can optimize the path to the maximum, reduce the flow of logistics to the maximum, and effectively share resources. Through optimization, distribution cost can be effectively lowered. At the same time, cloud service platforms can facilitate the provision of services such as logistics consulting and logistics path planning to further lower transportation cost.

5.2. Optimization of Logistics Informatization Level Based on Cloud Distribution

5.2.1. Logistics Order Management under the Cloud Distribution Mode. As the initial stage of cloud logistics based logistics management, order management includes a series of operations such as order reception, order status tracking, and delivery based on the order [17]. There are many contents involved in order making, so a cloud distribution based order management system is established [18]. The system structure is as shown in Figure 5.

(1) The order management system can determine the time of order processing and the start time of corresponding distribution resources and discover and eliminate risk states in advance

(2) An effective order management system can facilitate the rapid reorganization of existing logistics resources and improve the dynamic responsiveness

(3) In the ever-changing market environment, the use of convenient networks can facilitate faster and more flexible order processing

In the process of implementation, enterprises should deeply integrate logistics resources and link up logistics networks to improve their dynamic response ability and flexibility.

5.2.2. Logistics Transportation Management under the Cloud Distribution Mode. Efficient and reasonable logistics

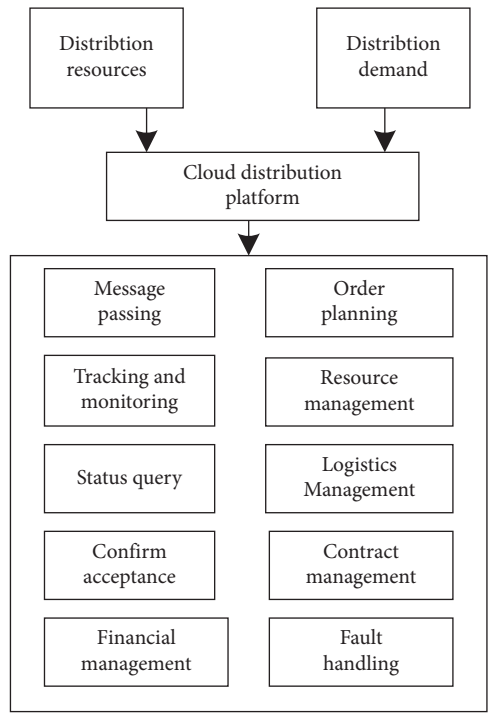


Figure 5: Order management system.

management is the basis of logistics activities and also the premise for logistics enterprises to integrate and share existing resources, expand logistics scale, improve logistics service, and reduce logistics cost:

(1) Transportation decision management is to select from various schemes before carrying out transportation activities including means of transportation, vehicles, transportation path, time of transportation, estimation of transportation cost, transportation personnel, and insurance. It also includes the management of customer resources [19], service items, and transportation resources, all of which are necessary for decision-making.

(2) The process management of transportation is an important part of transportation management, which involves the safety of shipment and transshipment of goods. Transportation management mainly involves the implementation of goods, inspection of packaging labels, arrangement of short-distance transportation, and transportation preparation [20]. Receiving management mainly involves handling of handover, unloading, preparation of freight space, direct allocation, and so on. Transshipment management should attach importance to transshipment connection, strengthen packaging, and remove and replace damaged goods to improve transportation quality. Transportation safety management is mainly to formulate various transportation safety systems, prevent and dispose traffic accidents, and carry out real-time dynamic monitoring of vehicles.

(3) Transportation settlement management includes transportation cost settlement and accounting

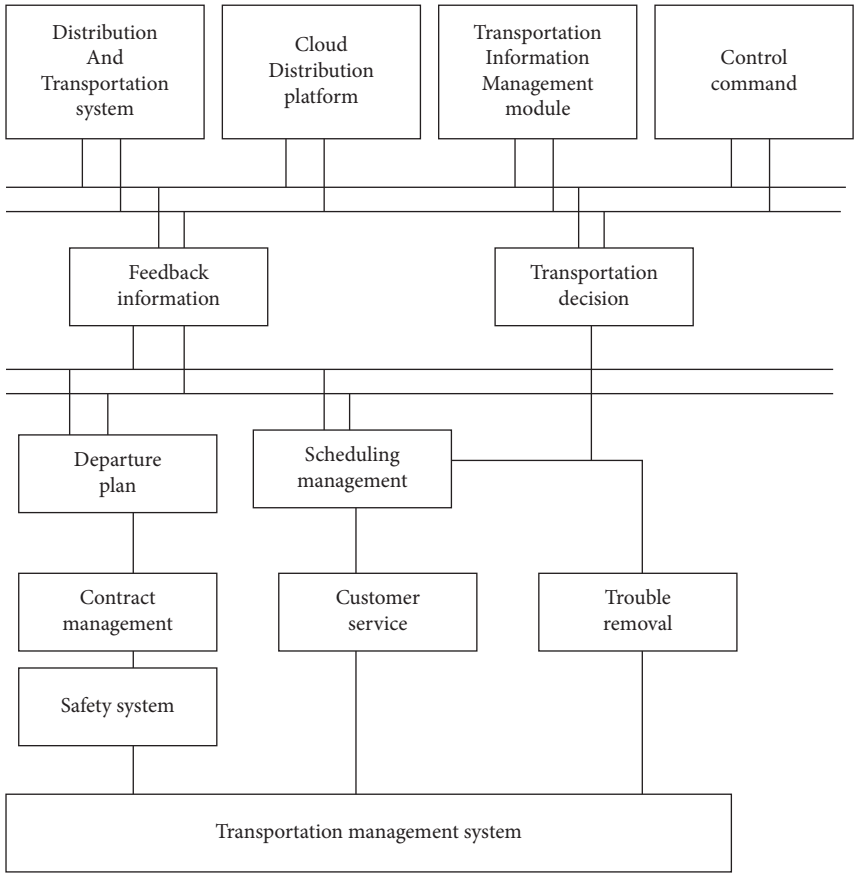


Figure 6: Cloud distribution transportation management system.

treatment. It also includes handling of claims and claims of other people, transportation equipment maintenance, warehousing, and so on.

(4) Transportation information management refers to the management, storage, summary, and analysis of logistics information so as to learn about real-time traffic conditions [21] and provide guarantee for the realization of transport service.

Under the cloud distribution mode, the logistics management system should realize the real-time monitoring of logistics, know the completion of the order all the time, make analysis, compare with historical data, and make the right decision. According to the business requirements of the system, the function modules of the transportation management system are designed as shown in Figure 6.

This system realizes not only static management including product and document management, but also dynamic management including the whole process tracking of products. Among them, the transportation decision management module is divided into planning and customer relationship [22] and the transportation process management includes two parts: enroute management and safety management. Under each subdivided unit, functions such as cost accounting and personnel flow management can be added as demanded. On the one hand, it receives information and issues commands, and on the other hand, it feeds the data of each module back to the cloud distribution platform in real time and summarizes and analyzes the data of each module at the same time. Cloud distribution logistics management enables reasonable path configuration and personnel scheduling, and third-party service helps save the technology development by logistics enterprises on their own, which can cut the cost by at least 20%. The introduction of barcode technology, database technology, electronic ordering system, etc. shortens the overall delivery time by 35%, which helps realize efficient logistics goods management.

5.3. Improvement of the Market Supervision System and the Credit Evaluation Mechanism. The establishment and improvement of the market supervision mechanism is the requirement to ensure the benign development of cross-border e-commerce in China. The cloud distribution technology is used to monitor international trade, improve China's international trade laws and regulations system and the corresponding patent protection system, and severely punish all kinds of crimes according to law. Establish an enterprise credit evaluation system, improve national supervision, and make analysis with big data technology so as to better identify and provide specific services, which can both reduce information exchange barriers between the two parties and improve consumer satisfaction at the same time [23]. The credit rating of enterprises shall be jointly assessed by international market regulatory authorities, e-commerce platforms, and consumers.

5.4. Improvement of the Talent Cultivating Mechanism. Due to the large scale of China's logistics industry, investment in fixed assets of logistics industry speeds up, and the requirements for engineering personnel are getting higher and higher. As technologies such as information technology, automatic storage technology, packaging technology, loading and unloading technology, and related equipment technologies spring up continuously, the development of the logistics industry requires more and more high-quality personnel and high-quality logistics personnel have become an important part of China's logistics industry [24].

At present, to meet the actual demand for cross-border e-commerce talents, responsible departments of the state are formulating relevant policies, improving the talent training and incentive system, and ensuring the implementation of talent training supporting facility construction, expenditure support, and tax relief and exemption. Many universities in China are constantly training talents to meet the practical needs of cross-border e-commerce in China. For example, they set up cross-border e-commerce practice bases with companies where companies can provide practical training for college students [25], thus creating a sound employment environment for graduates. In addition, governments, colleges, and enterprise associations should have meaningful discussions in talent cultivating. Industry associations function as a bridge in the cooperation among governments, colleges, and enterprises and can reflect market demand for talents as well as talent cultivating results in real time. Governments, colleges, enterprises, and industry associations will integrate resources and expertise to establish a superior talent cultivating mode in the cultivation of cross-border e-commerce talents through division of labor and cooperation. The mode of joint training of government, schools, enterprises, and industry associations is helpful to improve the talent training mechanism.

6. Conclusion

Based on the above process, the research on logistics cloud distribution development strategy under cross-border e-commerce environment is completed. This research probes deep into the development status quo and characteristics of e-commerce as well as problems in the existing e-commerce logistics distribution mode. It applies the cloud distribution method in e-commerce logistics distribution to optimize the distribution strategy, which can meet the requirements of cross-border e-commerce logistics distribution. The innovation of the strategy in this research lies in that the strategy makes full use of the cloud distribution mode and combines modern intelligent technology to make logistics distribution more intelligent, which can provide some help for related fields.

However, since cloud distribution involves many problems, and the current network business environment is constantly changing with other new elements being continuously integrated, further optimization is needed in the follow-up study so as to obtain superior development strategies.

Data Availability

All the data contained in this study can be obtained upon request to the corresponding author. Readers can also inquire part of the original data and the results of data processing in this paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was supported by Doctoral Foundation Project of Hebei College of Industry and Technology (bz2020003) and also supported by Hebei Provincial Department of Human Resources and Social Security(JRSHZ-2022-02107).

References

[1] S. Fu, W. Chen, and D. Wang, "Study on the collaborative development of cross-border E-commerce logistics supply chain," *Journal of Northeastern University*, vol. 23, no. 1, pp. 52–60, 2021.

[2] C. Ding and Z. Dai, "Cross-border e-commerce logistics development strategy analysis —— take mousse bedding as an example," *Tea in Fujian*, vol. 42, no. 2, pp. 63-64, 2020.

[3] C. Chen and S. Yang, "Research on logistics service provider selection of cross-border E-commerce using intuitionistic fuzzy TOPSIS method," *Science and Technology Management Research*, vol. 40, no. 5, pp. 186–192, 2020.

[4] E. Mardaneh, R. Loxton, S. Meka, and L. Gamble, "A decision support system for grain harvesting, storage, and distribution logistics," *Knowledge-Based Systems*, vol. 223, no. 1, Article ID 107037, 2021.

[5] D. Xue, Y. Lu, and R. Yang, "Demand analysis and training strategy research of cross-border e-commerce talents for enterprise demand," *Market Modernization*, no. 13, pp. 27–29, 2020.

[6] H. Zhou, W. Yan, J. He, and H. Li, "Strategy of cross-border E-commerce dual-channel supply chain under different cooperation scenarios," *Journal of Shanghai University(Natural Science Edition)*, vol. 27, no. 4, pp. 749–765, 2021.

[7] B. Burroughs and W. J. Burroughs, "Digital logistics: enchantment in distribution channels," *Technology in Society*, vol. 62, Article ID 101277, 2020.

[8] X. Zhang and Q. Weng, "Exploration on the safe development environment of urban logistics distribution in the Internet age —— comment on urban logistics distribution under the Internet environment," *China Forest Products Industry*, vol. 336, no. 4, 122 pages, 2020.

[9] H. Andreas, K. Heinrich, and G. Michael, "Product allocation to different types of distribution center in retail logistics networks," *European Journal of Operational Research*, vol. 264, no. 3, pp. 948–966, 2018.

[10] Y. Cao, L. Zheng, and X. Shi, "A study on the cross-border E-commerce logistics alliance in China under the belt and road initiative," *Railway Transport and Economy*, vol. 42, no. 10, pp. 7–13, 2020.

[11] J. Yu, Y. Zhang, W. Liu, and Z. Xiao, "Study on the temporal and spatial heterogeneity of global cross-border e-commerce

logistics resilience under the impact of epidemic," *Geographical Research*, vol. 40, no. 12, pp. 3333–3348, 2021.

[12] Y. Cao and J. Zhu, "Airport aviation logistic development strategy from the perspective of cross-border E-commerce," *Railway Transport and Economy*, vol. 43, no. 4, pp. 61–65, 2021.

[13] D. Jesica, F. Albert, A. Angel, and L. Eduardo, "Corrigendum to "Modeling and solving the non-smooth arc routing problem with realistic soft constraints," *Expert Systems with Applications*, vol. 98, pp. 205–220, 2018.

[14] Z. Wang, L. Yang, and L. Wang, "Research on cross-border e-commerce logistics of tea products under the background of Shijiazhuang 4 + 4 modern industrial development," *Tea in Fujian*, vol. 43, no. 8, pp. 41-42, 2021.

[15] B. Cao, "Problems and countermeasures of tannery enterprises developing cross-border e-commerce," *China Leather*, vol. 50, no. 11, pp. 21–23, 2021.

[16] M. Lv, "Study on the business strategy of tea e-commerce enterprises in cross-border e-commerce environment," *Tea in Fujian*, vol. 42, no. 10, pp. 41-42, 2020.

[17] K. Feng and X. Zhang, "Research on the business model of cross-border E-commerce based on mobile Internet," *International Business Research*, vol. 41, no. 1, pp. 39–49, 2020.

[18] L. Chen and Q. Feng, "Application research of real-time update system of third-party logistics information based on blockchain," *Electronic Design Engineering*, vol. 29, no. 22, pp. 42–46, 2021.

[19] W. Liu, "Research on cross-border e-commerce innovation model of leather products in China under the background of 'One Belt One Road," *China Leather*, vol. 50, no. 3, pp. 46–49, 2021.

[20] T. Fiorita, "Cloud-based precision technology gives last-mile logistics the boost it needs," *Supply chain brain*, vol. 23, no. 2, pp. 46-47, 2019.

[21] Z. Karabulut and M. Kasapbaşı, "Cloud computing integrated multi-factor Authentication framework application in logistics information systems," *Journal of International Trade*, vol. 3, no. 2, pp. 50–57, 2017.

[22] T. Zhang, N. Wei, and A. Li, *Research on the Development Strategy of Intra-city Clothing Distribution Based on O2O Mode*, Sprinker, New York, NY, USA, 2021.

[23] L. Ding, "Research on the invulnerability of cross-border bidirectional logistics network in e-commerce supply chain," *International Journal of Manufacturing Technology and Management*, vol. 1, no. 1, p. 35, 2021.

[24] J. Hao, "Research on the construction of international logistics supply chain based on cross-border E-commerce," in *Proceedings of the 2021 2nd International Conference on E-Commerce and Internet Technology (ECIT)*, Hangzhou, China, March 2021.

[25] Z. Min, X. Mikai, and D. Debao, "Research on game strategy of information sharing in cross-border e-commerce supply chain between manufacturers and retailers," in *Proceedings of the 4th International Conference on Intelligent, Interactive Systems and Applications (IISA2019) Bangkok*, Thailand, June 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2659939, 12 pages
https://doi.org/10.1155/2022/2659939

Research Article

Earnings Persistence and Abnormal Audit Fees

Xiaohui Zhou,[1] **Pengzheng Lou**,[2] **Yongmin Wu**,[3] **and Lijuan Zhang**[4]

[1]*School of Accounting and Business Administration, Yunnan Minzu University, Kunming 650504, China*
[2]*School of Accounting, Zhengzhou Business University, Zhengzhou 451299, China*
[3]*Business School, University of International Business and Economics, Beijing 100029, China*
[4]*Beijing Zhuoyue Education Consulting Co., Ltd., Beijing 100029, China*

Correspondence should be addressed to Yongmin Wu; 02665@uibe.edu.cn

Received 9 March 2022; Revised 7 April 2022; Accepted 8 April 2022; Published 25 April 2022

Academic Editor: Lele Qin

This study discusses the impact of earnings persistence on abnormal audit fees and explores the mechanism between earnings persistence and abnormal audit fees. The results show that the stronger the earnings persistence is, the lower the abnormal audit fees are. The earnings persistence only has a significant impact on the positive abnormal audit fees, and the impact on the negative abnormal audit fees is not obvious. Furthermore, it is found that the negative correlation between the earnings persistence and abnormal audit fees has obvious heterogeneity; that is, it is more significant in companies with low environmental uncertainty and state-owned companies. The mechanism test shows that earnings persistence reduces abnormal audit fees by improving company operating risk, which proves the "Risk Compensation View" of abnormal audit fees to a certain extent. The research provides an important reference for the management and shareholders to eliminate abnormal audit fees and for the regulatory authorities to regulate audit fees.

1. Introduction

Audit fees are the necessary reward for auditors to evaluate risks and complete audit work and are a necessary expenditure to evaluate the quality of company accounting information [1]. Normal audit fees can regulate the auditor's professional behavior and reflect the auditor's efforts and role in authentication, so as to improve the information quality of accounting reports. When audit fees cannot afford the auditor's efforts, the supervision mechanism of the audit will fail, and abnormal audit fees will be incurred. Zhu et al. [2] found that there was audit premium behavior due to company risk-taking, and the higher the level of company risk-taking, the higher the audit fees. Earnings persistence usually reflects the stable operation, good management level, and strong management ability of the company, which helps the company to reduce risks. Besides, it can predict a company's likelihood of achieving earnings in the future, which is an important indicator for auditors to assess firm risk [3]. The stronger the earnings persistence, the smaller the operating risk and financial risk of the company, and vice versa. When clients have poor earnings persistence, auditors usually do more work to reduce audit risk, so audit fees are abnormally high. In practice, auditors may be unwilling to save clients or make compromises with them, and the fees charged will be abnormally low [4], so the fees of the abnormal audit will decrease rather than increase. Then, what is the specific impact of earnings persistence on abnormal audit fees?

Furthermore, environmental uncertainty can reflect the degree of risks faced by companies, which is given special attention by auditors in the risk assessment stage. Chu et al. [5] proposed that the higher the uncertainty of economic policy, the higher the audit fees. As an entity in the market, the company cannot effectively resist the rise of system risks under great environmental uncertainty even if it maintains high earnings persistence. In order to reduce audit risks, auditors need additional work to ensure the quality of the audit and prevent the expected losses; then, abnormal audit fees will rise. In addition, the nature of company property rights will also affect earnings persistence and abnormal audit fees. Compared with nonstate-owned companies,

state-owned companies are under the government's implicit guarantees and show better performance, higher earnings persistence, lower audit risks, and fewer audit fees. Therefore, what impact will environmental instability and the nature of property rights have on abnormal audit fees and earnings persistence?

Earnings persistence has always been one of the important issues in capital market research. Researchers have discussed the persistence of industry-wide and firm-specific earnings and researched the relationship among earnings persistence with fair value accounting, real earnings management, and market value [6–9]. The research on abnormal audit fees is mainly related to audit opinion purchase, audit quality, and goodwill impairment [10, 11]. In fact, abnormal audit fees may be affected by earnings persistence. It is important to analyze the impact of earnings persistence on abnormal audit fees. However, little attention has been paid to this study, which is necessary.

Thus, we choose A-share listed companies in Shanghai and Shenzhen from 2011 to 2019 in China in this study and analyze the impact of earnings persistence on abnormal audit fees. We further discuss the adjustment mechanism of environmental uncertainty on the relationship between the two and clarify the importance of earnings quality in audit charge specifications from the nature of equity. The research results not only enrich the theories related to the company earnings persistence and abnormal audit fees but also provide an important reference for the management and shareholders to eliminate abnormal audit fees and for the regulatory authorities to regulate audit fees.

2. Theoretical Analysis and Research Hypothesis

2.1. Earnings Persistence and Abnormal Audit Fees. Accounting earning is the core information of a company's financial report, an important symbol of company profitability, and even a specific performance of company value. As an important attribute of the quality of accounting earnings, earnings persistence can reflect the possibility that current earnings are expected to continue or realize growth in the future and is the characteristic that current earnings can maintain a stable state in a relatively long period. It can effectively determine the relationship between current earnings and future earnings across periods and can also realize the effective forecast of future accounting earnings from current earnings information. Therefore, in the contractual role of accounting earnings, the persistence of earnings is considered to be a very ideal feature. Researchers have defined earnings quality through earnings persistence, in which high-quality earnings are sustainable [12, 13]. Early studies suggested that accounting earnings of the current period could help predict future earnings information. Earnings persistence can be seen as the impact of the unexpected part of the current accounting earnings on the future accounting earnings. Richardson et al. [14] showed that earnings persistence is the extent to which the current accounting earnings continue to the next period. Earnings persistence has an important impact on the length and stability of the company's future earnings. The smaller the volatility of earnings, the higher the continuity of earnings [12, 13], the greater the value of the company, and the smaller the transaction cost.

It is generally believed that audit fees are mainly influenced by the efforts of auditors, litigation risks, the bargaining power of auditors, and other factors [15]. Audit is an independent authentication service. Accounting firms charge audit fees within the normal range according to their audit costs and risks. In a fully competitive environment, audit fee variance mainly reflects the difference between the auditor's effort cost and the client's specific risk. Therefore, the higher the auditor's efforts, the higher the audit costs and the higher the compensation. Similarly, the greater the risk of clients, the higher the probability of audit failure, and the greater the possibility of being sued in the future, so the higher the charge is needed to compensate for the litigation loss in the future [15]. However, audit fees are also the result of bargaining between audit parties [16]. If audit fees are significantly higher than audit costs, it is likely that auditors have certain economic dependence on the auditees. Therefore, there are two viewpoints: "Risk Compensation View" and "Customer Dependency View" to explain abnormal audit fees in the academic circle.

The "Risk Compensation View" holds that audit fees are collected from the auditor's inputs. Researchers find that the market interprets abnormally high audit fees as the high earnings quality of the company. Blankley et al. [17] believed that, in the post-SOX era, based on the assurance of internal control quality, audit assessment expenses reflect more auditors' audit inputs, which makes the current abnormal audit fees negatively correlated with the company's future financial restatements. The abnormally high audit fees indicate that the auditor has put more effort and resources into the work, which should be compensated. With higher earnings persistence, the expected risk of the company is smaller, and the auditor can complete the work without extra inputs, while the abnormal audit fees are reduced. On the contrary, the decline of earnings continuity indicates that the business risks increase, the probability of the auditor's major misstatement increases, and litigation risks increase, thus charging abnormally high audit fees.

The "Customer Dependency View" holds that there is economic dependence between the auditor and the auditee. Due to audit costs and client switching costs, audit services are priced higher than the necessary cost to earn quasi-rents from specific clients. It binds the auditor and the auditee together economically, which not only reduces the auditor's independence but also increases the auditor's tolerance for the earnings management of the auditee [18]. Therefore, when the auditee expects the performance of the company to be poor, they will have an incentive to improve the expected adverse audit results. In order to make auditors yield, the auditee will input more benefits and pay too much audit fees. If a company's earnings persistence is stronger, it indicates the earnings quality of the company is better, and the company does not need to improve the audit results, and no need to purchase audit opinions. The abnormal audit fees are naturally low.

According to the above analysis, there is a negative relationship between earnings persistence and abnormal audit fees, on the whole, so Hypothesis 1 is proposed:

> H1: company earnings persistence and abnormal audit fees have a significantly negative correlation

Further analysis shows that, in the capital market, there are positive and negative abnormal audit fees, and the impact of earnings persistence on abnormal audit fees of different symbols may differ. If the company's abnormal audit fee is greater than 0, it is a positive abnormal audit fee. Whether it is risk premium or economic rent, there may be positive abnormal audit fees. The stronger the continuity of earnings, the lower the audit risk and the weaker the economic relationship between auditors and clients impact on positive abnormal audit fees.

When the abnormal audit fee is less than 0, it is a negative abnormal audit fee. Choi et al. [4] believed that low audit fees may indicate three situations: in the first case, the client is unprofitable, the auditor earns meager profits from the client, the expected cost of retaining the client is much greater than the benefit, and the auditor is unwilling to compromise to the noncompliance behavior of the client who pays too low expenses. At this time, the increase in the company earnings persistence will make the company profitable in the eyes of auditors. The auditors' motivation to retain clients will be strengthened. Bilateral cooperation tends to be normal, and negative abnormal audit fees will be corrected to a certain extent. In the second case, auditors do not want to compromise their independence on behalf of their clients and want to ensure audit quality. At this point, whether the company can achieve continuous earnings in the foreseeable future does not have much impact on the negative abnormal audit fees. In the third case, auditors are pressured by clients for biased financial statements in the current period and expect to earn excess returns in the future, thus allowing the current audit fees to be abnormally low and negative abnormal audit fees to occur. By this time, strong earnings persistence will weaken the motivation of earnings management clients, and the pressure of auditors from aggressive behavior of clients will be greatly reduced. There is no need to compensate for the current reduced audit fees through expected excess returns so that the negative abnormal audit fees can be corrected. It can be seen that earnings persistence may not be able to produce a significant improvement in negative abnormal audit fees.

In conclusion, the impact of earnings persistence on positive abnormal audit fees may not be exactly the same of negative abnormal audit fees. In contrast, the negative impact of earnings persistence on positive abnormal audit fees is more obvious. Therefore, Hypothesis 2 is proposed:

> H2: compared with negative abnormal audit fees, company earnings persistence has a more significant negative correlation with positive abnormal audit fees

2.2. Environmental Uncertainty, Earnings Persistence, and Abnormal Audit Fees. A stable external environment is the basis of an enterprise sustainable operation and the premise of enterprise development strategy and operation decisions. The external environment includes various competitors, suppliers, customers, regulators, and many other market participants, and the unpredictability of the behavior of market subjects ultimately leads to the uncertainty of the business environment.

First of all, environmental uncertainty will increase the business risks of enterprises. The advantages and disadvantages of the external macroenvironment of enterprises often affect the formulation and implementation of enterprise strategies. The external macroenvironment is poorer and uncertainty is bigger; it can affect the accounting information relevance and timeliness for decision-making and increase the enterprise's internal and external information asymmetry, and the management may not get sufficient enough information to determine the external changes of profit and loss. They find it difficult to grasp the development trend for a long time, unable to accurately predict the future development prospects of the enterprise, and face a greater risk of decision failure.

Secondly, a highly uncertain external environment will strengthen the opportunistic behavior of the management. Environmental uncertainty increases the fluctuation of company earnings, affects the company's market performance, and is not conducive to the maximization of management compensation. If the management is under pressure to meet financial performance targets, it will be more inclined to recognize future earnings in advance. Ghosh and Olsen [19] pointed out that environmental uncertainty would directly affect the earnings management of companies, and the higher the uncertainty, the stronger the motivation of the management to reduce earnings volatility by using excess accounts. In response to the impact of environmental uncertainty, auditors will increase audit fees, which may increase the abnormal audit fees.

Therefore, high environmental uncertainty will reduce continuous earnings, strengthen earnings management motivation, and weaken the improvement effect of earnings persistence on abnormal audit fees. So, this study proposes Hypothesis 3:

> H3: compared with companies with higher environmental uncertainty, companies with lower environmental uncertainty have a more significant negative correlation between earnings persistence and abnormal audit fees

2.3. Nature of Property Rights, Earnings Persistence, and Abnormal Audit Fees. State-owned companies are more likely to get financial and political support from the government because of their "blood ties" with the government. No matter obtaining loans from banks, subsidies from the government, or financing from the stock market, state-owned companies can get more support compared with nonstate-owned companies. The particularity of state-owned property rights reduces the financing constraints of state-owned companies, which can raise funds at a lower cost. It provides a guarantee for expanding production and

occupying the market, so as to improve profitability and enhance risk resistance. Zhu et al. [2] showed that, compared with nonstate-owned companies, state-owned companies reduce audit risk due to their lower inherent risks, making audit premiums relatively weak. On the contrary, nonstate-owned companies have limited policy support, higher capital costs, greater financing constraints, and more uncertainties, so the higher audit fees are higher. Meanwhile, as most senior executives of state-owned companies are appointed by the government, such as officials, they have to undertake more policy works such as employment increase and social stability. Compared with leisure, in-service consumption, and other private benefits, they pay more attention to the pursuit of political interests during their term of office and are more willing to keep the company profitable for a long time. As a result, the earnings persistence of state-owned companies is higher. In addition, some studies also show that, compared to nonstate-owned companies, state-owned companies are less likely to be issued modified audit opinions, and therefore, audit fees are less abnormal.

Therefore, the earnings persistence of state-owned companies is better than that of nonstate-owned companies, which is more conducive to a better playing improvement effect of earnings persistence on abnormal audit fees. Thus, this study proposes Hypothesis 4:

> H4: compared with nonstate-owned companies, the earnings persistence of state-owned companies has a more significant negative correlation with abnormal audit fees

3. Research Design

3.1. Sample Selection and Data Sources. In this study, A-share listed companies in Shanghai and Shenzhen from 2011 to 2019 are selected as the samples in the following ways: (1) delete financial listed companies, (2) delete ST and *ST companies, (3) delete listed companies with incomplete key data, and (4) delete listed companies whose annual reports have been disclosed continuously for less than 10 years to ensure the accuracy of the environmental uncertainty index. To reduce the interference of endogeneity among variables to the conclusions, the model in this study adopts the data of one-period lagging and losses the samples of 2011. Due to the impact of COVID-19 in 2020, auditors are faced with numerous tests such as limited audit scope, which requires auditors to make more efforts and maintain higher professional suspicion [20], which may have a great impact on audit fees. Therefore, this study tests the relationship between earnings persistence and abnormal audit fees by excluding the data of 2020. After collation, 9473 observations are finally obtained. The data used here come from the CSMAR database and the information obtained after sorting out the annual reports of listed companies. To prevent the potential influence of extreme values on the results, the *quantiles* of continuous variables at 1% and 99% are winsorized in this study. Moreover, Excel and Stata14 are used here for relevant data processing.

3.2. Variable Definition

3.2.1. Explained Variable: Abnormal Audit Fees (Abfee). According to the research method of Simunic [1], this study constructs an audit pricing model to predict abnormal audit fees for companies:

$$\begin{aligned} Lnfee = {} & \alpha_0 + \alpha_1 Opinion + \alpha_2 Size + \alpha_3 Cata + \alpha_4 Roa \\ & + \alpha_5 Lev + \alpha_6 Loss + \alpha_7 Com + \alpha_8 Liq + \alpha_9 Emplay \\ & + \alpha_{10} Big4 + \sum Year + \sum In\ du\ str y + \varepsilon. \end{aligned} \tag{1}$$

The explained variable of the above model is audit fee (Lnfee), which is expressed as the logarithm of the audit fee disclosed in the annual reports of listed companies. Explanatory variables are audit opinion (Opinion), company size (Size), current assets/total assets (Cata), return on assets (Roa), debt leverage (Lev), size of the loss (Loss), business complexity (Com), short-term liquidity (Liq), number of employees (Employ), and accounting firm difference (Big4). By regression, the residual ε of the model is the abnormal audit fee (Abfee). The greater the index after taking the absolute value of Abfee, the higher the abnormal audit fees of the company.

3.2.2. Explanatory Variable: Earnings Persistence (Ec). Referring to the mechanism of the Jones model, this study constructs the following models to measure the earnings persistence variable of companies:

$$Earn_{i,t} = \alpha_0 + \alpha_1 Earn_{i,t-1} + \alpha_2 Earn_{i,t-2} + \alpha_3 Earn_{i,t-3} + \varepsilon. \tag{2}$$

In the above model, the explained variable is the enterprise operating net profit rate (Earn), and the explanatory variable is the value of the enterprise operating net profit rate lagging 1–3 periods. Through the regression of this model, the residual is expressed as enterprise earnings continuity (Ec). If Ec > 0, it indicates that enterprise earnings continue to grow.

3.2.3. Regulatory Variable: Environmental Uncertainty (Ddeu). According to the Ghosh and Olsen [19] model, this study uses the industry-adjusted main business income index of listed companies to measure company environmental uncertainty. Specific methods are as follows.

First, a regression model is constructed to measure abnormal operating revenue (Abei). The operating revenue items in the income statement include revenue from sales and other operating revenues. However, according to the research practice, the operating revenue variable in this study is only measured by sales:

$$\begin{aligned} Ei_{i,t} = {} & \alpha_0 + \alpha_1 Ei_{i,t-1} + \alpha_2 Ei_{i,t-2} + \alpha_3 Ei_{i,t-3} + \alpha_4 Ei_{i,t-4} \\ & + \alpha_5 Ei_{i,t-5} + \varepsilon. \end{aligned} \tag{3}$$

In model (3), the explained variable is the company's operating revenue (Ei), and the explanatory variable is the

Table 1: Names, symbols, and definitions of related variables.

Variable type	Variable name	Symbol	Variable definition
Explained variable	Abnormal audit fees	Abfee	Audit pricing model (1) estimated residuals
Explanatory variable	Earnings persistence	Ec	Earnings persistence model (2) estimated residuals
Regulatory variable	Environmental uncertainty	Ddeu	If the environmental uncertainty is greater than the median, Ddeu = 1; if not, Ddeu = 0
Control variable	Nature of property rights	Soe	If the company is a state-owned company, Soe = 1; if not, Soe = 0
	Company size	Size	The natural logarithm of the total ending assets of a company
	Return on assets	Roa	Net profit/total ending assets
	Debt leverage	Lev	Total ending liabilities/total ending assets
	Customer sale	Sale	The natural logarithm of the company's main business income (million yuan)
	Business complexity	Com	Ending accounts receivable balance + ending balance of stock/ total ending assets
	Short-term liquidity	Liq	Ending current assets/ending current liabilities
	Accounting firm difference	Big4	If an accounting firm is one of the "international Big4," Big4 = 1; if not,Big4 = 0
	Tobin Q value	Tobinq	Company market value/book value
	Substantial shareholder control	Top1	The shareholding proportion of the Top1 substantial shareholder
	Separation of board of directors and general manager	Dual	If the chairman and the general manager are not the same person, Dual = 1 or Dual = 0
	Ratio of independent directors	Idr	Number of independent directors/number of directors
	Size of the loss	Loss	If annual ending loss occurs in that year, Loss = 1 or Loss = 0
	Audit opinion	Opinion	If company's financial report is issued with modified audit Opinion = 1, If not, Opinion = 0
	Current assets/total assets	Cata	Ending current assets/ending total assets
	Number of employees	Employ	The square root of the number of company employees in that year
	Equity restriction ratio		Shareholding proportion of the second to the tenth substantial shareholders

value of the company's operating revenue lagging 1–5 periods. With the regression of this model, the residual of this model is expressed as abnormal operating revenue (Abei).

Then, calculate the 5-year moving window standard deviation (Sdabei) of abnormal operating revenue and divide it by the 5-year moving window mean (Mei) of the company's operating revenue, and we get environmental uncertainty without industry adjustment: $Neu = S\ da\ bei/Mei$.

The median of Neu (Ieu) is then calculated, and the company's environmental uncertainty by industry adjustment is measured: $Eu = Neu/Ieu$.

Finally, the company's environment uncertaintyadjusted by industry is compared with the median, and the company's environment uncertainty greater than the median is regarded as large; that is, Ddeu is assigned to 1; otherwise, Ddeu is assigned to 0.

3.2.4. Control Variable. In order to better analyze the relationship between earnings persistence and abnormal audit fees, this study divides the control variables into financial characteristics, company characteristics, and management structure. Financial characteristic variables include return on assets, debt leverage, short-term liquidity, Tobin Q value, and size of the loss. Company characteristic variables include company size, business complexity, accounting firm difference, and customer sale; the variables of management structure include Substantial Shareholder Control, Separation of Board of Directors and General Manager, Ratio of Independent Directors, and Equity Restriction Ratio. Relevant variables in this study are shown in Table 1.

3.3. Model Design. In order to test the relationship between earnings persistence and abnormal audit fees, this study builds Model (10). In addition, in order to reduce the interference of endogeneity among variables to research conclusions, the explanatory variables of this model use data with a lagging period:

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} \\ & + \beta_6 Com_{i,t-1} + \beta_7 Liq_{i,t-1} + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} \\ & + \beta_{10} Top1_{i,t-1} + \beta_{11} Shrs_{i,t-1} + \beta_{12} Du\ al_{i,t-1} + \beta_{13} I\ dr_{i,t-1} \\ & + \beta_{14} Loss_{i,t-1} + \sum Year + \sum In\ du\ stry + \varepsilon. \end{aligned} \tag{4}$$

4. Empirical Results and Analysis

4.1. Descriptive Statistics. Table 2 is the descriptive statistics of the main variables. Among them, the standard deviation of the company abnormal audit fee (Abfee) index is 0.399, the minimum value is −1.049, and the maximum

Table 2: Summary statistics.

Variable	Mean	sd	min	max	p50
Abfee	−0.00690	0.399	−1.049	1.276	−0.013
Ec	0.000568	0.122	−0.739	0.624	−0.021
Ddeu	0.477	0.499	0	1	0.000
Size	22.58	1.331	19.53	26.66	22.411
Roa	0.0437	0.0504	−0.158	0.231	0.035
Lev	0.488	0.198	0.0708	0.927	0.496
Sale	8.121	1.464	4.361	12.41	7.997
Com	0.268	0.186	0.00429	0.815	0.236
Liq	1.843	1.616	0.215	12.97	1.398
Big4	0.0846	0.278	0	1	0.000
Tobinq	2.118	1.410	0.826	12.93	1.658
Top1	0.364	0.154	0.0845	0.788	0.345
Shrs	0.191	0.122	0.0131	0.546	0.173
Dual	0.831	0.375	0	1	1.000
Idr	0.371	0.0536	0.286	0.600	0.333
Loss	0.0645	0.246	0	1	0.000
Soe	0.601	0.490	0	1	1.000

value is 1.276, indicating that the abnormal audit fees of different listed companies vary greatly. The standard deviation of the index reflecting company earnings persistence (Ec) is 0.122, the minimum value is −0.739, and the maximum value is 0.624, indicating that the earnings persistence of different listed companies varies greatly. The mean value of the company environmental uncertainty (Ddeu) index is 0.477, indicating that 47.7% of the company samples have high environmental uncertainty on average. The mean value of the nature of property rights (Soe) index is 0.601, indicating that 60.1% of samples are state-owned companies.

4.2. Regression Analysis

4.2.1. Impact of Earnings Persistence on Abnormal Audit Fees. It can be seen from Table 3 that, at the statistical level of 1%, company earnings persistence has a significantly negative correlation with company abnormal audit fees. This indicates that the stronger the continuity of earnings, the better the earnings status of companies, the lower the risks of companies, and the lower the abnormal audit fees. Hypothesis 1 is confirmed.

Furthermore, this study refers to the practice of Choi et al. [4], groups the samples by symbols of abnormal audit fees, and divides the samples into negative abnormal audit fees (Table 4, Model 1 and Model 2) and positive abnormal audit fees (Table 4, Model 3 and Model 4). When the abnormal audit fee is less than 0, it is the negative abnormal audit fee (Under abfee). If the abnormal audit fee is greater than 0, it is the positive abnormal audit fee (Over abfee). The results show that earnings persistence has a significant negative correlation with positive abnormal audit fees at a 1% level, but not with negative abnormal audit fees. This shows that earnings persistence can effectively restrain positive abnormal audit fees, but it is difficult to have a significant impact on negative abnormal audit fees. Hypothesis 2 is confirmed.

Table 3: OLS regression results of earnings persistence and abnormal audit fees.

Variable name	M1	M2	M3
Ec	−0.230***	−0.236***	−0.165***
	(−6.79)	(−4.13)	(−2.86)
Size		−0.0384***	−0.0426***
		(−4.30)	(−4.72)
Roa		−0.00296	−0.308**
		(−0.02)	(−2.03)
Lev		−0.0578	−0.0596*
		(−1.61)	(−1.68)
Sale		0.0467***	0.0591***
		(5.91)	(7.48)
Com		−0.0700**	−0.0524*
		(−2.40)	(−1.77)
Liq		0.00421	0.000821
		(1.31)	(0.25)
Big4			0.0376**
			(1.98)
Tobinq			0.0236***
			(6.53)
Top1			−0.125***
			(−3.69)
Shrs			0.286***
			(7.10)
Dual			−0.0143
			(−1.32)
Idr			0.215***
			(2.75)
Loss			0.0146
			(0.70)
Year	Control	Control	Control
Industry	Control	Control	Control
Constant	−0.0121	0.524***	0.393**
	(−0.45)	(3.50)	(2.48)
N	9,473	9,473	9,473
Adj-R^2	0.003	0.008	0.027

Note. Variable definitions are in Table 3. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

4.2.2. Environmental Uncertainty, Earnings Persistence, and Abnormal Audit Fees. To test the heterogeneity of environmental uncertainty (to verify Hypothesis 3), this study groups the annual-industry median of company environmental uncertainty. The sample group with less than the median is the low sample group of environmental uncertainty (Table 5, Model 1), and the sample group higher than the median is the high sample group of environmental uncertainty (Table 5, Model 2). The regression results show that the coefficient of earnings persistence of the sample group with low environmental uncertainty is −0.262, which is significant at the level of 5%, indicating that the earnings persistence of companies with low environmental uncertainty has a more significant impact on abnormal audit fees. Hypothesis 3 is confirmed.

4.2.3. Nature of Property Rights, Earnings Persistence, and Abnormal Audit Fees. In order to test the impact of differences in the nature of property rights of companies on earnings persistence and abnormal audit fees (to verify

Table 4: OLS regression results of positive and negative abnormal audit fees.

Variable name	M1	M2	M3	M4
	Under abfee	Under abfee	Over abfee	Over abfee
Ec	−0.0777	−0.0658	−0.165***	−0.132***
	(−1.59)	(−1.32)	(−3.34)	(−2.60)
Size	−0.0274***	−0.0304***	0.0202**	0.0146*
	(−3.81)	(−4.18)	(2.36)	(1.72)
Roa	−0.00232	−0.0380	0.113	0.0729
	(−0.02)	(−0.29)	(0.89)	(0.56)
Lev	−0.0441	−0.0475	0.0692**	0.0623*
	(−1.52)	(−1.64)	(2.14)	(1.95)
Sale	0.00141	0.00604	0.0263***	0.0282***
	(0.22)	(0.93)	(3.59)	(3.83)
Com	−0.00719	−0.00332	−0.104***	−0.0946***
	(−0.31)	(−0.14)	(−3.60)	(−3.28)
Liq	−0.00549**	−0.00604**	0.00899***	0.00787***
	(−2.19)	(−2.44)	(3.11)	(2.74)
Big4	−0.0348**	−0.0255*	0.00808	−0.00111
	(−2.31)	(−1.67)	(0.47)	(−0.06)
Tobinq	0.00433	0.00299	0.0136***	0.0122***
	(1.36)	(0.93)	(4.43)	(3.97)
Top1		−0.0977***		0.0200
		(−3.61)		(0.65)
Shrs		0.0941***		0.213***
		(2.85)		(6.04)
Dual		−0.0113		−0.0117
		(−1.31)		(−1.18)
Idr		0.162***		−0.0651
		(2.62)		(−0.89)
Loss		0.00292		0.0286
		(0.17)		(1.51)
Year	Control	Control	Control	Control
Industry	Control	Control	Control	Control
Constant	0.370***	0.372***	−0.440***	−0.335**
	(2.99)	(2.98)	(−2.98)	(−2.24)
N	4,866	4,866	4,607	4,607
Adj-R^2	0.038	0.046	0.067	0.076

Hypothesis 4), this study divides the samples into two groups according to the nature of property rights: nonstate-owned companies (Table 5 Model 3) and state-owned companies (Table 5, Model 4). The results show that the coefficient of earnings persistence in the sample group of state-owned companies is significant at the statistical level of 1%, indicating that, compared with nonstate-owned companies, the earnings persistence of state-owned companies has a more significant impact on the improvement of abnormal audit fees. Hypothesis 4 is confirmed.

4.3. Endogeneity Test. Although the regression results above have shown that earnings persistence can significantly improve abnormal audit fees, the regression model may have the problem of reverse causality. At the same time, the conclusion of this study will be biased if companies with higher earnings persistence have lower environmental uncertainty, which leads to a decrease of abnormal audit fees. In this study, therefore, Heckman's two-stage regression model is used to test endogeneity.

In the first stage, the Probit model is established and the IMR is calculated. The model is as follows:

$$probit\left(Mec_{i,t}\right) = \beta_0 + \beta_1 Size_{i,t} + \beta_2 Roa_{i,t} + \beta_3 Lev_{i,t} + \beta_4 Othec_{i,t} + \sum Year + \sum Industry + \varepsilon. \tag{5}$$

In the second stage, the IMR value estimated in the first stage is inserted into Model (10). The model is as follows:

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} + \beta_6 Com_{i,t-1} \\ & + \beta_7 Liq_{i,t-1} + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} \\ & + \beta_{10} Top1_{i,t-1} + \beta_{11} Shrs_{i,t-1} + \beta_{12} Dual_{i,t-1} \\ & + \beta_{13} Idr_{i,t-1} + \beta_{14} Loss_{i,t-1} + \beta_{15} IMR \\ & + \sum Year + \sum Industry + \varepsilon. \end{aligned} \tag{6}$$

In the first stage, the study constructs the explanatory variable as the earnings persistence intensity (Mec) index. When the company's earnings persistence is greater than the industry median, Mec = 1; otherwise, Mec = 0. And control the company size (Size), return on assets (Roa), debt leverage (Lev), and other variables that affect the earnings persistence of the company. In addition, the "Exclusion Constraint" variable (Othec) is controlled in Heckman's first-stage regression model; the index is defined as the earnings persistence of other companies in the same industry during the same period. This is because other companies, in the same industry during the same period, have a "peer effect" with this company [21]. The earnings persistence of other companies, in the same industry during the same period, will have an impact on the earnings persistence of this company, while it has no direct impact on the abnormal audit fees of the company.

Table 6 reports the results of Heckman's Stage 1 regression. As shown in Table 7, the larger the company size (regression coefficient is 0.0551, significant at 1% level) and the higher the return on assets (regression coefficient is 33.48, significant at 1% level), the stronger the earnings persistence of listed companies. The lower the company's debt leverage (regression coefficient is −1.684, significant at 1% level), the stronger the earnings persistence of listed companies. The "Exclusion Constraint" variable (Othec) is significant at the 1% level, indicating that the earnings persistence of other companies, in the same industry during the same period, will affect the earnings persistence of the company, which meets the conditions for the selection of the exclusion constraint variable.

Table 7 reports the results of Heckman's Stage 2 regression. After controlling the self-selection bias of earnings persistence, there is still a significant negative correlation between earnings persistence and abnormal audit fees, and the negative correlation is still more significant in companies with low environmental uncertainty and state-owned

Table 5: Group test of OLS regression results.

Variable name	M1	M2	M3	M4
Groups	The low sample group of environmental uncertainty	The high sample group of environmental uncertainty	Nonstate-owned companies	State-owned companies
Ec	−0.262**	−0.104	−0.0750	−0.222***
	(−2.47)	(−1.52)	(−0.94)	(−2.76)
Size	−0.0413***	−0.0482***	−0.0604***	−0.0351***
	(−2.65)	(−4.21)	(−4.37)	(−2.96)
Roa	−0.332	−0.287	−0.123	−0.645***
	(−1.37)	(−1.46)	(−0.61)	(−2.93)
Lev	−0.114**	−0.0626	0.0544	−0.0879*
	(−2.09)	(−1.33)	(0.94)	(−1.89)
Sale	0.0709***	0.0603***	0.0551***	0.0669***
	(5.05)	(6.18)	(4.80)	(6.35)
Com	−0.125***	0.00615	−0.136***	−0.0294
	(−2.70)	(0.16)	(−2.99)	(−0.75)
Liq	−0.00927*	0.00478	−2.64e−05	0.00526
	(−1.81)	(1.17)	(−0.01)	(0.95)
Big4	0.0340	0.0431	0.0706**	0.0184
	(1.36)	(1.46)	(2.00)	(0.82)
Tobinq	0.0309***	0.0188***	0.00974**	0.0348***
	(5.44)	(3.97)	(2.16)	(6.03)
Top1	−0.173***	−0.100**	−0.113**	−0.0768*
	(−3.45)	(−2.16)	(−2.25)	(−1.66)
Shrs	0.256***	0.292***	−0.0265	0.433***
	(4.18)	(5.41)	(−0.47)	(7.62)
Dual	−0.0194	−0.00669	−0.00846	0.0224
	(−1.18)	(−0.47)	(−0.63)	(1.23)
Idr	−0.0181	0.396***	0.262**	0.195*
	(−0.16)	(3.63)	(2.30)	(1.83)
Loss	−0.00136	0.0265	0.0823***	−0.0262
	(−0.04)	(1.00)	(2.61)	(−0.97)
Year	Control	Control	Control	Control
Industry	Control	Control	Control	Control
Constant	0.493*	0.349*	0.830***	0.101
	(1.87)	(1.70)	(3.33)	(0.49)
N	4,618	4,855	3,817	5,656
Adj-R^2	0.040	0.033	0.036	0.051

Note. Variable definitions are in Table 5. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 6: The results of Heckman's stage 1 regression.

Variable name	Mec
Size	0.0551***
	(3.71)
Lev	−1.684***
	(−15.32)
Roa	33.48***
	(50.18)
Othec	−0.0178***
	(−4.79)
Year	CONTROL
Industry	CONTROL
Constant	−1.553***
	(−5.02)
N	11,017
Pseudo R^2	0.418

Note. Variable definitions are in Table 6. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

companies, which indicates that the research conclusion of this study is reliable. Although some studies believe that abnormal audit fees may damage the quality of accounting earnings and sever the connection between current and future accounting earnings [22]. However, in fact, earnings are the comprehensive reflection of the operating results that have occurred in the report after accounting confirmation and measurement, which is verified by the auditor before the accounting information is submitted to the external; from this, the audit fees occur. Therefore, this study argues that, under the circumstances of poor continuity caused by large fluctuation and weak stability of earnings, companies send signals of poor earnings quality and high-risk level to the outside world. In order to reduce risks, auditors may charge abnormal audit fees.

Besides, in the regression results of Heckman's Stage 2, the VIF values of Ec and IMR indexes are both less than 10, and there is no multicollinearity problem, which indicates

that the variable selection of the Heckman model is appropriate.

4.4. Mechanism Test. Based on the above analysis, it is found that company earnings persistence has a significant negative correlation with abnormal audit fees. Is this based on compensation for the risk premium or the dependence on customers? In order to explain the mechanism of earnings persistence on abnormal audit fees, a mechanism test was carried out in this study.

4.4.1. Mechanism Test Based on "Risk Compensation View". Earnings persistence may influence abnormal audit fees by reducing company risks. The intensity of the fluctuation of the company's main business income can often show the strength of company's business risks. Therefore, this study adopts the standard deviation of the natural logarithm of main business income in three periods of lagging to measure the business risk of companies (Risk). This study uses a three-step method to test the mechanism.

Step 1: use model (4) constructed above to test whether earnings persistence (independent variable) has a significant impact on abnormal audit fees (dependent variable):

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} + \beta_6 Com_{i,t-1} \\ & + \beta_7 Liq_{i,t-1} + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} \\ & + \beta_{10} Top1_{i,t-1} + \beta_{11} Shrs_{i,t-1} + \beta_{12} Du\ al_{i,t-1} \\ & + \beta_{13} I\ dr_{i,t-1} + \beta_{14} Loss_{i,t-1} + \sum Year \\ & + \sum Industry + \varepsilon. \end{aligned} \tag{7}$$

Step 2: build model (7) to test whether company earnings persistence has a significant impact on business risks (intermediary variable):

$$\begin{aligned} Risk_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} + \beta_6 Com_{i,t-1} \\ & + \beta_7 Liq_{i,t-1} + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} \\ & + \beta_{10} Top1_{i,t-1} + \beta_{11} Shrs_{i,t-1} + \beta_{12} Du\ al_{i,t-1} \\ & + \beta_{13} I\ dr_{i,t-1} + \beta_{14} Loss_{i,t-1} + \sum Year \\ & + \sum Industry + \varepsilon. \end{aligned} \tag{8}$$

Step 3: build model (8), and incorporate earnings persistence and business risks into the model to test whether they have a significant impact on abnormal audit fees:

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Risk_{i,t-1} + \beta_3 Size_{i,t-1} \\ & + \beta_4 Roa_{i,t-1} + \beta_5 Lev_{i,t-1} + \beta_6 Sale_{i,t-1} \\ & + \beta_7 Com_{i,t-1} + \beta_8 Liq_{i,t-1} + \beta_9 Big4_{i,t-1} \\ & + \beta_{10} Tobinq_{i,t-1} + \beta_{11} Top1_{i,t-1} + \beta_{12} Shrs_{i,t-1} \\ & + \beta_{13} Du\ al_{i,t-1} + \beta_{14} I\ dr_{i,t-1} + \beta_{15} Loss_{i,t-1} \\ & + \sum Year + \sum Industry + \varepsilon. \end{aligned} \tag{9}$$

Table 8 summarizes the statistical results of the three models above. It is found that, in Model 1, Model 2, and Model 3, the coefficient of earnings persistence is significant at the statistical level of 1%. The results show that earnings persistence has a significant negative correlation with abnormal audit fees. Abnormal audit fees can be restrained by reducing business risks, and since business risks plays a partial intermediary role between them. Therefore, this conclusion supports the explanation that abnormal audit fees are derived from the "Risk Compensation View" to a certain extent.

4.4.2. Mechanism Test Based on "Customer Dependency View". Company earnings persistence may also affect the abnormal audit fees of companies by affecting the economic relationship between companies and auditors. Therefore, this study measures audit collusion by adverse audit opinion improvement (Op) of listed companies. If the audit opinion of T is better than that of $T-1$, $\mathrm{Op}=1$. Otherwise, $\mathrm{Op}=0$.

In order to verify whether the mechanism of earnings persistence on abnormal audit fees is related to the "Customer Dependency View," the following models are constructed according to the three-step method to verify the relationship among earnings persistence, audit collusion, and abnormal audit fees:

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} + \beta_6 Com_{i,t-1} + \beta_7 Liq_{i,t-1} \\ & + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} + \beta_{10} Top1_{i,t-1} \\ & + \beta_{11} Shrs_{i,t-1} + \beta_{12} Du\ al_{i,t-1} + \beta_{13} I\ dr_{i,t-1} \\ & + \beta_{14} Loss_{i,t-1} + \sum Year + \sum Industry + \varepsilon, \end{aligned} \tag{10}$$

$$\begin{aligned} probit\left(Op_{i,t}\right) = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Size_{i,t-1} + \beta_3 Roa_{i,t-1} \\ & + \beta_4 Lev_{i,t-1} + \beta_5 Sale_{i,t-1} + \beta_6 Com_{i,t-1} \\ & + \beta_7 Liq_{i,t-1} + \beta_8 Big4_{i,t-1} + \beta_9 Tobinq_{i,t-1} \\ & + \beta_{10} Top1_{i,t-1} + \beta_{11} Shrs_{i,t-1} + \beta_{12} Du\ al_{i,t-1} \\ & + \beta_{13} I\ dr_{i,t-1} + \beta_{14} Loss_{i,t-1} + \sum Year \\ & + \sum Industry + \varepsilon, \end{aligned} \tag{11}$$

Table 7: The results of Heckman's stage 2 regression.

Variable name	M1	M2	M3	M4	M5
Groups	Total samples	The low sample group of environmental uncertainty	The high sample group of environmental uncertainty	Nonstate-owned companies	State-owned companies
Ec	−0.165***	−0.263**	−0.103	−0.0771	−0.223***
	(−2.85)	(−2.49)	(−1.52)	(−0.96)	(−2.78)
Size	−0.0426***	−0.0409***	−0.0482***	−0.0602***	−0.0347***
	(−4.71)	(−2.64)	(−4.20)	(−4.36)	(−2.93)
Roa	−0.331**	−0.402	−0.308	−0.0565	−0.732***
	(−2.08)	(−1.54)	(−1.51)	(−0.27)	(−3.16)
Lev	−0.0552	−0.101*	−0.0587	0.0419	−0.0718
	(−1.52)	(−1.78)	(−1.23)	(0.71)	(−1.52)
Sale	0.0588***	0.0701***	0.0602***	0.0560***	0.0659***
	(7.43)	(5.00)	(6.16)	(4.85)	(6.26)
Com	−0.0530*	−0.127***	0.00545	−0.135***	−0.0323
	(−1.79)	(−2.74)	(0.14)	(−2.96)	(−0.83)
Liq	0.000895	−0.00896*	0.00482	−0.000153	0.00552
	(0.28)	(−1.75)	(1.18)	(−0.04)	(1.00)
Big4	0.0375**	0.0337	0.0430	0.0699**	0.0176
	(1.97)	(1.34)	(1.45)	(1.98)	(0.78)
Tobinq	0.0235***	0.0309***	0.0187***	0.00996**	0.0344***
	(6.52)	(5.45)	(3.95)	(2.20)	(5.96)
Top1	−0.126***	−0.174***	−0.101**	−0.110**	−0.0789*
	(−3.71)	(−3.48)	(−2.17)	(−2.19)	(−1.71)
Shrs	0.285***	0.253***	0.291***	−0.0249	0.430***
	(7.07)	(4.14)	(5.37)	(−0.44)	(7.54)
Dual	−0.0143	−0.0196	−0.00673	−0.00752	0.0231
	(−1.32)	(−1.19)	(−0.47)	(−0.56)	(1.26)
Idr	0.216***	−0.0137	0.396***	0.258**	0.197*
	(2.76)	(−0.12)	(3.64)	(2.26)	(1.85)
Loss	0.0141	−0.00192	0.0259	0.0837***	−0.0283
	(0.68)	(−0.06)	(0.98)	(2.65)	(−1.05)
IMR	−0.00264	−0.00804	−0.00237	0.00837	−0.00946
	(−0.53)	(−0.76)	(−0.43)	(1.32)	(−1.35)
Year	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control
Constant	0.396**	0.496*	0.353*	0.811***	0.107
	(2.50)	(1.88)	(1.71)	(3.25)	(0.52)
N	9,473	4,618	4,855	3,817	5,656
Adj-R^2	0.027	0.040	0.032	0.036	0.051
Ec_VIFs	3.35	3.88	3.22	3.40	3.38
IMR_VIFs	1.51	1.78	1.41	1.42	1.60

Note. Variable definitions are in Table 7. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

$$\begin{aligned} Abfee_{i,t} = {} & \beta_0 + \beta_1 Ec_{i,t-1} + \beta_2 Op_{i,t-1} + \beta_3 Size_{i,t-1} \\ & + \beta_4 Roa_{i,t-1} + \beta_5 Lev_{i,t-1} + \beta_6 Sale_{i,t-1} \\ & + \beta_7 Com_{i,t-1} + \beta_8 Liq_{i,t-1} + \beta_9 Big4_{i,t-1} \\ & + \beta_{10} Tobinq_{i,t-1} + \beta_{11} Top1_{i,t-1} + \beta_{12} Shrs_{i,t-1} \\ & + \beta_{13} Du\ al_{i,t-1} + \beta_{14} I\ dr_{i,t-1} + \beta_{15} Loss_{i,t-1} \\ & + \sum Year + \sum In\ du\ str\ y + \varepsilon. \end{aligned} \tag{12}$$

Model (10) tests the impact of earnings persistence on abnormal audit fees. Model (11) verifies the impact of earnings persistence on audit collusion, and Model (12) further verifies whether earnings persistence has an impact on abnormal audit fees under the control of audit collusion. If $\beta 1$ is significantly not zero in Model (11), indicating that earnings persistence has a significant impact on audit collusion, regression is continued for Model (12); otherwise, the test is stopped.

According to Model 4 in Table 8, the coefficient of earnings persistence is not significant, indicating that earnings persistence does not have a significant impact on audit collusion and audit collusion does not play a mediating role in the relationship between earnings persistence and abnormal audit fees. Therefore, this conclusion does not support the explanation that abnormal audit fees are derived from the "Customer Dependency View."

In addition, in order to test the robustness of the mechanism test conclusion, the author replaced abnormal audit fees with the positive abnormal audit fees to conduct the mechanism test again, and the conclusion did not change substantially.

Table 8: The results of the mechanism test.

Variable name	M1	M2	M3	M4
	Abfee	Risk	Abfee	Op
Ec	−0.165***	−0.140***	−0.150***	−0.0355
	(−2.86)	(−3.58)	(−2.61)	(−1.18)
Risk			0.105***	
			(4.29)	
Size	−0.0426***	0.0174***	−0.0445***	−0.000604
	(−4.72)	(3.37)	(−4.92)	(−0.17)
Roa	−0.308**	0.828***	−0.395***	0.00129
	(−2.03)	(9.50)	(−2.60)	(0.02)
Lev	−0.0596*	0.176***	−0.0781**	0.0487***
	(−1.68)	(9.68)	(−2.18)	(3.98)
Sale	0.0591***	−0.0283***	0.0620***	−0.00329
	(7.48)	(−5.73)	(7.85)	(−0.89)
Com	−0.0524*	0.0120	−0.0536*	−0.0287***
	(−1.77)	(0.77)	(−1.82)	(−3.80)
Liq	0.000821	0.00736***	4.98e−05	0.00135**
	(0.25)	(4.53)	(0.02)	(2.32)
Big4	0.0376**	−0.0401***	0.0418**	0.00283
	(1.98)	(−5.91)	(2.20)	(0.86)
Tobinq	0.0236***	−0.00269	0.0239***	0.00172
	(6.53)	(−1.56)	(6.63)	(1.44)
Top1	−0.125***	0.122***	−0.138***	−0.00285
	(−3.69)	(7.65)	(−4.08)	(−0.43)
Shrs	0.286***	0.189***	0.266***	−0.0105
	(7.10)	(9.38)	(6.59)	(−1.37)
Dual	−0.0143	−0.0114**	−0.0131	0.00104
	(−1.32)	(−2.16)	(−1.21)	(0.45)
Idr	0.215***	0.0531	0.209***	−0.00319
	(2.75)	(1.61)	(2.68)	(−0.19)
Loss	0.0146	0.0471***	0.00962	0.0234***
	(0.70)	(5.61)	(0.46)	(2.97)
Year	Control	Control	Control	Control
Industry	Control	Control	Control	Control
Constant	0.393**	−0.202**	0.414***	0.0300
	(2.48)	(−2.42)	(2.62)	(0.52)
N	9,473	9,473	9,473	9,473
Adj-R^2/ pseudo -R^2	0.027	0.102	0.029	0.027

Note. Variable definitions are in Table 8. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

5. Conclusions and Implications

This study empirically tests the relationship between the company earnings persistence and abnormal audit fees by taking A-share listed company's in Shanghai and Shenzhen as study samples. The conclusions are as follows. (1) The stronger the earnings persistence, the lower the abnormal audit fees. (2) Earnings persistence only has a significant impact on positive abnormal audit fees. This means that earnings persistence cannot improve negative abnormal audit fees. (3) Further research shows that the negative correlation between earnings persistence and abnormal audit fees is more significant in companies with low environmental uncertainty and state-owned companies, and it has obvious heterogeneity. (4) The mechanism test shows that earnings persistence can reduce abnormal audit fees by improving business risks, which is consistent with the "Risk Compensation View."

The conclusions deeply understand the internal logic of the causes of abnormal audit fees. It will be necessary to normalize the risk-oriented audit behavior of Chinese accounting firms and be beneficial for the transformation of risk-oriented audit in China. At the same time, the conclusion makes an incremental contribution to solving the debate on the source of abnormal audits fees and provides an important reference for future research of the "Risk Compensation View," which improves the audit fee system and regulates audit fees by regulators.

The conclusions of this study have the following implications. Firstly, companies should constantly improve their profitability, ensure the quality of earnings, pay attention to the buffer effect of earnings persistence on abnormal audit fees, and reduce the adverse impact of business risks on audit fees. Nonstate-owned companies need to strengthen internal control, improve the quality of earnings, and reduce audit risk so as to reduce audit fees. And nonstate-owned companies should strengthen their core competitiveness and enhance their ability to resist risks. Secondly, management should fully consider the impact of environmental uncertainty on audit pricing and actively respond to changes in the external environment, so as to reduce business risks and improve abnormal audit fees.

6. Limitations and Future Studies

This research has been attempted and carried out by scientific procedures, but still has limitations:

(1) This study mainly considers the impact of earnings persistence on abnormal audit fees. The factors that affect abnormal audit fees in this study consist of mainly three variables: earnings persistence, the nature of property rights, and environmental uncertainty. At the same time, many other factors affect abnormal audit fees.

(2) The limitations of research using data from A-share listed companies in Shanghai and Shenzhen in China are that sometimes the sample's research results do not show the actual state.

Researchers are further advised to use other variables and develop variables in this study. This research can be used as a further reference and as a consideration for further research.

Data Availability

All data used in this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by Collaborative Education Project between Industry and University of Ministry of Education:

Research on the Construction of an Advanced Accounting Course Based on Cloud Class (project no. 202101086021), Beijing Social Science Foundation Project (project no. 18GLC049), General social science projects of scientific research plan of Beijing Municipal Education Commission (project no. SM201911417006), and the Academic Research Projects of Beijing Union University (project nos. SK20202005 and JY2021Y003).

References

[1] D. A. Simunic, "The pricing of audit services: theory and evidence," *Journal of Accounting Research*, vol. 18, no. 1, pp. 161–190, 1980.

[2] P. Zhu, D. Zhang, and Z. Zhou, "Can corporate risk-taking lead to audit fee premium: extending analysis from property rights and cost stickiness," *Journal of Zhongnan University of Economics and Law*, vol. 231, no. 6, pp. 72–80+160, 2018.

[3] U. Bhattacharya, H. Daouk, and M. Welker, "The world price of earnings opacity," *The Accounting Review*, vol. 78, no. 3, pp. 641–678, 2003.

[4] J.-H. Choi, J.-B. Kim, and Y. Zang, "Do abnormally high audit fees impair audit quality?" *Auditing: A Journal of Practice & Theory*, vol. 29, no. 2, pp. 115–140, 2010.

[5] J. Chu, X. Qin, and J. Fang, "Economic policy uncertainty and auditors' decisions: evidence based on audit fees," *Accounting Research*, vol. 374, no. 12, pp. 85–91, 2018.

[6] K. W. Hui, K. K. Nelson, and P. E. Yeung, "On the persistence and pricing of industry-wide and firm-specific earnings, cash flows, and accruals," *Journal of Accounting and Economics*, vol. 61, no. 1, pp. 185–202, 2016.

[7] D. Yao, M. Percy, J. Stewart, and F. Hu, "Fair value accounting and earnings persistence: evidence from international banks," *Journal of International Accounting Research*, vol. 17, no. 1, pp. 47–68, 2018.

[8] V. Li, "The effect of real earnings management on the persistence and informativeness of earnings," *The British Accounting Review*, vol. 51, no. 4, pp. 402–423, 2019.

[9] L. Simoni, S. Schaper, and C. Nielsen, "Business model disclosures, market values, and earnings persistence: evidence from the UK," *Abacus*, vol. 58, no. 1, pp. 142–173, 2022.

[10] J. D. Eshleman and P. Guo, "Abnormal audit fees and audit quality: the importance of considering managerial incentives in tests of earnings management," *Auditing: A Journal of Practice & Theory*, vol. 33, no. 1, pp. 117–138, 2014.

[11] A. Ghosh and C. Xing, "Goodwill impairment and audit effort," *Accounting Horizons*, vol. 35, no. 4, pp. 83–103, 2021.

[12] I. D. Dichev and V. W. Tang, "Matching and the changing properties of accounting earnings over the last 40 years," *The Accounting Review*, vol. 83, no. 6, pp. 1425–1460, 2008.

[13] I. D. Dichev, J. R. Graham, C. R. Harvey et al., "Earnings quality: evidence from the field," *Journal of Accounting and Economics*, vol. 56, no. 2-3, pp. 1–33, 2013.

[14] S. A. Richardson, R. G. Sloan, M. T. Soliman, and İ. Tuna, "Accrual reliability, earnings persistence and stock prices," *Journal of Accounting and Economics*, vol. 39, no. 3, pp. 437–485, 2005.

[15] T.-S. Hsieh, J.-B. Kim, R. R. Wang, and Z. Wang, "Seeing is believing? Executives' facial trustworthiness, auditor tenure, and audit fees," *Journal of Accounting and Economics*, vol. 69, no. 1, p. 101260, 2020.

[16] J. R. Casterella, J. R. Francis, B. L. Lewis, and P. L. Walker, "Auditor industry specialization, client bargaining power, and audit pricing," *Auditing: A Journal of Practice & Theory*, vol. 23, no. 1, pp. 123–140, 2004.

[17] A. I. Blankley, D. N. Hurtt, and J. E. Macgregor, "Abnormal audit fees and restatements," *Auditing: A Journal of Practice & Theory*, vol. 31, no. 1, pp. 79–96, 2012.

[18] S. C. Asthana and J. P. Boone, "Abnormal audit fee and audit quality," *Auditing: A Journal of Practice & Theory*, vol. 31, no. 3, pp. 1–22, 2012.

[19] D. Ghosh and L. Olsen, "Environmental uncertainty and managers' use of discretionary accruals," *Accounting, Organizations and Society*, vol. 34, no. 2, pp. 188–205, 2009.

[20] Auditing Research Editorial Department and F. Xin, "Research information reference: new coronary pneumonia epidemic and audit," *Auditing Research*, vol. 218, no. 6, pp. 122–128, 2020.

[21] T. Zhong and T. Zhang, "'Peer effects' in capital structure decision of Chinese firms: empirical investigation based on Chinese A-share listed firms," *Nankai Business Review*, vol. 20, no. 2, pp. 58–70, 2017.

[22] Y. Gao, F. Liao, and Z. Liu, "Abnormal audit fees and effectiveness of securities analysts earnings forecasting: based on data of A-share listed companies in our country," *Auditing Research*, vol. 198, no. 4, pp. 81–88, 2017.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7872935, 12 pages
https://doi.org/10.1155/2022/7872935

Research Article

Corporate Pension Payment System under the Constraints of Cost of Capital: An Empirical Study

Lingbin Shan [1] and Ming Su [2]

[1] *Business College of Beijing Union University, Beijing, China*
[2] *Accounting College of Henan University of Economics and Law, Zhengzhou, China*

Correspondence should be addressed to Lingbin Shan; lingbin.shan@buu.edu.cn

Received 23 February 2022; Accepted 6 April 2022; Published 23 April 2022

Academic Editor: Lele Qin

Reducing the cost of capital is an effective way to increase stockholders' wealth and can also constrain the amount of corporate pension payments. This paper, taking the companies listed on A-share market during the year from 2008 to 2019 as samples, examines the influence path and effect of corporate pension on cost of capital. It is different from the research results of Western scholars that, in all the samples, corporate pensions reduce the cost of capital through debt and incentive effects. For labor-intensive enterprises and those whose effective income tax rate is less than zero, corporate pensions fail to reduce the cost of capital significantly. While for capital-and-technology-intensive enterprises, those whose effective income tax rate is more than zero, and those whose financing restraint is more or less than zero, corporate pension is proven to significantly reduce the cost of capital. Innovation performance has a partial mediating effect between corporate pensions and cost of capital.

1. Introduction

Residents' pensions after retirement are directly affected by the amount and mode of pension insurance payments. In order to make up for the shortfall of replacement rate of basic pension insurance and guarantee a better life of employees after retirement, the Ministry of Labor and Social Security of the People's Republic of China promulgated "Corporate Pension Trial Method" on December 30th, 2003, where enterprises and employees are endowed with the right to pay their corporate pension in addition to basic pension insurance. On December 20th, 2016, the Ministry of Human Resources and Social Security of the People's Republic of China promulgated "Corporate Pension Method," stipulating that the portion of corporate pension paid by enterprises shall not exceed 8% of the payroll of all employees and the total amount of corporate pension paid by both enterprise and employees shall not exceed 12% of the payroll of all employees in the previous year. A specific amount of corporate pension payments is under negotiation between the enterprise and employees. However, no specific basis was given for the actual consultation, and no specific payment system was formulated from the perspective of protecting of shareholders' interests. The generation and completion of corporate pension payment obligations have both positive and negative impacts on the protection of shareholders' interests from several aspects. It is a topic worthy of in-depth study to ensure the healthy and lasting development of enterprises while protecting shareholders' interests and improving employees' pensions as much as possible. The income growth in enterprises does not necessarily increase stockholders' wealth. Only when the return rate of investment is higher than stockholders' required return rate, i.e., the cost of equity capital, the higher part can result in an increase in stockholders' wealth and the enterprise value. If other factors are fixed, reducing the cost of capital is an efficient way to increase stockholders' wealth [1]. If corporate pension payments increase the cost of capital, a higher return rate on investment will be required to balance the cost of capital. Then, the investment choices are reduced, or the difference between the return rate of investment and cost of capital is narrowed, and hence, the stockholders' interests are damaged. On the contrary, if corporate pension payments reduce the cost of capital, stockholders' interests

will increase correspondingly. Therefore, this paper examines the influence path and the effect of corporate pension on the cost of capital. The cost of debt capital is relatively fixed, while cost of equity capital changes greatly under the influence of other factors [1]. The cost of capital in this paper refers to the cost of equity capital.

There are two payment methods for corporate pension, i.e., defined benefit corporate pension plans and defined contribution corporate pension plans. The defined benefit corporate pension plans imply in-advance determination of supplementary pension benefits for employees after retirement. Regardless of the enterprise performance before employees retiring and whether the enterprise can pay a corporate pension in due, the annual accumulation rate of pension rights during employment has to be maintained at a certain level. Since the industrial revolution, corporate pension has begun to appear in Western countries, where defined benefit corporate pension plans were generally adopted, bringing a heavy financial burden to enterprises. Until the economic recession in America, when many enterprises went bankrupt due to excessive financial burden, defined contribution corporate pension plans gradually became a new favorite in Western countries. Many scholars take listed companies adopting defined benefit corporate pension plans in Western countries as samples to study the mechanism and effect of such a payment mode on the cost of capital. It is concluded that defined benefit corporate pensions increase the cost of capital (Rauh [2]; Franzoni [3]; Campbell et al. [4]; Michael and Neil [5]; Brian [6]; Berchtold et al. [7]). Other scholars show that a defined benefit corporate pension has no significant impact on the cost of capital [8]. However, listed companies in China are rarely taken as samples to study the mechanism and effect of the defined contribution corporate pension on the cost of capital. The defined contribution corporate pension plans adopted by Chinese enterprises claim that the amount of supplementary pension employees can get after retirement is not determined in advance but depends on the previous pension payment amount and its accumulated investment income, while the corporate pension payment amount of enterprises and employees is determined in advance. In this way, enterprises can selectively determine the proportion of corporate pension payments in salaries according to the level of business performance, so as to avoid excessive burden on enterprise finance and possible bankruptcy risk. Enterprises are allowed to determine their corporate pension payment proportions based on the service duration and the employee contribution. It is worthy of in-depth study to achieve a balance between the protection of shareholders' interests and the protection of supplementary pension rights and interests of employees by establishing a corporate pension payment system under the constraint of the cost of capital.

The contribution of this paper is reflected in two aspects. Firstly, it examines the influence mechanism and effect of corporate pension on the cost of capital under the defined contribution corporate pension plan based on the data in China. Western scholars generally do relevant research based on defined benefit corporate pension plans instead of defined contribution corporate pension ones, leaving there little literature to consult. The research of this paper enriches the literature in related fields.

Secondly, based on cross-sectional heterogeneity, this paper examines the impact of corporate pension on the cost of capital in labor-intensive and capital-and-technology-intensive enterprises, enterprises with or without financing constraints, and enterprises with different effective income tax rates. The partial mediating effect of innovation performance between the corporate pension and cost of capital is examined as well. The studies provide a theoretical and empirical basis for enterprises to determine the appropriate payment proportion for the corporate pension. At present, there is little literature to do relevant research. The research of this paper enriches the literature in relevant fields.

2. Literature Review and Development of Hypotheses

2.1. The Influence of Corporate Pension on the Cost of Capital Based on Debt Effect and Incentive Effect

2.1.1. Debt Effect. Corporate pension is a detailed account of employee compensation payable, endowed with the nature of short-term liability. Corporate pension failing to be timely paid in this period will be converted into long-term liabilities. The increase in corporate pension this year is the corporate pension liability belonging to employees and needs to be paid this year. Therefore, the payment of corporate pension is essentially the payment of corporate pension liabilities. Corporate pension liabilities can affect the cost of capital in different sizes and directions through tax shield interests, financial risks, corporate governance, and signal transmissions.

On Jan 1st, 2008, the Ministry of Finance and State Administration of Taxation promulgated "Notice on Enterprise Income Tax Policies Related to Supplementary Endowment Insurance Premiums and Supplementary Medical Insurance Premiums" stipulating that the payment of corporate pension will be deducted before tax within the part not exceeding 5% of the total employee salaries, thus offsetting taxes and reducing the cost of capital. However, according to the trade-off theory, the increase of corporate pension liabilities increases the financial risk of enterprises. When the debt ratio reaches a certain height, the cost of financial crisis will gradually increase and tax shield benefits can be gradually offset, so that the cost of capital will increase.

Corporate pension also plays the role of corporate governance. Although its contribution proportion is not high, with an upper limit of 8%, the total amount of employee compensation has been increasing in recent years, resulting in a significant increase in the total amount of corporate pension liabilities, an increase in the financial burden of enterprises, an increase in the risk of bankruptcy, and an increase in the possibility of damage to the reputation and economic interests of managers. To avoid possible losses, managers have no alternative but to work harder to improve the quality of management, so as to reduce the risk of damage to investment income of investors and reduce the

cost of capital. Meanwhile, an obligation to pay corporate pension liabilities will restrain managers from misusing corporate funds, help curb excessive on-the-job consumption and overinvestment of the management, and reduce the risk of damage to investment income of investors, so as to reduce the cost of capital as well.

According to signal transmission theory, the burden of corporate pension liabilities means that the enterprise expects good performance in the future and sends a positive signal to the capital market. Only enterprises with confidence in future performance have the ability to bear corporate pension liabilities for a long time and receive positive feedback from the capital market, so that investors have a higher and more stable evaluation of its future performance and are willing to further maintain or increase their investment, reduce their investment risk expectations, and reduce the cost of capital. Enterprises with poor future performance do not have the ability to get positive feedback from the capital market by increasing corporate pension liabilities. Therefore, according to the signal theory, the burden of corporate pension sends a positive signal, which is conducive to the reduction of the cost of capital.

2.1.2. Incentive Effect. Corporate pensions have the attribute of postincentive. Working years and employee performance determine the amount of rights and interests that employees can obtain from corporate pension payments. The longer the working years is, the greater the amount of corporate pension rights and interests employees obtains and the greater the gap between the ownership of corporate pension rights and interests and their marginal output will be. By contrast, the shorter the working years is, the less the ownership of corporate pension rights and interests employees obtains. The ownership rules of corporate pension rights and interests increase the losses caused by the unemployment of employees with short working years due to work slack and then encourage them to work hard in turn [9]. Therefore, corporate pensions are conducive to encouraging long-term and high-quality service behavior of employees and conducive to the long-term sustainable development of enterprises, the improvement of enterprise investment and operation efficiency, the reduction of investors' investment risk expectation, and the reduction of cost of capital.

Corporate pensions have the function as tax benefit incentives. The corporate pension paid by the enterprise and the income obtained by the enterprise through investment and operations using corporate pension funds can be exempted from paying individual income tax. The portion of corporate pensions within 4% of the tax base of employee salaries paid by employees can be deducted from their taxable income in the current period. These tax benefit incentive policies play an incentive role and further stabilize the workforce, encourage employees to improve their work quality, reduce investors' investment risk expectations, and reduce the cost of capital. However, the amount of corporate pensions is much smaller than that of salaries and bonuses, and the incentive effect of individual income tax benefit policies on employees remains rather limited, leading to limited reduction in cost of capital correspondingly.

From the above analysis, it can be seen that corporate pensions play a positive role in reducing the cost of capital from the following paths, i.e., tax shield interest, corporate governance, signal transmission, postincentives, and tax benefit incentives. Financial risk paths play a positive role in increasing the cost of capital. However, given that Chinese enterprises adopt defined contribution corporate pension plans, the payment of corporate pension is controlled in a certain proportion and the amount is small, which brings a limited financial burden to enterprises and results in limited increasing in the cost of capital. It is therefore concluded that, on the whole, corporate pensions reduce the cost of capital.

Therefore, this paper proposes hypothesis 1: corporate pension will reduce the cost of capital.

2.2. The Effect of Corporate Pension on the Cost of Capital of Labor-Intensive Enterprises and Capital-and-Technology-Intensive Enterprises. Enterprises with a result of more than 0.08 when the number of employees (10000 persons) is divided by the original price of fixed assets (100 million yuan) are defined as labor-intensive enterprises [10]. The labor cost of labor-intensive enterprises is higher than that of capital-and-technology-intensive enterprises, and its proportion of the total cost is also relatively higher. The payment of the corporate pension is determined by taking the salary as the base and multiplied by a certain proportion. Compared with capital-and-technology-intensive enterprises, the same payment proportion of corporate pension in labor-intensive enterprises produces more total payments for corporate pensions. A substantial increase in cost will negatively influence the effective investment and normal operation of enterprises, resulting in an increased risk of loss of enterprise profits, which will have an adverse impact on cash dividend distribution and stock price changes and increase the risk of damage to shareholders' interests, increase the financial burden, and increase the financial risk to a greater extent. This will boost a significant increase in the cost of capital.

Secondly, the burden of corporate pensions on labor-intensive enterprises transmits a signal that the financial burden of the enterprise is too heavy. This causes investors to improve the risk assessment level of investment income, and the cost of capital increases correspondingly. Given the small incentive effect of tax benefits, corporate pension can reduce the cost of capital relatively more significantly only through tax shield interests and corporate governance. In general, the higher payment base of corporate pensions in labor-intensive enterprises offsets the reduction in capital cost through other relevant paths.

Therefore, this paper proposes hypothesis 2: corporate pensions of labor-intensive enterprises cannot significantly reduce the cost of capital, while corporate pensions of capital-and-technology-intensive enterprises can significantly reduce the cost of capital.

2.3. The Effect of Corporate Pension on the Cost of Capital under Different Effective Income Tax Rates. Modified MM theory (capital structure theory based on tax included) holds that in the case of enterprise income tax, debt interest can be deducted before tax, so as to reduce the cost of capital and improve enterprise value. The payment of corporate pensions also comes before income tax. When the enterprise is subjected to a higher income tax rate, the tax offset function generated by the payment of the same amount of corporate pension becomes stronger, which saves tax on the enterprise and reduces the cost of capital. For enterprises with a negative effective income tax rate, the payment of corporate pensions fails to produce a tax-saving effect or to reduce the cost of capital. It is found statistically that the mean and median of the effective income tax rate of enterprises with a positive effective income tax rate are both approximately 0.15, which can play an immediate role in reducing the cost of capital to a great extent. However, enterprises with a negative effective income tax rate lose this means that can have a significant effect on reducing their cost of capital. Although corporate pensions can reduce the cost of capital through the paths of corporate governance, signal transmission, postincentive, and tax benefit incentives, it still performs weakly to attract investors to make a low-level evaluation of their investment risk through signal transmission, since the securities market in China is obviously speculative. Employees in many enterprises are not clearly aware of the policy of corporate pensions, and the pension rights and interests available after retirement are uncertain. Therefore, the postincentive effect is rather limited. Moreover, the tax benefit incentives have little effect on cost of capital reducing. However, corporate pensions can increase the cost of capital through the financial risk path. Several factors mutually offset the effects on the cost of capital. Overall, for enterprises with negative income tax rate, the payment of corporate pensions cannot significantly reduce the cost of capital [11].

For enterprises with a positive enterprise income tax rate, the higher the income tax rate is, the better the corporate pension payment enables the enterprise to obtain tax shield benefits, which in turn reduces the capital cost more greatly. In these enterprise samples, corporate pension payments significantly reduce the capital cost.

Therefore, this paper proposes hypothesis 3 that for enterprises subjected to negative effective income tax rate, corporate pensions cannot significantly reduce the cost of capital; while for enterprises with a positive effective income tax rate, corporate pensions can significantly reduce the cost of capital.

2.4. The Effect of Corporate Pension on the Cost of Capital under Different Financing Constraints. Many Western scholars have studied the impact of corporate pensions on the cost of capital under external financing constraints, claiming that the payment of corporate pension liabilities urges the enterprise to carry out external financing, so as to raise sufficient funds. The existence of external financing constraints causes a high cost of external financing and thus leads to the increase of cost of capital. (Rauh [2]; Franzoni [3]; John et al. [4]; Michael and Neil [5], Brian [6]; Berchtold et al. [7]). However, in the Chinese securities market, the threshold for additional issuance of new shares is low, which makes the refinancing obstacles of listed companies small.

Listed companies can obtain large amounts of funds by issuing new shares. At the same time, the actual capital cost, that is, cash dividend, remains rather low. This is because, there are no mandatory policies or regulations requiring enterprises to pay cash dividends to shareholders for a long time. Many listed companies cannot provide shareholders with reasonable cash dividends to satisfy them, and the actual cost of equity financing is rather low. "Ring money" has become a pronoun for many listed companies to issue shares and raise funds. The majority of stock investors does not know or gradually ignores their legitimate rights and interests to obtain reasonable cash dividend returns, ignores the performance and dividend policies of listed companies, turns to pay attention to the stock market, and is forced to change their identity from investors to speculators. Even if the company's performance is not ideal or the dividend policy is not clear or ideal, it can successfully sell additional new shares. Most listed companies can issue shares at a low cost to raise a large amount of funds under a low threshold. Therefore, in contrast to the research results acquired by Western scholars, enterprises with obvious financing constraints will not experience a significant increase in the cost of capital [12]. In contrast, the payment of corporate pensions keeps reducing the cost of capital. Meanwhile, the financing constraint can be taken as a moderating variable to verify that the financing constraint has no significant impact on the correlation between corporate pensions and the cost of capital.

Therefore, this paper proposes hypothesis 4 that both enterprises with higher and lower financing constraints can significantly reduce the cost of capital. For enterprises with higher financing constraints, higher financing constraints do not significantly weaken the negative correlation between corporate pensions and cost of capital.

2.5. Mediating Effect Test of Enterprise Innovation Performance. According to the relevant policies on corporate pensions of Beixin Building Materials, if employees leave within five years of employment, they will lose part of the rights and interests formed by the enterprise payment included in the individual account and this part of loss will decrease with the extension of employees' working years. If dismissed within five years, the employee will lose all of his or her rights and interests. Therefore, the rights and interest vesting design of corporate pensions greatly increases the turnover cost of employees and reduces the desire of talent flow. The stability of human resources will help employees engage in innovative research and design more persistently and intensively and will be more conducive to the improvement of enterprise innovation performance. As a supplementary pension benefit, corporate pension can attract and retain knowledge workers with strong employability by increasing the expected benefits after their

retirement, so as to improve their satisfaction with and loyalty to the enterprise. Knowledge workers are the important driving factor in innovation [13]. Meanwhile, as high-quality human capital, knowledge workers have comparative advantages in terms of learning and using new technologies. They can effectively reduce the uncertainty in the process of enterprise innovation and improve the success rate in the innovating process of by means of imitation, learning by doing, and resource integration [14].

Enterprises can improve their original products or develop new products through technological innovation, so as to enhance the differentiation advantages of their products, which is also conducive to the stability and improvement of their market competitive position. Additionally, enterprise innovation accumulates and integrates technology, optimizes production processes, improves production efficiency, reduces production costs, makes products and services provided by enterprises with strong exclusivity and added value, improves the imitation difficulty of competitors, and further enhances their long-term competitive advantage. The advantageous competitive position of enterprises can give play to the "hedging effect," transmit the favorable signal of their sound future development, reduce the investment risk of investors, attract more potential investors to invest in stocks, and reduce the cost of capital [15]. Charles believes that innovation activities of enterprises can improve their innovation ability and produce innovation performance, which enables investors to expect the economic benefits generated by innovation performance, and attracts more shareholder investment and enhance the willingness of shareholders to hold corporate shares. Finally, the higher the innovation performance is, the greater the probability that investors can get investment income, and hence, the lower the risk of investment damage will be and then the lower the cost of enterprise capital [16]. Fateh and Sajjad propose that innovation performance can reduce the required return rate by investors and reduce the cost of capital of enterprises through "competitiveness enhancement effect" and "investor concern effect" [17].

Therefore, this paper proposes hypothesis 5 that innovation performance is a mediating variable between corporate pension and the cost of capital.

3. Research Methodology

3.1. Variable Selection. All variables including dependent variables, independent variables, control variables, mediating variables, moderating variables, and dummy control variable are listed in Table 1.

3.1.1. Dependent Variable: Cost of Capital. As the cost of debt capital is determined by the debt contract and has little variability, the impact of corporate pension is examined on the cost of equity capital, where the cost of capital refers to the cost of equity capital. This paper selects the cost of equity capital of A-share listed companies in the Shanghai and Shenzhen stock market as the dependent variable. The estimation methods of equity capital cost are divided into two types, i.e., the cost of the capital estimation model of risk compensation technology based on historical data and the implicit capital cost estimation model based on future forecast data. The cost of the capital estimation model of risk compensation technology well reflects the required return rate by investors based on risk assessment. The CAPM model is the representative one, which has been widely used in both the theoretical and practical circles [18]. It is also the estimation model used in this paper. However, it is unreasonable to estimate the beta coefficient based on historical data to estimate the cost of capital to provide data analysis for future decision-making. The implicit cost of capital estimation model based on future forecast data avoids this defect. Comparatively speaking, the PEG model $R_e = \sqrt{eps_2 - eps_1/P_0}$ has been applied more broadly in theoretical and practical circles [19]. However, it fails to guarantee the accuracy of future forecast data, and the error can only be reduced by taking the average of forecast data of analysts.

Therefore, this paper uses the PEG and CAPM models to estimate the capital cost and takes the average value as the estimation result of equity capital cost. The combination of two different types of estimation models makes up for shortcomings of each other and allows them to learn from strengths of each other and compensate for their weakness.

3.1.2. Independent Variable: Corporate Pension. The added value of corporate pension, also the independent variable selected in this paper, in the current year reflects the corporate pension payable in the current period, which is endowed with the nature of short-term liabilities, and well reflects the payment amount of supplementary endowment insurance borne by enterprises.

3.1.3. Control Variables. This paper selects asset-liability ratio, enterprise size, beta coefficient, book-to-market ratio, and asset turnover ratio as control variables of model 2 based on the research of Mokhova and Zinecker [20], Faysal et al. [21], Muslim and Setiawan [22], and Franc-Dąbrowska et al. [23]. Meanwhile, this paper selects shareholding ratio of the largest shareholder, board size, shareholding ratio of senior executives, return on total assets, and asset-liability ratio as control variable of model 4 on the basis of the research of Jones [24], Duong et al. [25], and Steele and Stefan [26]. Besides, this paper selects dummy variables of the industry and year as the control variables for all models.

3.1.4. Moderating Variable: Financing Constraints. Scholars have proposed many indicators to measure financing constraints, including univariate and multivariable indicators. Some scholars take company size as the evaluation index of financing constraints, while others use dividend payment level as the evaluation index of financing constraints. However, given the diversity of the influencing factors of financing constraints, the method of single index evaluation of financing constraints has been widely doubted.

Table 1: Variable definition.

Variable category	Variable	Variable definition
Dependent variable	Re	Cost of equity capital
Independent variable	CP	Corporate pension: the ending added value of corporate pension is taken as logarithm
Control variable	Lev	Asset liability ratio: total liabilities at the end of the period/total assets at the end of the period
	Size	Size: natural logarithm of total assets
	Beta	Beta: β of that year's stock value
	B/M	Book to market ratio: book value of owner's equity/market value
	AT	Operating efficiency: main business income of the current year/total assets
	First	Shareholding ratio of the largest shareholder
	Board	Board size: natural logarithm of the number of directors
	Msh	Shareholding ratio of senior executives: number of shares held by senior executives/total shares
	Roa	Return on total assets: net income/total assets
Moderating variable	FC	Financial constraints
Mediating variable	Patent	Innovation performance: natural logarithm of the total number of patent applications of the enterprise in the current year plus 1
Dummy control variable	Indu	Industry dummy variable: according to the "Guidelines for Industry Classification of Listed Companies" issued by the CSRC in 2001, the industries are divided into 13 categories, excluding finance and insurance industry (I); the dummy variable is 1, when the enterprise belongs to an industry, otherwise 0
	Year	Year dummy variable: the dummy variable is 1, when the investigation time is the current year, otherwise 0

The main methods of multi-index evaluation of financing constraints are KZ index, WW index, ZFC index, LFC index, DFC index, and SA index. However, KZ index, WW index, ZFC index, LFC index, and DFC index involve endogenous indicators such as debt ratio, Tobin Q, and cash flow, which are seriously disturbed by endogenous factors. Hadlock and Pierce construct the SA index on the basis of two exogenous variables, i.e., enterprise size and enterprise age, and it is found that the two constituent variables of the index have a great degree of substitution for some constituent variables of other indexes [27]. Therefore, SA index is adopted to evaluate the degree of financing constraints of enterprises in this paper. The greater the absolute value of the index is, the lower the degree of financing constraints becomes.

$$SA = -0.737 \times (Ln\text{Size}) + 0.043 \times (Ln\text{Size})^2 - 0.04 \times \text{Age}. \tag{1}$$

3.1.5. Mediating Variable: Innovation Performance. The natural logarithm of the total number of patent applications plus 1 is chosen as the innovation performance of the enterprise based on the research of Steele and Stefan [26].

3.2. Sample Selection and Data Source. Since 2008, the number of enterprises paying corporate pensions has begun to increase and Damodaran's market risk premium rate was estimated to be only as high as 2019. Therefore, A-share listed companies in the Shanghai and Shenzhen stock markets from 2008 to 2019 are selected as the research object in this paper. The ST and ST $*$ data are from the RESSET database. Other data are obtained from the CSMAR database. The total number of samples is 2198, with ST and ST $*$ companies, financial and insurance companies, companies with missing data, and extreme outlier companies excluded. The sample size of labor-intensive enterprises is 150, and the sample size of capital-and-technology-intensive enterprises is 2038. The sample size of effective income tax rate less than 0 is 384, and the sample size of effective income tax rate greater than 0 is 1635. In this paper, a nonequilibrium panel regression analysis is conducted. This paper winsorizes all variables at the level of 1%.

3.3. Model Setting. For the six hypotheses, the regression models constructed in this paper are as follows:

$$\begin{aligned} R_e = {} & \alpha + \beta_1 CP + \beta_2 \text{Lev} + \beta_3 \text{Size} + \beta_4 \text{Beta} + \beta_5 B/M \\ & + \beta_6 \text{AT} + \sum \beta_i \text{Indu} + \sum \beta_i \text{Year} + \varepsilon. \end{aligned} \tag{2}$$

$$\begin{aligned} R_e = {} & \alpha + \beta_1 CP + \beta_2 FC + \beta_3 CP * FC + \beta_4 \text{Lev} \\ & + \beta_5 \text{Size} + \beta_6 \text{Beta} + \beta_7 B/M + \beta_8 AT \\ & + \sum \beta_i \text{Indu} + \sum \beta_i \text{Year} + \varepsilon. \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Patent} = {} & \alpha + \beta_1 CP + \beta_2 \text{First} + \beta_3 \text{Board} + \beta_4 Msh \\ & + \beta_5 \text{Roa} + \beta_6 \text{Lev} + \sum \beta_i \text{Indu} + \sum \beta_i Year + \varepsilon. \end{aligned} \tag{4}$$

$$\begin{aligned} R_e = {} & \alpha + \beta_1 \text{Patent} + \beta_2 CP + \beta_3 \text{Lev} + \beta_4 \text{Size} + \beta_5 \text{Beta} \\ & + \beta_6 B/M + \beta_7 \text{AT} + \sum \beta_i \text{Indu} + \sum \beta_i \text{Year} + \varepsilon. \end{aligned} \tag{5}$$

Equation (2) is adopted to test hypotheses 1, 2, 3, and 4 and to test the correlation between corporate pension and cost of capital in full samples and small samples divided according to different factors. Equation (3) is used to test hypothesis 4, the correlation between corporate pension and capital cost in the samples with high financing constraints, and whether the financing constraints weaken the negative correlation between corporate pensions and the cost of

capital [28]. Equations (4) and (5) are used to test hypothesis 5 and the mediating effect of enterprise innovation performance between corporate pensions and the cost of capital.

4. Results and Discussion

4.1. Descriptive Statistics. The descriptive statistics in Table 2 show that the capital cost of the whole sample company is mainly concentrated between 0.0512 and 0.1801, with a 25th quantile at 0.0793 and a 75th quantile at 0.1079, indicating that there are certain differences in the cost of capital between the samples. Doubt on whether the difference in the payment of corporate pensions contributes to difference in the cost of capital needs to be further tested by virtue of univariate empirical analysis. The median is 0.0924, and the mean is 0.0955. They are close to each other and equivalent to the experience level of capital cost of listed companies in China. The corporate pension is mainly in the range of 7.9860–20.4900, with the 25th quantile at 14.4070 and the 75th quantile at 16.9857, indicating that there is a certain gap in the sample companies' corporate pension payment amounts. Since the samples selected in this paper include labor-intensive and capital-and-technology-intensive enterprises, different industry characteristics may be an important reason for the difference in the payment level of corporate pensions, which will be further empirically tested in the multiple regression test.

4.2. Correlation Analysis. In this paper, the correlation coefficient of each variable is examined by virtue of the Pearson test in the whole sample, so as to judge whether there is a serious multicollinearity problem between each variable.

As shown in Table 3, the correlation coefficient of each variable is lower than 0.6. According to Ho and Wong, multicollinearity does not exist, when the correlation coefficient of each variable does not exceed 0.8 [29]. Therefore, it can be reasonably concluded that there is no multicollinearity problem among the variables of the entire sample.

4.3. Univariate Empirical Test. The mean difference and median difference of multiple variables in both high and low corporate pension enterprise groups are tested in Table 4 in order to further verify the correlation between corporate pension and the cost of capital. The high and low corporate pension groups are distinguished by higher or lower corporate pension than the median of the corporate pension. The mean of capital cost of the high corporate pension enterprise group is 0.078, and the mean of capital cost of the low corporate pension enterprise group is 0.113. The mean of capital cost of the high corporate pension enterprise group is lower. The mean difference is 0.036, which is significant at the level of 1%. The median of capital cost of the high corporate pension enterprise group is 0.079, and the median of capital cost of the low corporate pension enterprise group is 0.108. The median of capital cost of the high corporate pension enterprise group is lower. The median difference is 0.029, which is significant at the level of 1%. It can be once again concluded that the higher the current corporate pension liabilities are, the lower the enterprise capital cost becomes.

It is also shown in Table 4 that enterprises in the high corporate pension group have more investment value, perfectly reflected in the two indicators of operating efficiency and book-to-market value ratio. The mean and median of operating efficiency of enterprises in the high corporate pension group are higher than those in the low corporate pension group. The differences are significant at the level of 1%, indicating that the enterprise unit assets of the high corporate pension group create more operating income. The mean and median of the book-to-market ratio of enterprises in the high corporate pension group are higher than those in the low corporate pension group. The differences are also significant at the level of 1%. A higher ratio of book value to market value indicates that the market underestimates the actual value of the enterprise and there will be better investment return and growth potential in the future. Fama and French take the relevant data of American listed companies for 27 years as samples and find that the monthly average return of the portfolio with the highest book-to-market ratio is 1.53% higher than that of the portfolio with the lowest book-to-market ratio [30]. Jun and Xu explore A-shares in Shanghai and Shenzhen and figure out that when an enterprise is believed to have a higher investment value by investors, the risk assessment level of its investment will be reduced and so will the cost of capital [31].

4.4. Multivariate Regression Test. The regression results of the whole sample in Table 5 confirm a significant negative correlation between corporate pension and capital cost at the level of 1%, indicating that corporate pension can significantly reduce the cost of capital, thus verifying hypothesis 1. The regression results of the labor-intensive samples show that there is no significant negative relationship between corporate pensions and the cost of capital [28]. It shows that for labor-intensive enterprises, the corporate pension payment burden is too heavy due to the high labor cost. There are many adverse effects on effective investment and normal operation, and financial risk increases significantly. It also transmits the signal of an overburden to the capital market, resulting in the positive effect of corporate pension liabilities on reducing the cost of capital being offset by the negative effect, and corporate pensions cannot significantly reduce the cost of capital. The regression results of capital-and-technology-intensive samples show a significant negative correlation between corporate pensions and the cost of capital at the level of 5%, indicating that for capital-and-technology-intensive enterprises, the positive effect of corporate pension liabilities determined by relatively low human cost expenditure on reducing cost of capital exceeds the negative effect and corporate pension can significantly reduce the cost of capital. Hypothesis 2 is therefore verified. The regression results of samples with effective income tax rates less than 0 show that there is no significant negative correlation between corporate pensions and the cost of capital. This shows that the effective income tax rate is less

Table 2: Descriptive statistic of the whole samples.

Variable	Re	CP	Lev	Size	Beta	*B/M*	AT
Number of samples	2198	2198	2198	2198	2198	2198	2198
Mean	0.0955	15.4957	0.5025	23.4498	1.1075	1.1040	0.6096
Median	0.0924	15.7979	0.5065	23.3282	1.1116	0.9021	0.5154
Max	0.1801	20.4900	0.8732	27.2498	2.0514	5.0568	2.5683
Min	0.0512	7.9860	0.1031	20.0346	0.3528	0.1482	0.0921
25th quantile	0.0793	14.4070	0.3658	22.4150	0.9148	0.5858	0.3215
75th quantile	0.1079	16.9857	0.6544	24.3195	1.2900	1.1825	0.7445
Standard deviation	0.0234	2.3887	0.1889	1.3983	0.2979	0.8874	0.4391

Table 3: Correlation coefficient of each variable of the whole samples.

	Re	CP	Lev	Size	Beta	*B/M*	AT
Re	1.0000						
CP	−0.0333	1.0000					
Lev	0.2966***	0.1426***	1.0000				
Size	0.0916***	0.5509***	0.5032***	1.0000			
Beta	0.3244***	−0.1304***	0.0299	0.1962***	1.0000		
B/M	0.2107***	0.2022***	0.5495***	0.5300***	−0.0177	1.0000	
AT	0.0157	0.0027	0.0277	−0.0946***	0.0386*	−0.0772***	1.0000

Note. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

Table 4: Univariate empirical test.

Variable name	Means			Median		
	High corporate pension (1099)	Low corporate pension (1099)	Mean difference *t*-test	High corporate pension (1099)	Low corporate pension (1099)	Median difference *z*-test
Re	0.078	0.113	−0.036***	0.079	0.108	−0.029***
Lev	0.465	0.540	−0.075***	0.464	0.561	−0.097***
Size	23.546	23.354	0.192***	23.389	23.282	0.107
Beta	1.020	1.195	−0.174***	1.024	1.178	−0.154***
B/M	1.229	0.979	0.251***	0.957	0.854	0.103***
AT	0.624	0.596	0.028***	0.520	0.500	0.020***

*Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

Table 5: Multivariate regression test (whole sample and grouping sample).

Re	Whole sample	Labor-intensive sample	Capital technology-intensive sample	Samples with effective income tax rate less than 0	Samples with effective income tax rate more than 0	Samples with low financing constraints	Samples with high financing constraints
CP	−0.0005*** (−2.66)	−0.0008 (−0.92)	−0.0005** (−2.23)	−0.0001 (−0.17)	−0.0007*** (−3.11)	−0.0004* (−1.65)	−0.0055* (−1.68)
Lev	0.0185*** (6.18)	0.1423 (1.26)	0.0182*** (5.84)	0.0560*** (4.11)	0.0110*** (3.45)	0.0097*** (2.58)	0.0207*** (4.66)
Size	0.0012** (2.56)	0.0051*** (3.14)	0.0009∗∗ (1.96)	−0.0019 (−1.07)	0.0013** (2.62)	0.0010 (1.38)	0.0028*** (4.12)
Beta	0.0307*** (20.93)	0.0389*** (7.13)	0.0302*** (19.97)	0.0285*** (6.97)	0.0295*** (17.65)	0.0289*** (13.94)	0.0304*** (16.79)
B/M	0.0028*** (3.49)	0.0009 (0.38)	0.0030*** (3.66)	0.0027 (1.16)	0.0032*** (3.77)	0.0042*** (3.40)	0.0010 (1.11)
AT	0.0008 (0.75)	−0.0029 (−0.50)	0.0011 (0.98)	−0.0011 (−0.26)	0.0015 (1.37)	0.0016 (1.12)	0.0023 (1.57)
FC						—	0.0175 (0.99)
CP∗FC						—	0.0012 (1.36)
Indu	Control	Control	Control	Control	Control	Control	Control
Year	Control	Control	Control	Control	Control	Control	Control
N	2198	150	2038	384	1635	1090	1090
Adj-R^2	0.3784	0.582	0.3724	0.3743	0.3862	0.3342	0.4276

Note. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

than 0, resulting in the enterprise being unable to obtain the benefit of the tax shield and losing an important positive lever in reducing the cost of capital. Generally, corporate pensions do not significantly reduce the cost of capital. The regression results of samples with an effective income tax rate greater than 0 show a significant negative correlation between corporate pensions and cost of capital at the level of 1%. This reflects that the tax shield benefits generated by corporate pensions, together with other factors, play a more positive than negative role in reducing the cost of capital. Corporate pensions significantly reduce the cost of capital. Hypothesis 3 is therefore verified. The regression results of samples with low financing constraints and high financing constraints both show a significant negative correlation between corporate pension and cost of capital at the level of 10%, indicating that corporate pensions can significantly reduce the cost of capital, regardless of whether there is financing constraint. In addition, there is no significant positive correlation between the intersection item of financing constraints, corporate pension, and cost of capital. This indicates that financing constraints cannot significantly weaken the negative correlation between corporate pensions and cost of capital. Hypothesis 4 is therefore verified.

The test results of mediating effects in Table 6 show a significant positive correlation between corporate pensions and innovation performance at the level of 1%, indicating that corporate pensions can significantly increase the innovation performance of enterprises. Innovation performance is negatively correlated with the cost of capital at the level of 10%, indicating that innovation performance can significantly reduce the cost of capital. There is a significant negative correlation between corporate pension and the cost of capital at the level of 5%. Hypothesis 5 is thus verified, indicating that innovation performance has a partial mediating effect between corporate pensions and the cost of capital.

Table 6: Multivariate regression test (mediating effects).

Patent		Re	
CP	0.1536^{***} (6.42)	Patent	-0.0009^{*} (−1.90)
First	0.6630^{**} (1.97)	*CP*	-0.0007^{**} (−2.39)
Board	0.3044 (1.40)	Lev	0.0173^{***} (3.97)
Msh	1.4914^{**} (2.37)	Size	0.0030^{***} (4.70)
Roa	0.7123 (0.67)	Beta	0.0267^{***} (15.14)
Lev	1.7054^{***} (5.89)	*B/M*	0.029^{*} (1.69)
		AT	0.0002 (0.2)
Indu	Control	Indu	Control
Year	Control	Year	Control
N	1078	*N*	1078
Adj-R^2	0.2833	Adj-R^2	0.3642

Note. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

4.5. Robustness Check

4.5.1. Endogeneity. Endogeneity affects the explanatory power of the relationship between corporate pensions and the cost of capital. Therefore, the two-stage least square (2SLS) method is adopted for the test of endogeneity. Certain important variables might be omitted in the regression equation between corporate pensions and the cost of capital, resulting in endogeneity problems.

Some enterprises with lower cost of capital may possess stronger competitiveness, stronger capital, and stronger ability to pay corporate pensions, which creates a two-way impact between corporate pensions and the cost of capital. In order to eliminate the interference of the above problems with the research conclusions, instrumental variables and the two-stage least square method (2SLS) are adopted to regress the model. Given the certain path dependence of the increase of corporate pension, the past corporate pension liabilities of the enterprise will affect its current corporate pension liabilities and the industry standards on corporate pension will affect its corporate pension. Therefore, corporate pensions of enterprises lagging behind the first phase and the corporate pension at the industry level are taken as instrumental variables to test the endogeneity.

As shown in Table 7, the regression results of the first stage show that the coefficient of MeanCPt is 0.4168 and the correlation coefficient between corporate pensions at the industry level and the cost of capital has a significant negative correlation at the level of 1%. The coefficient of CP_{t-1} is 0.4316, and there is significant negative correlation between corporate pensions with one lag and the cost of capital at the level of 1%.

It shows that these two instrumental variables meet the correlation requirements. In the first stage, the F-statistic is 360.99, which is much higher than the empirical value of 10, indicating that the assumption of weak instrumental variables is rejected. The p value of the Sargan overidentification test result is 0.3019, indicating that the two instrumental variables are reasonable and effective exogenous variables. Additionally, the regression results of the second stage show that the coefficient of CP is −0.0016 and there is a significant negative correlation between corporate pensions and cost of capital at the level of 5%, which is consistent with the previous regression results.

4.5.2. Replacing Variable. Ohlson and Juettner-Nauroth propose the OJ model [32]. The formula of the model is as follows: $R_e = A + \sqrt{A^2 + eps_1/P_0[g - (\gamma - 1)]}$. $A = \gamma - 1 + dp\ s_1/P_0/2$ and $g = (eps_2 - eps_1)/eps_1$, where $\gamma - 1$ is the long-term revenue growth rate, and the value is 0.05 according to the practice of Hongbo Shen [33]. When $eps_1 > eps_2$, let $eps_1 = eps_2$. When the value under the root sign is negative, let $\mathrm{Re} = A$ [34]. Gode and Mohanram show that the OJ model can fully reflect the market's estimation level of risk premium and reduce restrictions on estimation of the cost of capital [35]. Therefore, the value of the OJ model is applied to replace the average value of the PEG and CAPM models used in the previous part of the paper for the estimation of the cost of capital, and the value of corporate pension divided by total assets is used to replace the value of the logarithm of corporate pension. The regression analysis is carried out again and passes the robustness tests, as depicted in Table 8.

Table 7: 2SLS regression test.

First stage		Second stage	
CP		Re	
$MeanCP_t$	0.4168^{***} (9.52)	CP	-0.0016^{**} (−2.36)
CP_{t-1}	0.4316^{***} (17.65)		
Lev	-1.3633^{***} (−5.73)	Lev	0.0283^{***} (8.87)
Size	0.7048^{***} (18.84)	Size	0.0009 (1.39)
Beta	0.0942 (0.76)	Beta	0.0249^{***} (16.58)
B/M	-0.1361^{***} (−2.87)	*B/M*	0.0022^{***} (2.81)
AT	0.3539^{***} (4.25)	AT	0.0005 (0.49)
Indu	Control	Indu	Control
Year	Control	Year	Control
N	2197	*N*	2197
Adj-R^2	0.5173	Adj−R^2	0.1928
F-test of instruments	360.99 (0.00)		
Sargan overidentification test	0.3198 (0.3019)		

Note. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

Table 8: Substitution variable regression test.

Re	The value of OJ model is used to replace the average value of the PEG model and CAPM model	The value of corporate pension divided by the total assets is used to replace the value of the logarithm corporate pension
CP	-0.0016^{***} (−3.28)	-1.6581^{**} (−2.10)
Lev	0.0298^{***} (4.50)	0.0382^{***} (6.64)
Size	0.0045^{***} (4.42)	0.0008 (1.05)
Beta	0.0001 (0.05)	−0.0026 (−0.95)
B/M	0.0006 (0.45)	0.0059^{***} (3.96)
AT	0.0047^{*} (1.94)	0.0022 (0.99)
Indu	Control	Control
Year	Control	Control
N	1788	2196
Adj-R^2	0.1977	0.2284

Note. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

5. Conclusive Remarks

5.1. Basic Conclusion. This paper theoretically analyzes and empirically tests the impact of corporate pensions on the cost of capital for the whole sample and grouping sample (labor-intensive and capital-and technology-intensive, effective income tax rate less than 0 and effective income tax rate greater than 0, financing constraints less than 0 and financing constraints greater than 0) based on the data of listed companies in Chinese A-share market from 2008 to 2019. The results show that corporate pensions can affect the cost of capital in two ways, i.e., debt and incentive effects. Corporate pensions can significantly reduce the cost of capita in the full samples, capital-and-technology-intensive samples, samples with effective income tax rate greater than 0, and samples with financing constraint more or less than 0. While for labor-intensive samples and samples with effective income tax rates less than 0, the positive effects of corporate pensions have an offsetting effect on reducing the capital cost and increasing the capital cost, resulting in the inability of corporate pensions to significantly reduce the cost of capital. Innovation performance is proven to have a partial mediating effect between corporate pensions and cost of capital.

In general, defined contribution corporate pension plans in China play a positive role in reducing the cost of capital, protecting the interests of shareholders, and increasing the value of enterprises under certain factors.

5.2. Policy Implication. Firstly, enterprises are supposed to increase the payment amount of corporate pensions as much as possible under the condition where the effective investment, normal operation, and on-the-job salary expenditure of employees are guaranteed. Sustainable and effective investment and normal operation are the most important means for enterprises to achieve long-term sustainable development and continuous growth of shareholders' wealth. Limited funds must be set aside for this part of expenditure. The efficient work quality of employees is inseparable from the incentive for a scientific and reasonable salary. Compared with the guarantee of a corporate pension for life after retirement, salary is the basic source to guarantee the existing living standard of employees. Generally speaking, salary lasts longer, the amount is higher, and the incentive intensity for employees' work enthusiasm will be higher. Therefore, limited funds must serve to guarantee the payment of employees' reasonable salaries simultaneously. Except for the payment of effective investment, normal operation, and employee salaries, enterprises must increase the payment of corporate pensions as much as possible, in order to reduce the cost of capital through the debt effect and incentive effect of corporate pension so as to increase stockholders' wealth finally.

Secondly, enterprises can appropriately increase the payment of corporate pensions to benefit from the tax shield and reduce the cost of capital as the increase of effective income tax rate. "Appropriately" here refers to suitable increase of corporate pension to a certain extent, but it cannot be too high. Otherwise, excessive financial burden will lead to excessive financial risks, and the final comprehensive effect may increase the cost of capital or fail to maximize the reduction in the cost of capital.

Thirdly, corporate pension payments can promote the increase of enterprise innovation performance and ultimately reduce the cost of capital for innovative enterprises, i.e., enterprises with a large number of patents. Therefore,

compared with other types of enterprises, innovative enterprises can place more emphasis on the improvement of the proportion of corporate pension payments, so as to increase the enterprise innovation performance and then reduce the cost of capital.

Fourthly, the construction of Chinese stock market requires further improvement. At present, the dividend distribution policies of Chinese listed companies are not optimistic. Generally speaking, the dividend level remains low and many enterprises fail to distribute any cash dividend. Therefore, it is necessary to promulgate corresponding rules for the supervision over listed companies, urging them to respect stockholders' interests and maintain a sufficiently high-level-cash dividend distribution, so as to guide investors to focus more on the performance and dividend policy of listed companies and guide investors to transfer their stock purchasing idea from short-term speculation to long-term investment. Therefore, the financing threshold of listed companies can be improved to guide investors to prudently treat enterprises with large financing constraints in order to avoid loss from blind speculation. Although this guidance will improve investors' assessment risk level for enterprises by virtue of larger financing constraints and increase the cost of capital correspondingly, it still helps investors avoid speculation loss, increase their long-term investment interest, and eventually increase their wealth.

Finally, in order to avoid excessive financial risk and increase of cost of capital resulting from the transmission of bad signals to the capital market, labor-intensive enterprises are supposed to maintain their best caution when paying corporate pensions. Limited funds must be spared to meet effective investment, normal operations, and payment of employee salaries, while the remaining funds should be used for the payment of corporate pensions.

5.3. Limitation and Further Research. This paper fails to analyze specific enterprises and lacks policy suggestions from specific case analysis. Individual enterprises can be selected for case analysis from the samples of labor-intensive enterprises, capital-and-technology-intensive enterprises, enterprises with effective income tax rate greater than 0 and less than 0, and enterprises with financing constraints greater than 0 and less than 0, so as to make further research on the impact of corporate pension payment on capital cost. Based on the principle of protecting the interests of shareholders, this paper further explores the rules to be followed in the payment of corporate pension for different types of enterprises.

Data Availability

Data are from CSMAR and RESSET databases (https://www.gtarsc.com/ and http://www.resset.cn/).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. N. Huu, S. N. La, H. H. Hanh, and D. McMillan, "Environmental accounting practices and cost of capital of enterprises in Vietnam," *Cogent Economics & Finance*, vol. 08, no. 1, pp. 1–20, 2020.

[2] J. D. Rauh, "Investment and financing constraints: evidence from the funding of corporate pension plans," *The Journal of Finance*, vol. 61, no. 1, pp. 33–71, 2006.

[3] F. Franzoni, "Underinvestment vs. Overinvestment: evidence from price reactions to pension contributions," *Journal of Financial Economics*, vol. 92, pp. 55–79, 2009.

[4] L. John, D. S. Campbell, W. C. Dhaliwal, and J. Schwartz, "Financing constraints and the cost of capital: evidence from the funding of corporate pension plans," *Review of Financial Studies*, vol. 25, no. 3, pp. 868–912, 2012.

[5] J. A. Michael and L. S. Neil, "Pension policy and the value of corporate-level investment," *Financial Management*, vol. 42, pp. 413–440, 2013.

[6] S. Brian, "Defined benefit pension de-risking and corporate risk-taking," *Financial Management*, vol. 50, pp. 1085–1111, 2021.

[7] D. Berchtold, O. Dichter, C. Loderer, and U. Waelchli, "Pension risk and corporate investment distortion," *Journal of Corporate Finance*, vol. 68, pp. 1–20, 2021.

[8] S. Moody, "Pension reform will increase funding requirements for under-funded U.S. Pension plans," *Moody's Investor Service, Inc. Ssm Electronic Journal*, vol. 8, pp. 4091–4026, 2006.

[9] P. L. Edward, "Pensions as severance pay," *Financial Aspects of the United States Pension System*, vol. 8, pp. 182–203, 1983.

[10] X. G. Chen, "Comparison of industrial labor-intensive industrial structure between Guangxi and China," *Academic Forum*, vol. 10, pp. 114–119, 2005.

[11] B. Chen and A. J. Zhang, "How does corporate social responsibility affect the cost of equity capital through operating risk?" *Borsa Istanbul Review*, vol. 21, pp. 38–45, 2021.

[12] T. D. Huynh, T. H. Nguyen, and C. Truong, "Climate risk: the price of drought," *Journal of Corporate Finance*, vol. 65, pp. 77–86, 2020.

[13] P. M. Romer, "Endogenous technological change," *Journal of Political Economy*, vol. 98, no. 5, pp. 71–102, 1990.

[14] X. Sun, H. Li, and V. Ghosal, "Firm -level human capital and innovation:evidence from China," *China Economic Review*, vol. 59, no. 21, pp. 1–15, 2020.

[15] A. Leiponen, "The benefits of R&D and breadth in innovation strategies: a comparison of finish service and manufacturing firms," *Industrial and Corporate Change*, vol. 21, no. 5, pp. 122–126, 2012.

[16] S. Charles, *Finance and Occupational Pensions*, 18 pages, Springer Science and Business Media LLC, Berlin/Heidelberg, Germany, 2016.

[17] S. Fateh and M. J. Sajjad, "Does the research done by the institutional investors affect the cost of equity capital?" *Finance Research Letters*, vol. 41, pp. 1–11, 2020.

[18] W. F. Sharpe, "Capital asset prices: a theory of market equilibrium under conditions of risk," *The Journal of Finance*, vol. 19, no. 3, pp. 381–391, 1964.

[19] P. D. Easton, "PE ratios, PEG ratios, and estimating the implied expected rate of return on equity capital," *The Accounting Review*, vol. 79, no. 1, pp. 73–95, 2004.

[20] N. Mokhova and M. Zinecker, "A survey of external and internal factors influencing the cost of equity," *Engineering Economics*, vol. 30, no. 2, pp. 173–186, 2019.

[21] S. Faysal, M. Salehi, and M. Moradi, "The impact of ownership structure on the cost of equity in emerging markets," *Management Research Review*, vol. 43, no. 10, pp. 1221–1239, 2020.
[22] A. I. Muslim and D. Setiawan, "Information asymmetry, ownership structure and cost of equity capital: the formation for open innovation," *Journal of Open Innovation*, vol. 7, no. 1, pp. 1–17, 2021.
[23] J. Franc-Dąbrowska, M. Mądra-Sawicka, A. Milewska, and S. Salkuti, "Energy sector risk and cost of capital assessment-companies and investors perspective," *Energies*, vol. 14, no. 6, 1613 pages, 2021.
[24] L. W. Jones, "Four factors influencing when to terminate a defined benefit plan," *Employee Benefit Plan Review*, vol. 72, no. 10, pp. 22–24, 2018.
[25] H. N. Duong, B. Qiu, and S. G. Rhee, "Golden handcuffs and corporate innovation: evidence from defined benefit pension plans," vol. 11, no. 1, pp. 128–168, 2022.
[26] J. Steele and L. Stefan, "Pension innovation," *Plans & Trusts*, vol. 32, no. 3, pp. 18–22, 2014.
[27] C. J. Hadlock and J. R. Pierce, "New evidence on measuring financial constraints: moving beyond the KZ index," *Review of Financial Studies*, vol. 23, no. 5, pp. 1909–1940, 2010.
[28] H. Gao, Z. Shen, Y. Li, X. Mao, and Y. Shi, "Institutional investors, real earnings management and cost of equity: evidence from listed high-tech firms in China," *Emerging Markets Finance and Trade*, vol. 56, no. 14, pp. 3490–3506, 2020.
[29] S. Ho and K. Wong, "A Study of Relationship between Corporate Government GovernanceStructure and the extent of voluntary disclosure," *Journal of International Accounting, Auditing and Taxation*, vol. 10, pp. 139–156, 2001.
[30] E. F. Fama and K. R. French, "The cross-section of expected stock returns," *The Journal of Finance*, vol. 47, pp. 427–465, 1999.
[31] X. Jun and X. Z. Xu, "An empirical study on the effectiveness of value reversal investment strategy in China's stock market," *Economic Research*, vol. 3, pp. 55–64, 2004.
[32] J. A. Ohlson and B. E. Juettner-Nauroth, "Expected EPS and EPS growth as determinants of value," *Review of Accounting Studies*, vol. 10, no. 2, pp. 349–365, 2005.
[33] H. B. Shen, "Market segmentation, cross-border listing and expected cost of capital -- Empirical evidence from Ohlson-Juettner model," *Financial research*, vol. 2, pp. 146–155, 2007.
[34] H. Ole-Kristian, T. Kang, B. T. Wayne, and Y. K. Yoo, "Impact of Excess Auditor Remuneration on Cost of Equity Capital Around the World," *Working paper*, vol. 24, no. 2, 2008.
[35] D. Gode and P. Mohanram, "Inferring cost of capital using the ohlson -juettner mode," *Review of Accounting Studies*, vol. 8, no. 4, pp. 399–431, 2003.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 4340553, 13 pages
https://doi.org/10.1155/2022/4340553

Research Article

Pension Security Level of Urban Employees in China Based on CHIPs

Chengyu Gao [1] **and Yake Wang** [2]

[1] *School of Insurance and Economics, University of International Business and Economics, Beijing 100029, China*
[2] *School of Finance, University of International Business and Economics, Beijing 100029, China*

Correspondence should be addressed to Chengyu Gao; 201600912014@uibe.edu.cn

Received 2 March 2022; Revised 23 March 2022; Accepted 25 March 2022; Published 16 April 2022

Academic Editor: Lele Qin

In 2019, the Chinese government has put forward comprehensive plan for reducing social insurance premium rate, which will affect the measurement of the pension security level. In order to evaluate the pension level, this paper uses CHIPs data from 1988 to 2018 to calculate "empirical" pension replacement rate by "empirical" method based on different wage calibers. The result shows that the pension replacement rate and income replacement rate of urban employees have gradually declined in the past 30 years. The pension level of nonprivate employees is lower than that of insured employees, and that of insured employees is lower than that of full-scale employees. The pension level of male, high-income groups, the older generation, organs, and institutions is much higher than that of female, low-income groups, the younger generation, and enterprises relatively. Compared with other countries, the pension replacement rate of urban employees in China is not low, but the income replacement rate is relatively low. This paper makes an in-depth analysis of the actual pension level under the new policy. As a result, it is necessary to vigorously develop multilevel and multipillar pension system such as enterprise annuity, occupational annuity, and commercial pension insurance, so as to improve the pension level of urban employees.

1. Introduction

Since the 21st century, China's per capita life expectancy has increased from 70.4 years in 2000 to 77.3 years in 2021, which promotes the increasingly serious problem of population aging. At the same time, according to the latest data of the seventh census released in 2021, the population aged 60 years and above of the Chinese mainland reached 264.02 million people, accounting for 18.7% of the national population, and the population aged 65 years and above reached 190.64 million, accounting for 13.5% at the end of 2020. Compared with the fifth national census in 2000, the proportion of people aged 60 years and above increased by 8.24%, and the proportion of people aged 65 years and above increased by 6.54%. Obviously, if we divide the degree of aging according to the international standard that "the population aged 65 years and above accounts for more than 7% or the population aged 60 years and above accounts for more than 10%," China has entered a deeply aging society, and the population structure will further age. This aging population phenomenon will also greatly increase the pension burden of families and society. In order to deal with this problem, the report of the 19th National Congress of the Communist Party of China clearly proposed comprehensively building a multilevel social security system with appropriate pension security level. Pension security system is an important part of social security. The Fourth Plenary Session of the 19th CPC Central Committee also stressed the importance of steadily improving the pension security level. In view of the demand for higher-level and higher-quality pension security, "the outline of the 14th five-year plan" proposes accelerating the development of multilevel and multipillar pension insurance system, improving the coverage of enterprise annuity, and standardizing the development of the third pillar pension insurance. In this context, it is of great theoretical and practical significance to choose which index to measure the actual level of pension security for urban employees in China, compare and evaluate it with

international empirical research, and then put forward policy suggestions to improve the pension security level in China, so as to provide an academic basis for accelerating the development of second and third pillar pension insurance. Relevant research has also become the focus of the government and academia.

Whether international or domestic research, there are relatively many studies on measuring the pension level by using the "institutional" pension replacement rate, but there are few studies on measuring the pension level by using the "empirical" pension replacement rate, especially domestic research. Under the policy background of the comprehensive scheme for reducing social insurance rates in 2019, this paper will measure the pension level under different wage calibers in China from 1988 to 2018 based on the "empirical" method, discuss with international research, and analyze the impact of the implementation of this scheme on the pension level. In addition, with the aggravation of China's aging population and the policy background that the government attaches great importance to improving the pension security level, it is of great significance to measure and analyze the actual pension security level of urban employees in China.

In terms of system construction, China's pension insurance system has developed for more than 20 years since the State Council officially promulgated the decision on establishing a unified basic pension insurance system for enterprise employees (GF [1997] No. 26) in 1997. The decision on improving the basic pension insurance system for enterprise employees (GF [2005] No. 38), published in 2005, improved the system and adjusted the proportion of individual accounts and the calculation and payment method of basic pensions, in which stipulated that the employer's contribution is 20% and individual contribution is 8%. According to the system design calculation, for urban employees who have worked for 35 years, the target replacement rate of basic pension insurance is 59.2%, of which the replacement rate of basic account pension is 35% and that of personal account pension is 24.2%. The target replacement rate includes the target replacement rate of basic pension and the target replacement rate of individual account pension. For standard beneficiaries who have continuously contributed for 35 years and retired at the age of 60 and whose contribution wage is equal to the social average wage, W_{average} is used to represent the average social wage, and then the target replacement rate of basic pension $= (W_{\text{average}} * 35 * 1\%)/W_{\text{average}} = 35\%$, and the target replacement rate of individual account pension $= (W_{\text{average}} * 8\% * 35 * 12)/(139 * W_{\text{average}}) = 24.17\%$. At the same time, in order to develop a multipillar pension system and make up for the lack of relying only on the first pillar, the Ministry of Labor and Social Security promulgated the Trial Measures for Enterprise Annuity in 2004, but so far the coverage is still limited and the growth rate of coverage is slow. According to the 2020 national enterprise annuity fund business data released by the Ministry of Human Resources and Social Security, the enterprise annuity coverage rate is only 6.8%, with an average annual growth rate of less than 1%. Therefore, it is still difficult to promote the development of the second pillar and give full play to the role of the second pillar in pension security.

The State Council issued the decision on the reform of the pension insurance system for staff of organs and institutions, officially ending the "two-track system" in 2015, merging the pension insurance system of organs and institutions with that of enterprises, and adopting the same system model, payment proportion, and payment method. This system reform will have a crucial impact on the pension security level of staff in organs and institutions. Relevant research has also attracted extensive attention in domestic academic circles. Many scholars believe that the reform will reduce the pension treatment of staff, so it is necessary to build a supporting occupational pension. It can be seen that it is also of great significance to measure the pension security level of organs and institutions before and after the system reform.

2. Literature Review

Internationally, scholars often use the index of pension replacement rate to measure the security level of pension insurance system and conduct international and interinstitutional comparative research (Whiteford, 1995; OECD, 2005; Mitchell and Phillips, 2006; Borella and Forner, 2009) [1–4]. Specifically, the pension replacement rate includes "institutional" and "empirical" calculation methods. "Institutional" refers to the ratio of the expected future pension income of employees to their personal wage income for representative individual characteristics, that is, the target replacement rate. This method needs to estimate pension income and wage income by assuming working years, social average wage growth rate, and other parameters (Whitehouse, 2007; European Union, 2009; OECD, 2021; Congressional Budget Office, 2019; S. Ba, 2022) [5–9]. The "empirical" pension replacement rate directly compares the pension of current retirees with the wage income of on-the-job employees. Most relevant studies use statistical survey data to directly measure the actual replacement rate level of current retirees, which can more accurately reflect the security degree of the pension system [10, 11]. Among them, some studies calculate the pension replacement rate in different countries based on the average wage of on-the-job employees [12, 13]. In addition, the replacement rate level at all levels is calculated based on the total and net average wage income or median wage income [14, 15]. In addition, some scholars have analyzed the differences of pension replacement rate among different groups such as the nature of different units, age, gender, and marital status [16–21].

In domestic academic circles, there are many studies on using the "institutional" replacement rate index to measure the pension security level, including measuring the security level of different pension systems such as organs and institutions, enterprise employees, and enterprise annuity [22–24]. There are few studies based on the "empirical" pension replacement rate. Some studies mainly use the official statistical data to calculate the overall average wage of employees and take this as the caliber to calculate and analyze the difference of security level between enterprises and organs or different regions (Wang Xiaojun and Qiao Yang, 2007; Wang Xiaojun and Zhao Tong, 2006) [25, 26]. Li

Shi et al. (2013), based on the income data from CHIPs 1988 to 2007, measured the pension security level of urban retirees in China by using the "empirical" replacement rate index with two dimensions: the average wage of full-scale employees before retirement and the average wage of employees close to five years before retirement [27].

In conclusion, it can be seen that, due to the relative lack of micro statistical data in China, especially the long-term follow-up survey data, there are relatively few studies on using "empirical" indicators to measure the pension security level in China. This paper attempts to solve the following problems: in the process of the gradual reform of the pension insurance system for urban employees in China, what is the development trend of the actual security level of the pension system? What is the impact of different wage caliber on measuring the pension security level? What are the differences in the pension level of different income levels, the nature of the organization, the level of education, and different gender and age groups? How much has the pension level of organs and institutions decreased? Compared with other countries in the world, how much is the pension security level for urban employees in China?

Compared with the existing literature, the main contributions of this paper are as follows: first, based on the "empirical" replacement rate indicator, the six CHIPs data from 1988 to 2018 are used to calculate and analyze the actual level of pension security for urban employees in China and make some international discussions; second, relying on the comprehensive plan for reducing social insurance rates issued in 2019, the calculation standard of average wage is adjusted from the average wage of on-the-job employees of urban nonprivate units to the average wage of full-scale employees weighted by urban nonprivate units and private units, so as to reduce the burden of social security payment. According to the data of the National Bureau of Statistics, in 2019, the average wage of on-the-job employees in urban nonprivate units in China was 93383 yuan, while the average wages of employees in nonprivate and private units were 90501 yuan and 53604 yuan, respectively, so the weighted average wage of full-scale employees was 73561 yuan (average wage of full-caliber employees = (average wage of employees in urban non private units ∗ number of employees in urban nonprivate units + average wage of employees in urban private units ∗ number of employees in urban private units)/(number of employees in urban nonprivate units + number of employees in urban private units)). Since the National Bureau of Statistics has not published the number of employees in private units in 2020, for this reason, only 2019 values have been calculated. It can be seen that the average wage of full-scale employees is significantly lower than that of on-the-job employees in nonprivate units and also lower than that of employees in nonprivate units. Obviously, this adjustment plan is bound to affect the measurement of the pension security level of urban employees in China, but how will it affect, increase, or decrease? From the perspective of insured employees, is their security level higher or lower than that of nonprivate units and higher or lower than that of full-scale employees? Therefore, this paper will measure the replacement rate level under different wage caliber and analyze the impact of the comprehensive fee reduction scheme on the measurement of pension security level. The third is to make an in-depth analysis of the differences in the pension level among different income levels, the nature of the unit, the level of education, and different gender and age groups, especially whether the reform of organs and institutions will reduce the security level of their staff and how to compare with enterprise employees in order to provide academic basis and development direction for future policy reform.

3. Research Method

3.1. Research Method. This paper adopts the "empirical" calculation method of the pension replacement rate, which can evaluate the actual security level more accurately. Firstly, according to whether the pension and wage income are gross or net, the pension replacement rate can be divided into total pension replacement rate and net pension replacement rate [28]. However, the estimation of total pension replacement rate ignores social security contributions and individual income tax, which will underestimate the relative benefits of pension [29, 30]. The wage income of on-the-job employees in China needs to pay social security contributions and individual income tax, while the pension income of retirees does not need to pay, so the net pension replacement rate can measure a more real security level.

$$\begin{aligned}
\text{Total pension replacement rate} &= \frac{\text{total pension}}{\text{total wage income}},\\
\text{Net wage income} &= \text{total wage income} - \text{individual income tax} - \text{social security fee},\\
\text{Net pension replacement rate} &= \frac{\text{net pension}}{\text{net wage income}}.
\end{aligned} \tag{1}$$

Secondly, the income replacement rate refers to the ratio of retirement income including pension and all other retirement incomes to the total income of active employees [20, 31, 32]. Income replacement rate integrates all sources of income after retirement and measures the overall living security level of retirees. Generally speaking, the income replacement rate is higher than the pension replacement rate; especially in countries with developed multipillar

pension system, the income after retirement does not only come from the basic pension [12, 15]. (Retirement income should include cash income, employer pension, private pension, investment income, government noncash subsidies, and savings; the income of on-the-job employees should include wages and other labor incomes, investment income, and government noncash subsidies; the expenditure before and after retirement includes direct tax and indirect tax (Whiteford, 1995).) The net income replacement rate is similar to the net pension replacement rate. The corresponding net value is obtained by subtracting social security contributions and individual income tax from the income before and after retirement, so as to measure the more real income security level.

$$\text{Total income replacement rate} = \frac{\text{total retirement income}}{\text{total income of active employees}},$$
$$\text{Net income replacement rate} = \frac{\text{net retirement income}}{\text{net income of active employees}}. \tag{2}$$

Finally, in the specific calculation of pension replacement rate, the choice of wage income caliber will also have a great impact on the results. Generally, it can be divided into the average wage of employees in nonprivate units and the average wage of employees in private units. Most previous studies have only calculated the pension replacement rate level under the average wage of employees in nonprivate units, and the result is low. If the average wage of full-caliber employees is measured, the actual replacement rate level may not be very low. Therefore, when calculating the total and net pension replacement rate and total and net income replacement rate, this paper will calculate them by different wage caliber and use multiple indicators to more comprehensively measure and effectively evaluate the security level of the pension insurance system.

3.2. Data. The data of this paper comes from the six urban household survey data CHIPs (Chinese household income project survey) of China Income Distribution Research Group from 1988 to 2018. This survey spans the 30-year process from the establishment of the pension insurance system to the establishment and perfection of the system, which can better reflect the historical changes of the pension insurance security level of urban employees. CHIP1988 covers 10 provinces, cities, and autonomous regions in Beijing, Shanxi, Liaoning, Jiangsu, Anhui, Henan, Hubei, Guangdong, Yunnan, and Gansu. It is the first micro sampling survey conducted in China using international standards and statistical methods. CHIP2018 removed Fujian and Xinjiang and added Inner Mongolia and Shandong, a total of 12 provinces, municipalities, and autonomous regions (municipalities directly under the central government). CHIP2007 further added Shanghai, Zhejiang, Fujian, and Hunan, a total of 16 provinces and autonomous regions (municipalities directly under the central government) on the basis of 2002. CHIP2013 removed Shanghai and Zhejiang provinces (municipalities directly under the central government) from the provinces in 2007 and added Xinjiang, a total of 15 provinces, municipalities, and autonomous regions (municipalities directly under the central government). CHIP2018 is based on 2013. In addition to Fujian and Xinjiang, Inner Mongolia and Shandong are added, with a total of 15 provinces, municipalities, and autonomous regions (municipalities directly under the central government). Among them, the data covers 15 provinces, cities, and autonomous regions (municipalities directly under the central government) in Beijing, Shanxi, Liaoning, Jiangsu, Anhui, Henan, Hubei, Guangdong, Yunnan, Gansu, Sichuan, Chongqing, Fujian, Inner Mongolia, and Shandong. The survey covers different cities and regions in the east, central, and western regions, including pensions, wages, and other income conditions of different caliber and different groups, so that the actual level of pension security can be measured in an all-round way.

Since the legal retirement age in China is 60 years for male employees, 50 years for female employees, and 55 years for female cadres, the pensions in the CHIPs data analyzed in this paper are mainly concentrated in the people who have reached the age of 50 and enjoy pension benefits. At the same time, the sample of urban employees with wage income and relatively stable jobs is mainly concentrated in men aged 16–59 years and women aged 16–54 years. Total wage income mainly refers to the broad wage income including basic wage, post wage, performance wage, and various allowances and subsidies.

Table 1 makes descriptive statistics of the data by using Stata software. Among them, the employees of nonprivate units include the employees of party and government organs, institutions, state-owned and holding enterprises, collective enterprises, and foreign-invested or joint ventures; in addition, the full-caliber employees also include those of private and individual enterprises but do not include the employees of land contractors and other units. It can be seen from the table that the pension and wage income of urban employees in China have increased significantly in the 30 years from 1988 to 2018. The average wage has increased by about 53–55 times, while the pension has increased by more than 30 times.

4. Results and Analysis

4.1. Pension Security Level under Different Wage Caliber. According to the annual pension, wage income, retirement income, and on-the-job employee income of CHIPs from

Table 1: Descriptive statistics of data (unit: yuan, sample size: piece).

Year	Variable	Mean	Median	Minimum	Maximum	Sample size
1988	Pension	1188	1090	36	4566	2131
	Wages (nonprivate)	1404	1298	126	21002	9134
	Wages (nonprivate + private)	1332	1198	126	21002	15418
	Wages (insured employee)	1403	1298	126	21002	9541
1995	Pension	4575	4093	100	21980	2562
	Wages (nonprivate)	6019	5476	100	55407	9199
	Wages (nonprivate + private)	5807	5252	100	55407	10952
	Wages (insured employee)	5937	5300	100	55407	9581
2002	Pension	8104	7000	100	64355	3228
	Wages (nonprivate)	12735	11435	120	144530	6518
	Wages (nonprivate + private)	11894	10422	100	144530	8461
	Wages (insured employee)	12522	11059	100	144530	7205
2007	Pension	14901	12989	100	75320	5568
	Wages (nonprivate)	24997	20075	282	271623	11526
	Wages (nonprivate + private)	23683	18900	200	271623	13235
	Wages (insured employee)	24640	19742	282	271623	12185
2013	Pension	22847	18754	120	126680	4555
	Wages (nonprivate)	49600	41904	240	800000	4243
	Wages (nonprivate + private)	44673	36313	198	1170000	7296
	Wages (insured employee)	48578	40000	240	1170000	5293
2018	Pension	37156	34786	150	211882	3961
	Wages (nonprivate)	77758	67283	156	1117000	4878
	Wages (nonprivate + private)	71039	57831	156	1117000	9046
	Wages (insured employee)	75544	62645	156	1117000	6334

Source: authors' calculations by using CHIPs data.

1988 to 2018, the "empirical" pension replacement rate and income replacement rate under different caliber are calculated, respectively. The results are shown in Table 2. First of all, the level of pension replacement rate showed a downward trend in the 25 years from 1988 to 2013. It only increased slightly from 2013 to 2018 but decreased by about 38 percentage points as a whole. Taking the total pension replacement rate of full-scale employees, insured employees, and nonprivate employees as an example, the decline of the three is the same in each year. For example, it decreased by 8–10 percentage points from 1988 to 1995, by 10–13 percentage points in 2002, by about 4 percentage points in 2007, and by about 13 percentage points in 2013 but rose slightly by about 2 percentage points until 2018. However, the total pension replacement rate in 2018 was below 53%, still far below the target replacement rate of 59.2%. It can be seen that, in recent years, China's pension insurance policy reform has played a role in improving pension treatment and improving the pension security level, but there is still a gap from the expected goal.

The gradual decline of pension replacement rate is mainly because the average annual growth rate of wage is faster than that of pension, but the decline degree in different periods mainly depends on the gap between wage growth rate and pension growth rate in different periods. (The National Bureau of Statistics and the Ministry of Human Resources and Social Security focused on the wages of nonprivate units. Whether employed or on-the-job employees, the average annual growth rate of nominal nonprivate wages in China was about 18% from 1988 to 1995, 13% from 1995 to 2002, 15% from 2002 to 2007, 14% from 2007 to 2013, and 10% from 2013 to 2018. According to the adjustment mechanism on the basic pension of retirees issued by the Ministry of Human Resources and Social Security and the Ministry of Finance, the average annual growth rate of pension treatment was 10% from 2005 to 2015 and decreased to 6.5%–5% from 2016 to 2018. It can be seen that the more the wage growth rate was higher than the pension growth rate, the more the replacement rate decreased. In addition, inflation accelerates the growth rate of nominal wage, making the wage growth rate faster than the pension growth rate, which further leads to the decline of pension replacement rate.) According to CHIPs data, the specific growth rate of both can be seen in Figure 1. It can be seen that the average annual wage growth rate from 1988 to 2007 was about 2 percentage points higher than the average annual pension growth rate, while it was about 5 percentage points higher from 2007 to 2013, resulting in a gradual decline in the pension replacement rate from 1988 to 2007 and a bigger decline from 2007 to 2013. From 2013 to 2018, the average annual growth rate of wages was about 1 percentage point lower than that of pensions, which increased the pension replacement rate from 2013 to 2018. It can be seen that the more the wage growth is higher than the pension growth, the more the pension replacement rate decreases. When the wage growth is lower than the pension growth, the pension replacement rate will rise.

Secondly, from the perspective of income replacement rate, no matter what the caliber, it also showed a downward trend in the 25 years from 1988 to 2013, increased slightly in 2018, and still decreased by 30 percentage points as a whole. Taking the total income replacement rate of full-caliber

Table 2: Pension replacement rate and income replacement rate of urban employees in China.

	Caliber division	1988 (%)	1995 (%)	2002 (%)	2007 (%)	2013 (%)	2018 (%)
Total pension replacement rate	Nonprivate	84.62	76.01	63.64	59.61	46.06	47.77
	Nonprivate + private	89.19	78.78	68.14	62.92	51.14	52.29
	Insured employee	84.68	77.06	64.72	60.47	47.03	49.17
Net pension replacement rate	Nonprivate	84.62	76.72	69.33	68.04	48.56	52.39
	Nonprivate + private	89.19	79.54	74.08	71.45	53.76	56.20
	Insured employee	84.68	77.71	70.99	68.33	49.73	53.67
Total income replacement rate	Nonprivate	88.16	76.41	68.54	66.32	52.69	56.95
	Nonprivate + private	91.05	80.09	72.68	69.81	58.33	60.37
	Insured employee	88.72	77.26	69.38	67.17	53.16	58.09
Net income replacement rate	Nonprivate	88.16	77.00	78.98	74.80	55.35	61.55
	Nonprivate + private	91.05	80.67	83.93	78.35	61.01	64.42
	Insured employee	88.72	77.84	80.52	75.81	56.07	62.52

Source: authors' calculations by using CHIPs data.

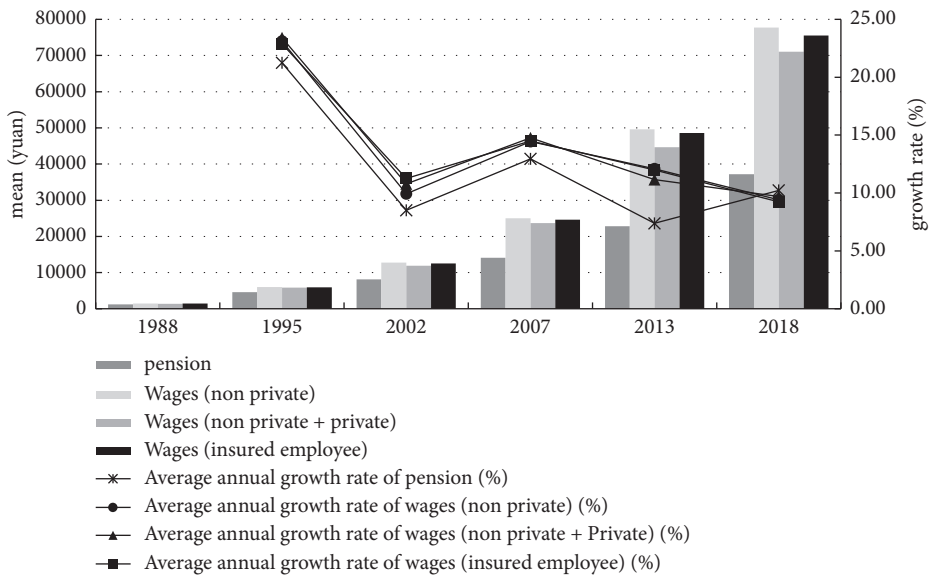


Figure 1: Average value and average annual growth rate of total pensions and total wages.

employees, insured employees, and employees in nonprivate units as an example, the replacement rate under the three calibers decreased by about 11 percentage points from 1988 to 1995, about 8 percentage points in 2002, about 3 percentage points in 2007, and nearly 13 percentage points in 2013 but rose slightly 2–4 percentage points in 2018.

At the same time, it is also found that the income replacement rate is always higher than the pension replacement rate, 1–9 percentage points higher, because retirement income also includes other incomes except pension income. In view of the situation that China's pension pillar is "dominated by one" and the development of the second and third pillar pension insurance is relatively lagging behind, in most years, the degree of income replacement rate higher than pension replacement rate is not high.

In addition, Table 2 also shows that the pension security level of nonprivate employees in each year is lower than that of insured employees, and that of insured employees is lower than that of full-caliber employees. This is because the average wage of employees in nonprivate units, including organs and institutions, as well as state-owned and collective enterprises, is usually higher than that in private units, so that the average wage of full-caliber employees is lower than that in nonprivate units and higher than that in private units, so the replacement rate is naturally higher than that in nonprivate units. The average wage of insured employees is the product of the average wage of nonprivate employees and their own wage index. This index is the ratio of individual actual contribution wage to social average wage, which is generally greater than zero and less than one. Therefore, the average wage of insured employees is lower than that of nonprivate employees and higher than that of full-caliber employees, so the replacement rate is between the two.

Finally, it can be seen from Table 2 that the net replacement rate of pension also showed a downward trend from 1988 to 2013 and rebounded in 2018, but it still decreased by more than 30 percentage points as a whole. For example, the net replacement rate of full-caliber employees decreased from 89.19% in 1988 to 53.76% in 2013 and

increased to 56.20% in 2018. In addition, because the individual income tax and pension insurance system have not been implemented in 1988, the total and net replacement rates are the same. After that, the net replacement rate of pension is always higher than the total replacement rate, less than 1 percentage point higher in 1995 and 2–8 percentage points higher in 2002–2018. This is because employees need to pay social security contributions and personal income tax but do not need to pay after retirement, which makes the pension replacement rate higher when taking the net wage income as the measurement standard. It can be seen that taking into account the impact of social security contributions and individual income tax also plays an important role in measuring the pension level in China, which can more accurately measure the actual security level of employees.

4.2. Pension Level among Different Social Groups. In this paper, for different groups, the difference of pension security level calculated based on nonprivate and full-caliber wages is similar. Therefore, this paper selects the total social average wage income of full-caliber employees as the denominator to calculate the pension replacement rate of different socio-economic groups, so as to measure the difference of pension security level between different groups.

4.2.1. Different Income Levels. Based on different income, the pension level varies greatly. In this paper, the pension income of retirees is divided into five groups and compared with the total average wage of employees from the lowest to the highest income group, which is relative level of pension, so as to calculate the pension security level under each income group. The results are shown in Figure 2. Obviously, the pension security level of different income groups increases with the increase of income groups. For example, in 2018, the pension replacement rates of the lowest to highest income groups were 14.34%, 38.27%, 49.49%, 63.60%, and 99.38%, respectively. Only the highest and second highest (fourth) income groups reached the target replacement rate of 59.2%. Among them, it is worth noting that the security level of the highest and lowest income groups decreased significantly from 2013 to 2018, while the security level of the second, third, and fourth income groups increased. It can be seen that the redistribution effect between different income groups occurs more in the transfer of the highest and lowest to the middle-income group.

From the perspective of different income groups, the security level of the middle-income group from 1988 to 2018 was 82.36%, 77.82%, 59.07%, 54.66%, 43.62%, and 49.49%, respectively, while that of the lowest income group remained at 14%–45%, about half of that of the middle-income group. The security level of the highest income group decreased from 147.15% in 1988 to 99.38% in 2018. The pension security level of the high-income group was 3–5 times that of the low-income group and twice that of the middle-income group. It can be seen that the pension treatment of high-income group is higher relative to the social average wage, and the pension security level is higher, while the pension of low-income group is relatively low, which is difficult to ensure the basic living standard after retirement.

4.2.2. Different Age Groups. As the pension security level among different age groups of retirees is also quite different, this paper divides the groups aged 50 years and above with pension into one group every five years, compares them with the average wage of employees, and analyzes the difference of pension security level among different age groups, so as to evaluate the redistribution effect between generations. Figure 3 shows the pension level of retirees in different age groups relative to social average wage. Obviously, the security level of different age groups is obviously different, and the characteristics of different periods are also different. From the change trend in various years, the pension security level of retirees aged 60–64 years was the highest in 1988, aged 65–69 years in 1995, 70–74 in 2002, 75–79 in 2007, and above 79 in 2013 and 2018. It is obvious that the older the age is, the higher the security level is in 2013 and 2018. From 1988 to 2013, a gradual change trend was shown. It can be seen that the pension security level of people born in the 1930s has been at the highest level compared with other age groups, while that of those born in other ages was lower, which reflects that the design of pension insurance system has a significant intergenerational transfer effect.

4.2.3. Gender Grouping. Due to the different working years, wage level, and retirement age of males and females, their pension security levels are naturally different. This paper analyzes the pension security levels of different genders, and the results are shown in Figure 4. It is obvious that the pension security level of males is higher than that of females in all years. From the long-term trend from 1988 to 2018, the pension security levels of males and females were 103.98% and 76.43%, respectively, in 1988, with a difference of about 28 percentage points, and 78.73% and 59.54%, respectively, in 2002, with a difference of about 19 percentage points, but then began to shrink gradually. They were 57.68% and 46.38%, respectively, in 2013. Males were only about 12 percentage points higher than females, but the difference widened slightly in 2018, 60.23% and 46.34%, respectively, about 14 percentage points higher. Obviously, the pension replacement rate of males has reached the level of the target replacement rate, while that of females needs to be improved. Because the legal retirement age of males in China is 60 and those of female cadres and workers are 55 and 50, the late retirement age and long contribution years of males also make their pension treatment relatively high, so their pension security level will be higher than that of females.

4.2.4. Nature of Different Units. In China, before the insurance system reform in 2015, the pension insurance system of government organs and institutions implemented a two-track pension system with enterprise; that is, the staff of government organs and institutions do not need to pay, and the pension is paid according to a certain proportion of the last year's wage after retirement, which only involves the

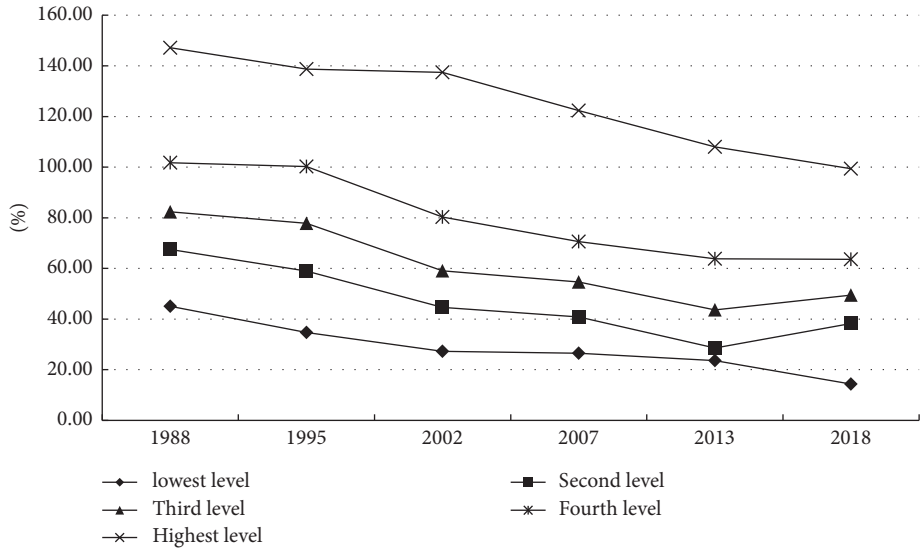


Figure 2: Pension security level of different income level.

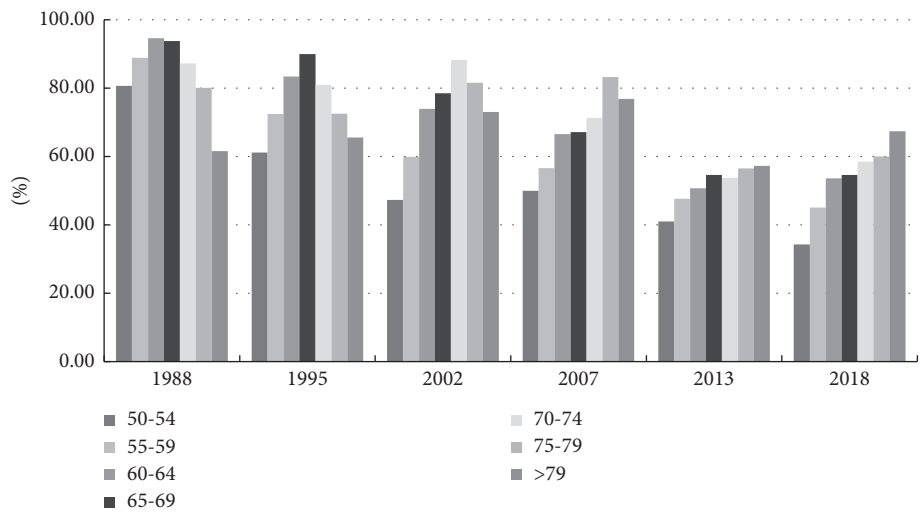


Figure 3: Pension security level of different age groups.

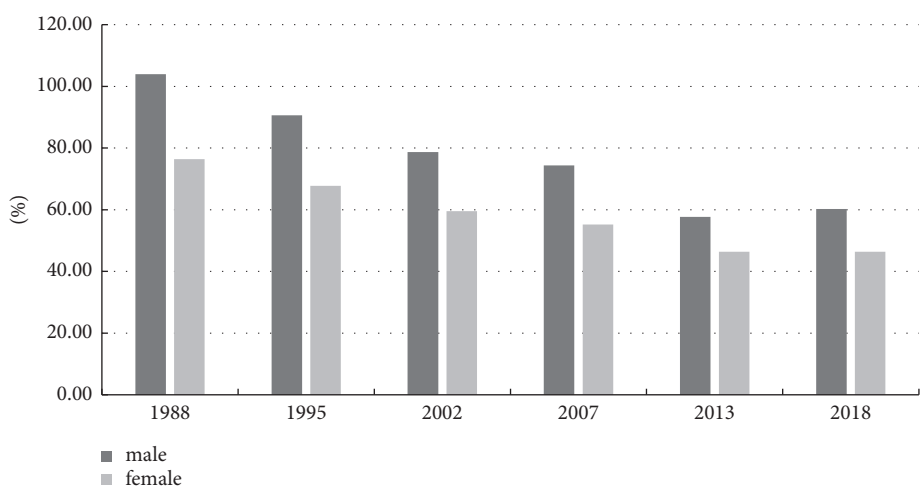


Figure 4: Pension security levels of males and females.

public account, while the enterprise employees need to pay jointly by enterprises and individuals. After retirement, they receive pensions according to a certain proportion of the contribution base, resulting in a great difference in pension treatment between the two groups. After the "system merger" in 2015, the two groups will implement the same contribution and payment methods. According to the six CHIPs data surveys from 1988 to 2018, a specific distinction survey was conducted in 1995, 2002, 2013, and 2018 on whether urban employees worked in enterprises or government institutions before retirement. Therefore, using this information, we can compare the differences of pension security levels between the two groups from 1995 to 2018.

For the retirees working in the enterprise before retirement, the pension replacement rate is the ratio of their pension income to the average wage income of the enterprise employees, and the pension relative level is the ratio of their pension income to the average wage of all employees, that is, the social average wage. Both of these can be used to measure the level of their pension security. Similarly, for those who work in organs and institutions before retirement, the ratio of their pension income to the average wage of employees working in organs and institutions is their pension replacement rate, while the ratio of their pension income to the average wage of all employees is their pension relative level. In this paper, the two indicators of enterprises and institutions are calculated, respectively, and the results are shown in Figure 5. For convenience, we use QPR and JPR to represent the pension replacement rate results of enterprises and institutions and QRR and JRR to represent the relative level results of enterprises and institutions.

As can be seen from Figure 5, the pension relative levels of government institutions and enterprises were 106.22% and 67.75%, respectively, in 1995 and 104.63% and 58.79%, respectively, in 2002. The pension relative levels of government institutions were about 38 and 47 percentage points higher than those of enterprises, respectively, in 1995 and 2002. The pension relative levels of government institutions and enterprises were 71.34% and 46.45%, respectively, in 2013. After the merger of pension system in 2015, they increased to 73.74% and 48.07%, respectively, in 2018. The pension relative level of government institutions was about 25 percentage points higher than that of enterprises in 2013 and 2018. Obviously, the gap between the two groups is gradually narrowing.

In terms of pension replacement rate, the results of government institutions and enterprises from 1995 to 2018 were 96.39% and 71.18%, 90.06% and 66.57%, 66.42% and 46.53%, and 64.22% and 50.87%, respectively. The pension replacement rate of government institutions was about 25 percentage points higher than that of enterprises in 1995 and 2002, while there were only about 20 and 13 percentage points in 2013 and 2018. It can be seen that the integration of pension system has indeed significantly reduced the gap in the pension level between organs, institutions, and enterprises.

In more than 20 years from 1995 to 2018, the relative level and replacement rate of pensions in government organs and institutions decreased by about 32 percentage points, and those of employees in enterprises also decreased by about 20 percentage points. Among them, the pension relative level in government institutions is always higher than its own pension replacement rate, while the pension relative level in enterprises is always lower than its own pension replacement rate. In other words, the pension treatment of enterprise employees is lower relative to the social average wage and slightly higher relative to their own wage level, while the pension treatment of organs and institutions is just the opposite of that of enterprises. Obviously, whether measured by the replacement rate index or the relative level index, the pension security level of organs and institutions is always relatively high, which can ensure that their living standard will not decline after retirement, but that of enterprise employees is relatively low, far below the target replacement rate 59.2%, and cannot maintain half of own income before retirement.

4.2.5. Different Education Level. The education level of pensioners aged 50 years and above is divided into primary school and below, junior middle school, senior high school, technical secondary school, junior college, and university and above. Comparing the pension income of each group with the social average wage income, it is also found that the difference of pension security level is also reflected in different education levels.

As can be seen from Figure 6, from 1988 to 2018, the pension security level increased with the education level, and the pension level of technical secondary school and above education group was significantly higher than those of the other education groups. Specifically, in 1988, it increased from 76.80% in the primary school and below education group to 129.88% in the university and above education group, from 63.13% in the minimum education group to 114.45% in the maximum education group in 1995, from 53.80% to 111.39% in 2002, from 47.41% to 108.66% in 2007, and from 41.21% to 81.02% in 2013. In 2018, the pension level results under various education levels were 42.96%, 47.27%, 50.43%, 65.99%, 64.29%, and 84.06%, respectively.

It can be seen that the pension treatment of retirees with technical secondary school and above education level is more than 60%, which fully meets the level of the target replacement rate, and can ensure that the living standard after retirement is maintained at a high level, while the pension treatment of senior high school and below education level is low, at 50% and below, which is inadequate security level and pension treatment. This is because those with higher education level naturally have higher wage income and large contribution base. According to the contribution principle of "contribute more, get more," after retirement, they also get relatively high pension treatment and higher security level.

5. Discussion

By means of comparison with the level of pension replacement rate in the world, which is used to evaluate the pension security level in China and make some discussions,

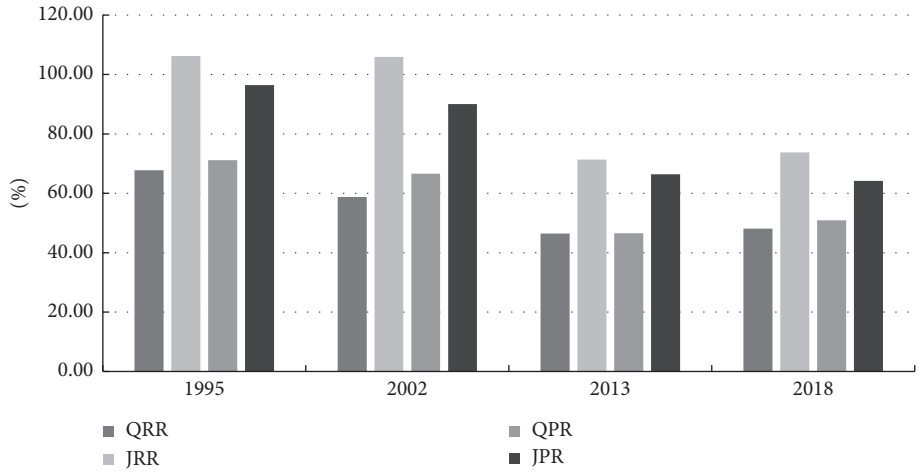


Figure 5: Pension security level of employees in enterprises, organs, and institutions.

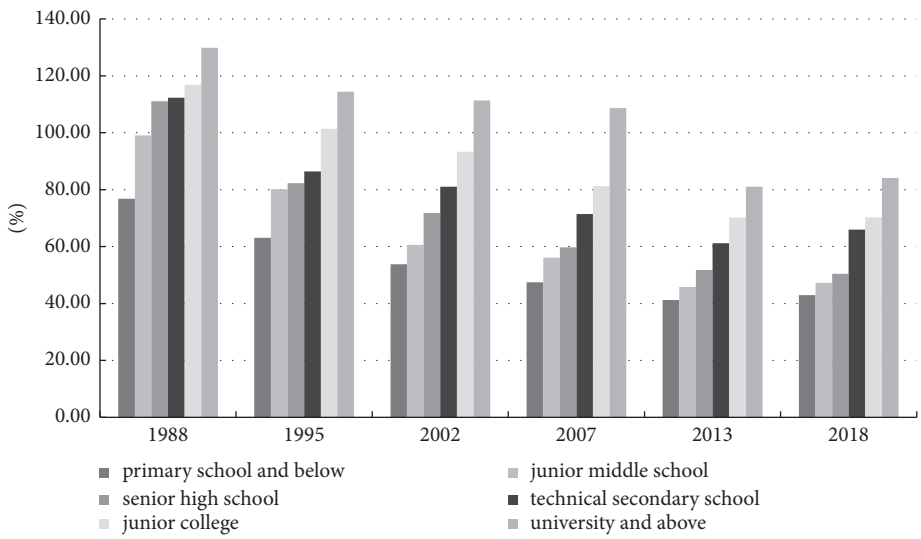


Figure 6: Pension security level under different education levels.

this paper collects the "empirical" replacement rate research consistent with the index caliber of this paper, that is, the results based on the full-caliber wage caliber. Because of the need for more detailed micro income data, there are not many new "empirical" results calculated with a full caliber in the world. For the pension replacement rate, the official website of the European Union will regularly update the relevant data every year. This paper collects the calculation results in 2018. Its caliber is the ratio of the median pension of retirees aged 65–74 years to the median wage of employees aged 50–59 years (Eurostat, 2019) [33]. For the income replacement rate, the paper collected the OECD calculation results in 2001. Its caliber is the ratio of the net average income of retirees aged 65–74 years to the net average income of employees aged 51–64 years (OECD, 2001) [34].

Similarly, for comparison and discussions, this paper uses the median pension of retirees aged 65–74 years and the median wage of employees aged 50–59 years in CHIPs data in 2018 to calculate the corresponding pension replacement rate and uses the net retirement income of retirees aged 65–74 years and the net average income of employees aged 51–64 years to calculate the corresponding income replacement rate, compared with international indicators, so as to better evaluate the pension security level in China.

Table 3 reports the international comparison of pension security levels under the two indicators of pension replacement rate and income replacement rate. From the perspective of pension replacement rate, China's pension replacement rate is not low compared with most EU countries, reaching 69%, higher than the average level of the EU and higher than that of almost all developed countries. It can be seen that China's basic pension insurance for urban employees has a relatively high security level and can meet the basic life level of retired elderly people.

However, from the perspective of income replacement rate, it is found that the retirement income replacement rate of nine OECD developed countries is at the level of 70%–90%, while that of China is relatively low, only 66%. It can be seen that although China has established a relatively mature pension insurance system, so the pension security

Table 3: Pension security levels in some countries (China and EU in 2018 and OECD in 2001).

European Union	Pension replacement rate (%)	European Union	Pension replacement rate (%)	OECD	Income replacement rate (%)
Italy	73	Netherlands	53	Canada	87
Spain	70	Romania	51	Germany	84
France	67	Belgium	50	Netherlands	81
Portugal	67	Czech republic	50	United States	80
Austria	62	Switzerland	50	Japan	80
Poland	60	Denmark	49	Italy	79
Hungary	59	Germany	46	Sweden	76
Norway	58	Lithuania	40	Finland	76
Sweden	56	Ireland	35	United Kingdom	74
United Kingdom	55	European Union (mean)	55	OECD (mean)	80
Finland	54	China	69	China	66

Source: the data of China (2018) are calculated by the author, using Stata measurement software according to CHIP 2018, and the data of EU are from Eurostat (2019); OECD (2001) data come from aging and income: financial resources and retirement in nine OECD countries.

level is not low, the pension pillar is relatively single, mainly relying on the basic pension insurance system of the first pillar, while the second and third pillars such as enterprise annuity and commercial pension insurance are not fully developed; that is, the development of different pillars is seriously unbalanced. As a result, the replacement rate of retirement income is relatively low. Therefore, we should speed up the construction of multipillar and multilevel pension system. On the premise of maintaining the continuous growth of the absolute pension value, we should appropriately reduce the replacement rate of basic pension and increase the replacement rate of other pillar pensions, so as to ensure that the basic living standard of retired elderly people will not continue to decline.

6. Conclusions and Policy Recommendations

6.1. Conclusions. Based on the data of six CHIPs household income surveys of urban households from 1988 to 2018, this paper calculates and analyzes the actual level of pension security for urban employees in China based on multiple indicators such as pension replacement rate and income replacement rate and measures them, respectively, according to different wage caliber, so as to more accurately measure and evaluate the actual level of pension security. The results show that the pension replacement rate under any caliber decreased from about 90% in 1988 to about 50% in 2018. The income replacement rate is higher than the pension replacement rate, but it also shows a downward trend, from about 90% in 1988 to about 60% in 2018. Moreover, based on the background of the comprehensive plan for reducing social insurance premium rate in 2019, in view of the wage income under different caliber, the replacement rate level under nonprivate caliber is always lower than that of insured employees, and that of insured employees is lower than that under full caliber. It can be seen that different measurement indicators and measurement caliber will have a crucial impact on the evaluation of the pension level. As a result, comprehensive plan for reducing social insurance premium rate in 2019 will improve the replacement rate level of urban employees by adjusting wage caliber.

In addition, the pension security level under different income levels increases with the increase of income group. The pension security level in low-income group is low, while that in high-income group is high. The pension security level of different age groups showed a positive correlation with age in 2013 and 2018, indicating that pension insurance system played a redistribution effect of transferring from the younger generation to the older generation. The pension security level of males is 12–28 percentage points higher than that of females. The pension replacement rate of government organs and institutions is 13–25 percentage points higher than that of enterprises, and the pension relative level is 25–47 percentage points higher than that of enterprises. Both of them decreased by 18–30 percentage points in more than 20 years from 1995 to 2018. Compared with international empirical research, it is found that the pension replacement rate of urban employees in China is not low, but the income replacement rate is low.

6.2. Policy Recommendations. In view of the gradual decline of the replacement rate in the 30 years from 1988 to 2018, in order to ensure the pension security level of urban employees after retirement, the following suggestions are put forward: First of all, taking into account the factors such as the extension of China's per capita life expectancy, the deepening of population aging, the increase of education level, and the change of labor structure, we can gradually delay the legal retirement age based on the principles of small-step adjustment, flexible implementation, classified promotion, and overall consideration and improve the pension security level. Secondly, there are great differences in the security levels among different income groups; in particular, those in the high-income group are much higher than those in the low-income group. It can be seen that, in order to improve the pension security level in China, it is bound to improve and perfect the pension treatment

adjustment mechanism, improve the treatment level of low-income groups, and promote the social public basic pension to play a greater redistribution effect. The difference in the security level of different age groups is due to the discontinuity and ups and downs in the process of policy reform. Therefore, we should ensure the stability of future policies and carry out gradual reform, because a certain system guarantee is also an important measure and content to steadily improve the pension security level in China. Finally, in order to improve the income replacement rate, some measures should be taken to encourage the development of enterprise annuity and commercial pension insurance, such as preferential tax policies. At the same time, expand the coverage of the second and third pillars, improve the pension replacement rate of corresponding pillars, and make up for the insufficient level of retirement income security caused by relying only on the basic pension of the first pillar, actively improving the pension security level of urban workers in China.

7. Limitations and Further Research

7.1. Limitations. On the one hand, the calculation of pension replacement rate is not comprehensive enough. Based on the six CHIPs micro data from 1988 to 2018, this paper calculates and analyzes the "empirical" pension replacement rate and better reflects the historical changes of the actual pension security level of China's urban employees in recent three decades. However, because there are no long-term micro tracking survey data, we can only use the wages of on-the-job employees and the pensions of retirees in the same year to calculate the overall average pension replacement rate in the current period, that is, the horizontal pension replacement rate, but cannot calculate the vertical pension replacement rate for the individual life cycle based on the income difference before and after retirement. On the other hand, it is difficult to accurately unify the income caliber. Due to historical changes, the income caliber of CHIPs data is slightly different in the annual survey. For example, the severance pay was a transfer income in 2002 and 2007, but it was a part of wage income in 2013 and 2018. In addition, due to the different classification of income such as housing provident fund, reimbursement of medical expenses, and estimated rent of self-owned housing, or the lack of data, it is difficult to analyze specifically, which makes the calculation accuracy of replacement rate biased.

7.2. Further Research. The further research of this paper can start from the following aspects: First, in the future, we can calculate the vertical pension replacement rate based on individual own wage income and pension income before and after retirement by creating long-term micro tracking survey data, so as to evaluate the security level difference across the whole life cycle of individuals from work to retirement. There is also further research under the new policy background. Since China has established different basic pension insurance systems for different groups and the periods for the establishment and reform of different systems are different, the existing literature has conducted relatively rich research on the security level of basic pension insurance for urban enterprise employees in China. However, due to the short implementation time of urban and rural residents' pension insurance and the newly reformed pension insurance system for organs and institutions, there is relatively little further research on these systems. More in-depth research is needed to deal with the increasing population aging and downward economic pressure under the new policy background and international situation, so as to provide theoretical basis and policy suggestions for the government's institutional reform.

Data Availability

CHIPs data come from China Income Distribution Research Institute. The official website of China Income Distribution Research Institute has a large number of relevant research literature on these data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by "the Fundamental Research Funds for the Central Universities" in UIBE (ZD4-01).

References

[1] P. Whiteford, "The use of replacement rates in international comparisons of benefit systems," *International Social Security Review*, vol. 48, no. 2, pp. 3–30, 1995.

[2] OECD, *Pensions at a Glance 2005: Public Policies across OECD Countries*, OECD, Paris, Frrance, 2005.

[3] O. S. Mitchell and J. W. R. Phillips, "Social security replacement rates for alternative earnings benchmarks," *Benefits Quarterly*, vol. 4, no. 22, pp. 37–47, 2005.

[4] M. Borella and E. Fornero, "Adequacy of pension systems in Europe: an analysis based on comprehensive replacement rates," *ENEPRI Research Report*, vol. 68, 2009.

[5] E. Whitehouse, *Pensions Panorama: Retirement-Income Systems in 53 Countries*, World Bank, Washington, DC, USA, 2007.

[6] European Union, "Updates of current and prospective theoretical pension replacement rates 2006-2046," EU, Report by Indicators' Sub-Group (ISG) of the Social Protection Committee (SPC), 2009.

[7] OECD, *Pensions at a Glance 2021: OECD and G20 Indicators*, OECD Publishing, Paris, France, 2021.

[8] Congressional Budget Office, *Social Security Replacement Rates and Other Benefit Measures: An In-Depth Analysis*, Congressional Budget Office, Washington, DC, USA, 2019.

[9] S. Ba, "On treatment level of China's basic endowment insurance system," *The New Cycle and New Finance in China*, Springer, Singapore, pp. 163–179, 2022.

[10] A. H. Munnell and M. Soto, *What Replacement Rates Do Households Actually Experience in Retirement?* Centerfor Retirement Research at Boston College, Chestnut Hill, MA, USA, no.10, 2005.

[11] V. Bajtelsmit, A. Rappaport, and L. Folster, *Retirement Adequacy in the United States: Should We Be Concerned?*, Society of Actuaries, Schaumburg, IL, USA, 2018.
[12] R. F. Disney, M. Mira d'Ercole, and P. Scherer, *Resources during Retirement*, OECD, Paris, France, Ageing Working Paper No.4.3, 1998.
[13] M. F. Förster and M. Pellizzari, *Trends and Driving Factors in Income Distribution and Poverty in the OECD Area*, OECD, Paris, France, Labor Market and Social Policy Occasional Paper, no. 42, 2000.
[14] J. P. Smith, "Trends and projections in income replacement during retirement," *Journal of Labor Economics*, vol. 21, no. 4, pp. 755–781, 2003.
[15] A. G. Biggs and G. R. Springstead, "Alternate measures of replacement rates for social security benefits and retirement income," *Social Security Bulletin*, vol. 68, no. 2, pp. 1–19, 2008.
[16] R. F. Disney and P. G. Johnson, *Pension Systems and Retirement Incomes across OECD Countries*, Edward Elgar, Aldershot, England, 2001.
[17] P. P. Martin, "Comparing replacement rates under private and federal retirement systems," *Social Security Bulletin*, vol. 65, no. 1, pp. 17–25, 2003.
[18] A. H. Munnell and M. Soto, *How Much Preretirement Income Does Social Security Replace?" Issue Brief*, Vol. 36, Center for Retirement Research at Boston College, Chestnut Hill, MA, USA, 2005b.
[19] P. J. Brady, "Measuring retirement resource adequacy," *Journal of Pension Economics and Finance*, vol. 9, no. 2, pp. 235–262, 2008.
[20] P. J. Purcell, "Income replacement ratios in the health and retirement study," *Social Security Bulletin*, vol. 72, no. 3, 2012.
[21] S. Nivakoski, "Determinants of pension coverage and retirement income replacement rates – evidence from TILDA," *Economic and Social Studies*, vol. 45, no. 3, pp. 299–328, 2014.
[22] X. J. Wang, Y. Wang, and B. W. Kang, "Calculation of pension replacement rate of different types of people in China's social pension insurance," *Statistics & Decisions*, vol. 25, no. 20, pp. 10–12, 2009.
[23] B. W. Zheng, *China Pension Development Report 2012*, Economic Management Press, Beijing, China, 2012.
[24] Y. K. Wang, B. Wang, B. J. Han, and Y. Gao, "Research on the difference of pension security level in China -- Based on the comparative analysis of replacement rate and relative level," *Management World*, vol. 29, no. 8, pp. 109–117, 2013.
[25] X. J. Wang and Y. Qiao, "Analysis on the gap between pension treatment of employees in enterprises and government institutions in China," *Statistical Research*, vol. 24, no. 5, pp. 36–40, 2007.
[26] X. J. Wang and T. Zhao, "Analysis on the gap between provinces and regions of China's social endowment insurance," *Population Research*, vol. 30, no. 2, pp. 44–50, 2006.
[27] S. Li, R. W. Zhao, and X. Gao, "Analysis of horizontal and vertical imbalance in income distribution of Chinese retirees," *Financial Research*, vol. 56, no. 2, pp. 1–18, 2013.
[28] R. Holzmann and U. Guven, *Adequacy of Retirement Income after Pension Reforms in Central, Eastern, and Southern Europe: Eight Country Studies*, The World Bank, Washington, DC, USA, 2009.
[29] E. Whitehouse, *The Value of Pension Entitlements: A Model of Nine OECD Countries*, OECD Social, Paris, France, Employment and Migration Working Papers, 2003.
[30] F. Chybalski and E. Marcinkiewicz, "The replacement rate: an imperfect indicator of pension adequacy in Cross-Country analysis," *Social Indicators Research*, vol. 1, no. 126, pp. 99–117, 2016.
[31] R. F. Disney and E. Whitehouse, "The economic well being of older people in international perspective: a critical review," *Luxemburg Income Study Working Paper*, vol. 306, 2002.
[32] A. H. Munnell and M. Soto, *The House and Living Standards in Retirement*, Center for Retirement Research at Boston College, Chestnut Hill, MA, USA, no. 39, 2005.
[33] "Eurostat," 2019, https://ec.europa.eu/eurostat/databrowser/view/tespm100/default/table?lang=en.
[34] OECD, *Ageing and Income: Financial Resources and Retirement in Nine OECD Countries*, OECD Publishing, Paris, France, 2001.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1329632, 7 pages
https://doi.org/10.1155/2022/1329632

Research Article

Research on Literary Translation Based on the Improved Optimization Model

Hongjian Liu [1,2]

[1] *School of English Language and Culture, Xi'an Fanyi University, Xi'an 710105, China*
[2] *Faculty of Educational Studies, Universiti Putra Malaysia, Serdang 43400, Malaysia*

Correspondence should be addressed to Hongjian Liu; gs60760@student.upm.edu.my

Received 21 February 2022; Accepted 1 April 2022; Published 16 April 2022

Academic Editor: Lele Qin

Machine translation is widely used in people's daily lives and production, occupying an important position. In order to improve the accuracy of the literary intelligent translation, research on literary intelligent translation is based on the improved optimization model. Based on semantic features, the semantic ontology optimization model including an encoder and a decoder is created by machine translation. In order to improve the accuracy of the intelligent translation literature of the semantic ontology optimization model, the conversion layer, including the forward neural network layer, residual connection layer, and normalization layer, is added between the encoder and decoder of the semantic ontology optimization model. An improved optimization model is established, and syntax conversion is realized by using the conversion layer, which completes the intelligent translation of literature. It is found that the BLEU value of using this method to translate literary sentences can reach 17.23 when the number of training steps is set as 8000, and the training time is low. The translation result has a low correlation misalignment rate, which can meet the user's literary translation needs.

1. Introduction

The "Going out" of Chinese culture has become an important development strategy to enhance the soft power of national culture. Literary works are important carriers of national cultural elements. How to translate and introduce literary works with regional characteristics to overseas and achieve the dissemination and acceptance target in the context of Chinese culture and literature is the key to the "going out" of Chinese culture and literature [1]. Literary intelligent translation has received widespread attention. Although some of the current literary works are translated by practitioners, the translation workload is large, and the speed of manual translation and proofreading cannot meet the needs of a large number of literary translations, requiring a large amount of manual input [2].

With the implementation of the "One Belt, One Road" initiative and the "Going Global" strategy of Chinese culture, Chinese-English translation, especially the English translation of Chinese literature, is an important field of translation research in the future. At present, a large number of researchers have developed machines for the English translation of Chinese literature translation research. Gnevsheva K et al. are innovators in machine translation research. They studied the Australian English bilingual corpus and determined the automatic forced alignment accuracy of Russian and English [3]. However, this method takes a long time to complete when querying a literary corpus, which reduces the translation efficiency. Lestari et al. fully considered the importance of phrases in language [4] and studied amplification and description techniques in Arabic phrase translation. Neural injection of phrase translation resources is by Sen et al. [5]. The above two methods decompose long sentences into words for translation, but because the words in Chinese literature have different meanings in different long sentences, the translation accuracy of the above two methods needs to be further analyzed; Pan et al. combined machine translation with a multisource neural model [6] to improve language translation performance; Li et al. established the Attention-seq2seq model with fusion feature based on CRNN

[7], which has very high translation effect; Wunier et al. researched on improving Mongolian-Chinese machine translation based on the CNN root morphological selection model [8]; Wu et al. studied multimodel fusion Mongolian-Chinese neural machine translation based on CSGAN [9], both of which are more effective machine translation methods. The above four methods use other models to improve the original machine translation model and improve the translation performance. However, considering that Chinese characters have the characteristics of large information entropy and strong ideographic ability, they have a certain ambiguity in translating literary works.

Research on intelligent literary translation based on the improved optimization model uses the improved optimization model to achieve intelligent literary translation and achieves literary translation from an intelligent perspective, which can meet the needs of literary translation and proofreading. This research improves the optimization model applied to the intelligent translation of literature, fully considers the characteristics of Chinese use, and establishes an optimization model of semantic ontology. And add the conversion layer of changeable syntax to the encoder and decoder to meet the needs of Chinese characters with large information entropy, many types, and strong semantic ability and process literary sentences into word sequences. The experimental results verify the effectiveness of this method with high intelligent translation, and the results of this research are helpful to promote the overseas translation and dissemination of Chinese literature.

2. Research Methods

2.1. Semantic Ontology Optimization Model. Based on semantic features, machine translation is used to realize intelligent literary translation, and a literary intelligent translation semantic ontology optimization model including encoder and decoder is created.

Suppose there is a five-tuple $O = \{C, H^C, R, I, A\}$, where C and H, respectively, represent the concept set and the attribute set; R and I, respectively, represent the object set and the relationship network; A represents the semantic relationship between concepts. Applying it to the semantics of intelligent literary translation, the fuzzy mapping of machine translation can be obtained as follows:

$$\begin{aligned} &\theta\colon S \longrightarrow S^*[-0.5, 0.5], \\ &\theta(s_i) = (s_i, 0), s_i \in S, \end{aligned} \tag{1}$$

where S represents the method set of the ontology.

The distribution structure model of intelligent literary translation phrases is as follows:

$$\begin{aligned} O &= <C, I, H^C, R, A, \\ O' &= <C', I', H^C, R', A'. \end{aligned} \tag{2}$$

Using the extraction of semantic features to achieve intelligent literary translation [10], the fuzzy inference method is selected to obtain the literary intelligent translation parameters as follows:

$$\Delta\colon [0, T] \longrightarrow S^*[-0.5, 0.5]. \tag{3}$$

Formula (3) can be transformed into

$$\Delta(\beta) = \begin{cases} s_k, K = \text{round}(\beta), \\ a_k = \beta - k, a_k \in [-0.5, 0.5], \end{cases} \tag{4}$$

where T represents the threshold and β represents the explanatory function.

The feature parameters of the two-tuple fusion are obtained by using associative semantic mapping as follows:

$$\begin{aligned} (\bar{s}, \bar{a}) &= \omega_2(((s_1, a_1), (\omega_1, a_1)), \ldots, ((s_n, a_n), (\omega_n, a_n))), \\ &= \Delta\left(\frac{\sum_{j=1}^{n} \Delta^{-1}(\omega_j, a_j)\Delta^{-1}(S_j, a_j)}{\sum_{j=1}^{n} \Delta^{-1}(\omega_j, a_j)}\right), \\ &= \Delta\left(\frac{\sum_{j=1}^{n} \beta_j \beta_j}{\sum_{j}^{n} \uparrow \beta'_j}\right), \end{aligned} \tag{5}$$

where ω represents the weight.

Use adaptive semantic variable optimization and context feature matching semantic ontology model to obtain the optimal semantic feature matching results of literary intelligent translation as follows:

$$J^*(m) = \max_{\beta}\{J^*(\beta) + R_m(\beta) + C\}, J^*(0) = 0. \tag{6}$$

Semantic discretization is used to process the original literary text information, and the parameters of the semantic text are adaptively estimated to obtain the feature matching degree formula output by the literary intelligent translation output as follows:

$$P(x_1^l|\alpha) = \prod_{i=1}^{L} P(y_i|\alpha, r_i, l), \tag{7}$$

where α represents the semantic feature, l represents the length of the literary sentence, x represents the text, and y represents the semantic text feature amount.

To analyze the characteristics of automatic vocabulary in intelligent translation literature, the relevant context information decomposition formula for obtaining intelligent translation vocabulary of literature is as follows:

$$E_j = \sum_{k=1}^{n} E_{j,k}, \tag{8}$$

$$P_{j,k} = \frac{E_{j,k}}{E_j}, \tag{9}$$

where E represents the degree of association.

Use the cross-comprehensive evaluation and decision-making method to obtain the output results of the correlation feature between literary vocabulary is as follows:

$$W_{E_k} = -\sum_j P_{j,k} \ln\left(P_{j,k}\right). \tag{10}$$

Thresholding processes the semantic ontology information of intelligent literary translation [11] and uses the empirical mode decomposition method to obtain the closeness of the translation result and the similarity formula as follows:

$$K_x = E\left[x^4(t)\right] - 3E^2\left[x^2(t)\right]b, \tag{11}$$

$$S_x = E\left[x^3(t)\right] + \sqrt{s}bu\left[s(t-\tau_0)\right], \tag{12}$$

where b represents the time scale of literary features and u represents the literary signal sequence.

According to the obtained closeness and similarity features, the translation results are extracted, and the translation results are corrected by differences [12], and the revised literary intelligent translation text collection is obtained as follows:

$$\text{Computition}\left(x_j\right) = \left[\left(E_j + E_k\right)\beta + E_j + \alpha b_j^2\right]l. \tag{13}$$

2.2. Improved Optimization Model. A conversion layer that can realize syntax conversion is added between the encoder and the decoder of the semantic ontology optimization model. The conversion layer mainly includes three parts: the forward neural network layer, the residual connection, and the normalization layer.

2.2.1. Forward Neural Network Layer. The ReLU activation function is selected as the nonlinear transformation of the forward neural network layer. The ReLU activation function is also called the modified linear unit [13], and its nonlinear transformation formula is as follows:

$$\text{Re}LU(x) = \max(0, x). \tag{14}$$

Both h_{encoder} and c_{encoder} in the binary group need to pass through the forward neural network layer, but both have independent parameters. Using the forward neural network layer to transform the binary group $(c_{\text{encoder}}, h_{\text{encoder}})$ to (c', h'), the formula is as follows:

$$\begin{aligned} c' &= \text{Re}LU\left(c_{\text{encoder}}W_{c1} + b_{c1}\right)W_{c2} + b_{c2}, \\ h' &= \text{Re}LU\left(h_{\text{encoder}}W_{h1} + b_{h1}\right)W_{h2} + b_{h2}, \end{aligned} \tag{15}$$

where W_{c1} and W_{c2} represent the transformation matrices for the first and second linear transformations of c_{encoder} and b_{c1} and b_{c2} represent the offset vectors for the first and second linear transformations of c_{encoder}.

In order to keep the unit state vector dimensions of the long short-term memory (LSTM) in the decoder and encoder consistent, the input and output conversion layer dimensions are the same [14], and the normalization layer vector dimensions are not changed, c_{encoder}, h_{encoder}, c', and h' are all vectors of the same dimension.

Use h and d to denote the first linear transformation dimension and the model state vector dimension. The dimensions of W_{c1} and W_{h1} and the dimensions of W_{c2} and W_{h2} are $d \times h$ and $h \times d$, respectively, and the offsets of b_{c1} and b_{h1} and the offsets of b_{c2} and b_{h2}. The dimensions are h and d, respectively. It can be seen that the number of parameters included in this layer is $4dh + 2d + 2h$, and the number of parameters in each layer is $h = 4d$ for the model $16d^2 + 10d$ established. When the cyclic neural network contains a stacking quantity of n, a total of $16nd^2 + 10nd$ parameters exist in the forward neural network layer of the model conversion layer, and the multiplication operation of the vector and the matrix is multiplied by the number of operations $16nd^2$ times.

2.2.2. Residual Connection. $(c_{\text{encoder}}, h_{\text{encoder}})$ uses the residual connection to act on the forward neural network layer output (c', h') in the conversion layer structure, and the residual result $(c_{\text{res}}, h_{\text{res}})$ is obtained as follows:

$$\begin{aligned} c_{\text{res}} &= c' + c_{\text{ebcoder}}, \\ h_{\text{res}} &= h' + h_{\text{ebcoder}}. \end{aligned} \tag{16}$$

Taking full account of the transformation of the forward neural network layer, the residual connection processing can make the established model regain the lost semantic information and improve the accuracy of the literary intelligent translation results. The residual connection processing does not need to increase the parameters, so the computational complexity of the model does not change, and it does not affect the back propagation training results of the recurrent neural network.

2.2.3. Standardization Layer. Normalized processing is commonly used in deep learning. Normalized processing can not only be applied to the preprocessing stage in deep learning [15] but it can also be applied to the processing of various layers in the network to implement standardized processing of input data. Use g and u to represent the variance and expectation of the normalization processing in the normalization layer, and the input c_{res} layer normalization processing formula is as follows:

$$C_{\text{trans}} = \frac{g}{\sigma}\left(c_{\text{res}} - \eta\right) + u, \tag{17}$$

where σ represents the original variance of the input feature and η represents the original expectation of the input feature. The formula is as follows:

$$\begin{aligned} \mu &= \frac{1}{d}\sum_{i=1}^{d} c_{\text{res}_i}, \\ \sigma &= \sqrt{\frac{1}{d}\sum_{i=1}^{d}\left(c_{\text{res}_i} - \eta\right)^2}, \end{aligned} \tag{18}$$

where d and c_{res_i}, respectively, represent the feature dimension and the dimension feature value and h_{res} can also be processed through the above-normalized operation process.

Using the canonical layer to normalize $(c_{\text{res}}, h_{\text{res}})$ into $(c_{\text{trans}}, h_{\text{trans}})$, the result can be used as the initial state of the decoder LSTM. The normalization layer is not only included in the conversion layer; there is also a normalization layer in the LSTM units of the decoder and the encoder to implement normalization operations.

3. Result Analysis and Discussion

In order to verify the effectiveness of the literary intelligent translation based on the improved optimization model for the translation of literary works, the Chinese-English translation dataset TED2018 in the Tatoeba project was selected as the experimental object. The dataset contains a large number of literary works, including Chinese and English translation number of sentences is 25645 and the comparative translation of each group of literary sentences starts and ends with the characters \t and \n, respectively. The method in this study uses LSTM as the encoder and decoder to obtain the Chinese and English mapping dictionary and converts the text data in the dataset to digital form through mapping. Set the number of batch training samples of the improved optimization model used in this study to 100, the number of hidden layer nodes to 128, and the number of termination iterations to 100.

3.1. Qualitative Test. In order to visually verify the intelligent translation results of literary works with the method of this study, statistics of 10 random sentences used in the method of this study to translate literary works are counted.

From the experimental results in Table 1, it can be seen that the method in this study has a high performance for intelligent literary translation. It can realize intelligent translation of sentences in literary works, and the translation results have high versatility and effectiveness.

3.2. Quantitative Test. In order to intuitively reflect the intelligent translation performance of the method in this study, the literature CNN method and the literature CSGAN method are selected as comparison methods.

Using this method to intelligently translate the literary sentences in the TED2018 dataset, the training loss function results for different training steps in the translation process are shown in Figure 1.

Different data need to be selected when testing the loss function values of different methods. The obtained loss function values have high volatility, which is mainly caused by random gradient descent. Figure 1 shows the curve result after smoothing the true loss function value. As can be seen from the experimental results in Figure 1, the loss function value decreases with the increase in the number of training steps. The method in this study has the lowest loss function value at different training steps, which effectively verifies that the method in this study has higher translation performance, and the loss is small when the number of training steps increases.

The BLEU value is an important indicator for evaluating the effect of machine translation. The BLEU value of literary sentences in the intelligent translation dataset using three methods is counted. The statistical results are shown in Figure 2.

Table 1: Translation results of the method in this study.

Serial number	English translation result
1	Pain past is pleasure
2	While there is life, there is hope
3	God helps those who help themselves
4	In doing we learn
5	Constant dropping wears the stone
6	Misfortunes never come alone
7	From small beginning come great things
8	Good advice is beyond all prices
9	Good company on the road is the shortest cut
10	A bold attempt is half success

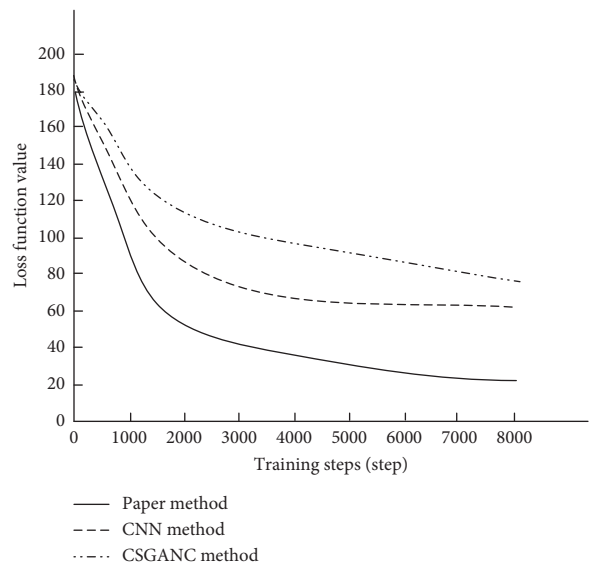


Figure 1: Loss function values of different methods.

The experimental results in Figure 2 show that the BLEU value of the literary sentence translated by this method tends to be stable when the number of training steps is 4000; when the number of training steps is 8000, the highest can reach 17.23; the BLEU value of the other two methods to translate literary sentences is lower than the method in this study at different training steps, which effectively verifies that the method in this study has higher translation performance.

The statistical results are shown in Figure 3 for the statistics of the training errors of different training steps using the method in this study.

It can be seen from the experimental results in Figure 3 that using this method to intelligently translate literary sentences, the training error at different training steps is significantly lower than that of the other two methods. The method in this study can keep the training error to a minimum when the number of training steps is low, which shows that the improved optimization model used in this method has a higher convergence effect.

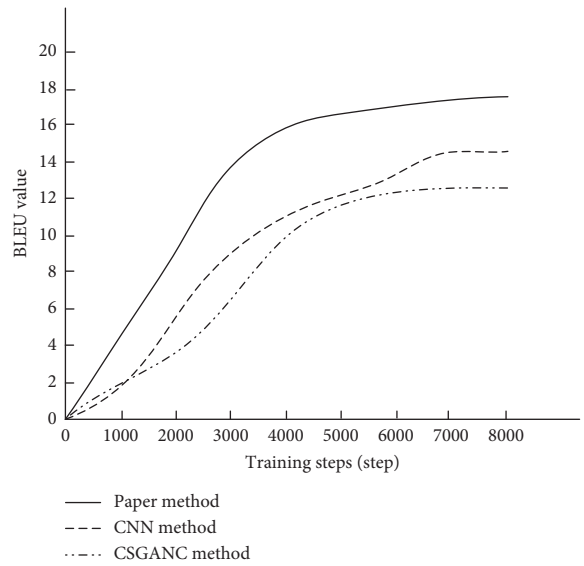


Figure 2: Comparison of BLEU values of different methods.

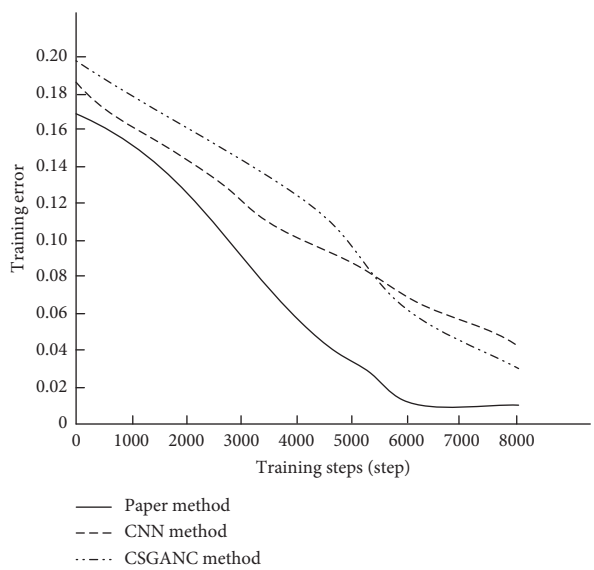


Figure 3: Comparison of training errors of different methods.

Table 2: Comparison of translation performance.

Subset number	Subset size (MB)	Method of this article		CNN method		CSGAN method	
		Training time (min)	BLEU value	Training duration (min)	BLEU value	Training time (min)	BLEU value
1	23.54	9.85	17.85	23.54	12.64	29.52	10.85
2	42.64	15.34	19.52	21.52	13.85	28.64	11.64
3	51.74	16.24	18.43	21.42	12.64	24.76	12.48
4	62.78	14.52	16.58	29.64	11.94	23.65	9.85
5	47.85	12.64	17.54	28.46	12.64	31.64	7.58
6	56.61	17.52	18.64	27.64	10.64	29.52	8.64
7	75.61	18.64	19.52	26.38	12.64	27.85	7.46
8	85.64	19.57	17.45	31.22	11.64	32.85	9.52
9	49.52	16.25	19.52	29.58	10.58	27.52	10.05
10	51.64	16.75	17.52	27.64	9.85	27.85	11.64

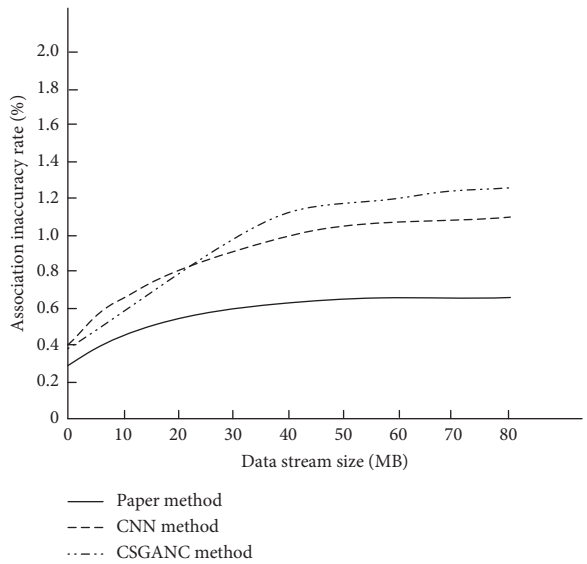


Figure 4: Comparison of correlation misalignment rate.

The statistics, using the method of this study, intelligently translate literary sentences, the training time, and the BLEU value of different training subsets. The statistical results are shown in Table 2.

It can be seen from the experimental results in Table 2 that the training time for the intelligent translation of literary sentences using this method is less than 20 minutes; while the training time for the intelligent translation of literary sentences using the other two methods is both higher than 20 minutes. This method proposes that the conversion layer idea has strong translation performance, the training time of the improved optimization model used is significantly reduced, and the BLEU value of the translation result is significantly higher than the other two methods.

The statistical results are shown in Figure 4 for the correlation misalignment rate when using different methods to translate literary sentences with different data streams.

As can be seen from the experimental results in Figure 4, using this method to intelligently translate literary sentences, the correlation misalignment rate of different literary sentence data streams is significantly lower than that of the other two methods. The comparison result of the correlation misalignment rate effectively verifies that the intelligent translation of literary sentences using the method in this study has a higher degree of relevance and higher accuracy of the translation results.

4. Discussion

Machine translation is an automatic translation technology developed with the help of computer technology and corpus technology. Although it has the advantages of fast translation speed and high efficiency, the translation quality is mediocre and can only meet general reading needs. For texts with rich emotions, such as literary works, the translation quality is obviously insufficient. Combined with the three principles of Skopos Theory and the evaluation system of machine translation quality, the author finds that the current machine translation literary translation has the following typical problems:

4.1. It Is Not Eloquent and Has Low Intelligibility. For translators, they can find or choose the most appropriate translation by looking up dictionaries, searching online resources, or according to the content before and after the text. However, for machine translation, the only criterion for machine selection is the translation version in the selected termbase. There is a greater possibility of a mistranslation of special nouns representing people, place names, and things. These proper nouns may be far from the background of the text, and the term library producer did not add the entry to the library or is it that some people's names or place names have a conventional translation method, and machine translation adopts literal translation or transliteration, resulting in errors.

4.2. Logical Confusion and Poor Organization. Whether it is machine translation or manual translation, it is a permanent standard to achieve the logic of sentence translation, enable readers to correctly understand the meaning of the translation, and meet the "localized" expression in the target language environment. However, at present, machine translation has not reached such an "intelligent" stage. Its translation method is to follow the program to perform the mechanical transformation of vocabulary, grammar, and semantics, which has not risen to the level of "emotion" and context matching.

Based on the established semantic ontology optimization model, this study optimizes and improves the transformation layer, which includes the forward neural network layer, residual connection layer, and standardization layer. The transformation layer is used to realize syntax transformation, realize literary intelligent translation, and improve the translation effect.

5. Conclusion

With the rapid development of the Internet, machine translation has become an important research part in the field of artificial intelligence. It studies the intelligent translation of literature based on the improved optimization model. Based on the establishment of the semantic ontology optimization model, by adding a conversion layer to the encoder and decoder of the model, an improved optimization model is established to realize the intelligent translation of literary works. Experiments have verified that this method has high effectiveness. However, this study did not conduct an in-depth analysis of the ideographic ability of literary words and lacked verification of the emotion of translated literary sentences. Accurate and intelligent translation of literary sentences can be realized. In the future, the amount of training data should be further used to optimize the structure of the recurrent neural network, and various efficient methods should be integrated to improve the effect of intelligent literary translation, accurately express

the emotions of literary works by analyzing the ideographic ability of literary words, and further promote the translation and dissemination of Chinese literature.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the Scientific Research Team in the Xi'an Fanyi University (Grant no. XFU21KYTDB01), the Shaanxi Federation of Social Science (Grant no. 2020Z012), and Shaanxi Social Science (Grant no. 2021K022).

References

[1] H. Han, Y. Jiang, and X. Yuan, "Overseas translation and introduction of Chinese literature from the perspective of complex systems—taking the translation and introduction of Shaanxi contemporary literature as an example," *Shanghai Translators*, vol. 041, no. 06, pp. 69–74, 2019.

[2] F. Tao, "Artificial intelligence translation and world literature," *Journal of Humanities*, vol. 041, no. 08, pp. 30–37, 2019.

[3] K. Gnevsheva, S. Gonzalez, and R. Fromont, "Australian English bilingual corpus: automatic forced-alignment accuracy in Russian and English," *Australian Journal of Linguistics*, vol. 40, no. 2, pp. 1–12, 2020.

[4] W. Lestari, Y. Yoyo, and A. R. Zaini, "Amplification and description techniques in the translation of Arabic phrases in matan Al-ghayah wa Al-taqrib," *Izdihar : Journal of Arabic Language Teaching, Linguistics, and Literature*, vol. 3, no. 2, pp. 113–128, 2020.

[5] S. Sen, M. Hasanuzzaman, A. Ekbal, P. Bhattacharyya, and A. Way, "Neural machine translation of low-resource languages using SMT phrase pair injection," *Natural Language Engineering*, vol. 27, no. 3, pp. 271–292, 2020.

[6] Y. Pan, X. Li, and Y. Yang, "Multi-source neural model for machine translation of agglutinative language," *Future Internet*, vol. 12, no. 6, pp. 1–14, 2020.

[7] M. Li, Z. Miao, and W. Xu, "A CRNN-based attention-seq2seq model with fusion feature for automatic Labanotation generation," *Neurocomputing*, vol. 454, no. 23, pp. 430–440, 2021.

[8] S. Wunier and W. Liu, "Mongolian-Chinese machine translation based on CNN etyma morphological selection model," *Journal of Chinese Information Processing*, vol. 32, no. 05, pp. 42–48, 2018.

[9] Z. Wu, H. Hou, and T. Bai, "The research on multi-model fusion for Mongolian-Chinese neural machine translation based on CSGAN," *Journal of Jiangxi Normal University (Natural Sciences Edition)*, vol. 044, no. 002, pp. 153–159, 2020.

[10] Y. Fang, G. Ding, W. Wen et al., "Salient object detection by spatiotemporal and semantic features in real-time video processing systems," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 11, pp. 9893–9903, 2020.

[11] Y. Jiang, L. Wang, and R. Ma, "A retrospective observation of the dynamic and complex adaptive process of translation from the translator's view and lexical rank-frequency distribution," *Foreign Language Research*, vol. 41, no. 01, pp. 84–92, 2020.

[12] C. Valavani, C. Alexandris, and G. Mikros, "Improving machine translation output of German compound and multiword financial terms: comparison with cross-linguistic data," *Human-Intelligent Systems Integration*, vol. 2, no. 2, pp. 1–6, 2020.

[13] J. W. Siegel and J. Xu, "Approximation rates for neural networks with general activation functions," *Neural Networks*, vol. 128, no. 6, pp. 313–321, 2020.

[14] F. Christophe, "Learning algorithm recommendation framework for IS and CPS security: analysis of the RNN, LSTM, and GRU contributions," *International Journal of Systems and Software Security and Protection (IJSSSP)*, vol. 13, no. 1, pp. 1–23, 2022.

[15] W. Zhang, X. Wang, and X. Cui, "Prediction of satellite lifetime based on Short and long time memory networks," *Computer Simulation*, vol. 38, no. 09, pp. 80–83+128, 2021.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 8614056, 15 pages
https://doi.org/10.1155/2022/8614056

Research Article

Nonspatial Proximity and Project Team Resilience: The Role of Knowledge Sharing and Team Cohesion

Meng Wei, Shengyue Hao, and Xu Ren

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China

Correspondence should be addressed to Meng Wei; 17113158@bjtu.edu.cn and Shengyue Hao; haoshyue@bjtu.edu.cn

Received 4 March 2022; Accepted 29 March 2022; Published 14 April 2022

Academic Editor: Lele Qin

Project teams often work in a turbulent and uncertain environment, which tends to bring various dilemmas to them over the projects' duration. Resilience makes it possible for project teams to minimize, manage, and mend the damage caused by adversities. The research on project team resilience is emerging, but not fully developed. Many inputs of project team resilience including team composition have attracted less or even no attention. We explored the influence of team composition on project team resilience from the perspective of proximity and discussed the role of knowledge sharing and team cohesion in their relationship. An analysis of 256 responses from Chinese construction project teams shows that (a) cognitive proximity has a U-shaped effect on project team resilience, knowledge sharing, and team cohesion; (b) value and social proximity positively affect project team resilience, knowledge sharing, and team cohesion; (c) knowledge sharing and team cohesion have a positive influence on project team resilience and mediate the relationship between cognitive, value, social proximity, and project team resilience. This study enriches the empirical literature on team resilience, broadens the boundary of project management, team resilience, proximity, and conservation of resources theory, and provides practical suggestions and future direction.

1. Introduction

Project-based organizations (PBOs) are popular in engineering, IT, aerospace, and industries, as project-based configuration makes the organization more flexible so that the organization can respond to sophisticated customer needs in time and overcome the traditional obstacles of innovation and organizational change [1]. The main body of PBOs consists of project teams that are established temporarily for specific tasks [2]. These teams' working environment tends to be turbulent, complex, and full of uncertainty [3], and they will inevitably face adversities from chronic stressors (i.e., project time pressures and relationship conflict) to sudden shocks (i.e., equipment failure and natural disaster) [3, 4]. To ensure projects succeed under these adversities, project teams should develop the capacity [4] to address setbacks, conflicts, or any other threat [5] calmly and "bounce back" soon, that is, team resilience.

In recent years, there has been an increasing interest in team resilience, as it makes the team possible to succeed in difficulties and stresses. Since COVID-19, the discussion about team resilience is particularly heated. Emerging researches have explored its antecedents, including team leaders [6, 7], team culture or climate [8, 9], team process [2, 9, 10], team psychology [3], and emotion [9], whereas the team composition element has attracted less attention. This study aims to reduce the research asymmetry and focus on cognitive proximity, value proximity, and social proximity between team members. Teams are composed of a variety of members, whether these members have similar knowledge backgrounds, values, or have known each other, relate to team operation and state [11, 12]. According to proximity theory, these nonspatial proximity dimensions are important for knowledge flowing and unit stickiness that helps positive states such as coordination, innovation, and performance [11, 13]. Team resilience, as one of the positive team states, may also be influenced by nonspatial proximity, but few studies investigate their relationship, unlike regular, stable teams, project teams gather individuals together for a short and provisional period. Cognitive, value, and social

proximity may play more important roles in such a context because they are often involved in building rapid trust which is necessary for project teams fighting against hardship. Therefore, the first question this study tried to answer is how nonspatial proximity affects project team resilience.

To further explore the internal path between nonspatial proximity and project team resilience, we followed Hobfoll et al.' calls, combining the conservation of resources (COR) theory and crossover model for analysis. COR theory points out that team resilience capacity emerges from environments that are "(a) rich in personal, social, materials, and energy resources, (b) allow access to those resources, and (c) provide safety and protection against resource loss and promote resource growth" [8], which can be cultivated by resource crossover including knowledge resource crossover (i.e., knowledge sharing) and psychological resources crossover (i.e., team cohesion). In another word, the mechanism of resource exchange at the team level like knowledge sharing and team cohesion may be the foundation for creating and facilitating resilient teams [14]. Furthermore, COR theory and crossover model indicated that the intersection of resources is fertilized by team ecological conditions or the so-called resource passageways. Connecting these discussions to the key principles of proximity theory, we argued that nonspatial proximity functions are not only a resource but also a resource passageway of project team resilience, considered knowledge sharing, and team cohesion as the process of knowledge, and psychological resource crossover for project team resilience, separately. Accordingly, the second question we tried to answer is how knowledge sharing and team cohesion mediate the relationship between nonspatial proximity and project team resilience.

To answer the above two questions, we construct a research model of nonspatial proximity affecting project team resilience, in which knowledge sharing and team cohesion are conceptualized as mediators. After that, we tested the assumptions in the research model by questionnaire data from Chinese construction project teams. In doing so, we make four theoretical contributions. First, we respond to the calls to study resilience at the team level in projects [4] and prosper the knowledge on project team resilience. Second, we make a pioneering attempt to study team resilience with proximity theory, which widens the theoretical perspective of team resilience. Third, we answer the calls for analyzing proximity at the cross-individual level [15], confirm dimensions and their definitions, and provide individual and resilience insights for expanding proximity theory. Fourth, we respond to the initiative of Hobfoll et al. [14] to enlarge the application of conservation of resources theory by using the crossover model and explain how individual knowledge and psychology resources produce resilient project teams.

2. Theoretical Background

2.1. Nonspatial Proximity. The concept of "proximity" originated from the "agglomeration economy" notion puts forward by economist Marshall in 1890. It focused on the impact of spatial agglomeration on enterprise production and had been widely used in the field of industrial economics.

Subsequently, the connotation of proximity was further developed and expanded from one dimension to multidimension by "environmental innovation" theory and "proximity dynamics" theory and a wave of research on multidimensional proximity arose. Nonspatial proximity dimensions attracted more and more attention and even were regarded as more powerful than spatial proximity in interactive learning, knowledge transfer, cross-organizational collaboration, and organizational innovation [11]. The attention to nonspatial proximity also made proximity theory more widely used. Gradually, the researches on nonspatial proximity are no longer limited to the cross-organization level but extend down to the cross-individual level which is what we study.

There are no widely accepted dimensions of nonspatial proximity between individuals. Richard et al. (2021) divided it into two dimensions: cognitive and social proximity, while Hung et al. [11] believed that nonspatial proximity consists of organizational, institutional, and cognitive proximity. Their dimensions are both modified based on dimensions proposed by Boschma [16] at the cross-organization level including cognitive, organizational, institutional, and social proximity. Cognitive proximity means to the "degree of similarity of the knowledge bases" ([67]; [16]; organizational proximity requires agents to belong to the same relational network [16]; institutional proximity is derived from common norms and values between agents [11]; social proximity refers to socially embedded relations between agents at the microlevel [16]).

Among these dimensions, organizational proximity has great overlap with social proximity, they both highlight the role of connections, and many later studies combined the two. Compared with organizational proximity, the concept of social proximity can better reflect team members' relationships, and then, social proximity is selected as the research dimension here. Furthermore, the default premise of institutional proximity is the existence of different organizations. When the team members come from a common organization, the discussion is meaningless. We then eliminate norms and only retain the description of the similarity of values in institutional proximity. To sum up, we divide the nonspatial proximity among project team members into cognitive, value, and social proximity.

Cognitive proximity here is the degree of similarity of project team members' knowledge bases ([67]; [16]. Team members with similar educational background or work experience have fewer communication barriers [11], but they are difficult to get more thought sparks from other areas. In some situations, a certain degree of cognitive proximity may lead to subgroups [17] which is harmful to team united. For these reasons, there is still great controversy about whether cognitive proximity plays a positive or negative role, although its influence on knowledge sharing [11], decision-making [12], cooperation, conflict [12], or innovation [11] has been already investigated.

Value proximity is the degree of similarity of project team members' values [18]. According to organizational

behavior theory, value is the root element that controls an individual's behaviors and attitudes. The effect of value on team process and performance has attracted much attention, and many studies indicate that the similarity of values contributes to a good relationship and promote communication and cooperation between team members, while the heterogeneity of values may lead to conflict and reduce members' satisfaction and identity with the team, which is harmful to the team outcomes [13, 19].

Social proximity is socially embedded relations based on previous friendship, kinship, and experience between project team members [16]. Social proximity coexists with trust, can effectively reduce transaction costs and improve the transaction rate in the process of social transaction, and provide a relationship path for communication and cooperation among agents [11]. It has great significance for reducing risk and uncertainty in the process of technological progress. However, there are also some arguments that social proximity may lead to relationship locking and opportunistic behavior for long-term cooperative organizations, which makes the cost higher on establishing new contacts and acquiring new knowledge. In the project context, it is not clear whether social proximity will play a positive or negative role.

2.2. Project Team Resilience. Resilience originates in "resilire," which is a Latin word interpreted as "jump back" [3, 20]. It is usually considered as an ability to recover or bounce back from adversities. In fact, resilience is regarded as an important concept to explain how individuals, teams, or organizations successfully adapt to negative events [20]. A great many efforts have been made to discuss resilience at the individual, and organizational level for a long time, while team resilience has attracted widespread regard only in the last few decades [7] and is especially hot now [3].

There are many perspectives to explain team resilience including capacity, process, outcome, among which the most recognized is the argument that regarded team resilience as a kind of potential ability for the team to deal with frustration and stressors in an emergency [4], attaches importance to resource possession [8]. Following the view of capacity, project team resilience is defined "as the capacity to anticipate, contain, and recover from adversity or failure induced by the uncertainty and complexity of a project environment" [4]. According to this, project teams with high resilience can actively observe environmental changes, give early warning, and make good preparations for crises to minimize damage before adverse events, make rapid decisions and various solutions to deal with adversities in time, maintain the project's basic functions during adverse events, and recover from pressure, disasters, or other difficulties quickly after adverse events [7].

In terms of the research themes, the inputs of project team resilience are attracting more and more interest. For example, Varajao et al. [21] believed that trust and solidarity, focus on results, commitment, management and accountability, embracing conflicts, work conditions, skills, and behaviors are important contributors to project team resilience. Pavez et al. [4] empirically proved group potency and interpersonal trust are team resources in building project team resilience. Abraham Carmeli et al. [2] indicated that relational coordination drives project team resilience and problem solving through experiential learning and access to knowledge. Although the research on the antecedents of project team resilience is rising, the relevant empirical studies are still rare. We have not found any research on testing the impact of proximity on project team resilience.

2.3. Conservation of Resources Theory and Crossover Model. The basic principle of COR theory is that individuals have the motivation to protect their existing resources and obtain new resources [8]. Resources are things that individuals believe contribute to the achievement of their goals, such as knowledge and positive psychology [8]. The possession of these resources is an integral part of resilience [14], as adequate resources are needed to support coping with pressures and challenges. By contrast, the lack and loss of resources lead to difficulties for individuals to deal with crises and stressors and make individuals choose to withdraw before difficulties to avoid further loss of resources, resulting in vulnerability [14]. According to this, COR theory has frequently been used to explain the development of individual resilience [8, 14].

Gradually, COR theory has been widened from the individual level to the team and organization level. The availability of team resources is also regarded as an important condition for team resilience. Teams' knowledge and psychology resources mainly come from team members. It has been a problem that is not valued by COR theory how to transfer these resources from individuals to teams until Hobfoll et al. [14] discussed COR theory by crossover model. The crossover model holds that individuals' resources can be exchanged and crossed into teams. For example, a member's positive psychology state may infect others in the team and gradually spread to the whole team, and knowledge can be transferred to others and then flow in the team. These processes of resource crossover at the team level increase resource stock and create and sustain resilient teams. The exchange of resources is affected positively or negatively by the team conditions, which is called resource passageways [14]. In another word, resource crossover can help teams use resource passageways to develop and enhance team resilience. According to these, we believe that the path of team resilience development can be from resource passageways to resources crossover. The resource passageway here is nonspatial proximity, and the mechanisms of resources crossover are knowledge sharing and cohesion.

Knowledge is an important resource for any team or organization [11, 22, 23]. Knowledge sharing here refers to actors providing or receiving knowledge such as task information, know-how, and feedback [24], which is a knowledge crossover process, that highlights the frequency of knowledge interaction. This is different from knowledge transfer which emphasizes the effect of knowledge exchange. Knowledge sharing contributes to the knowledge resource

creation and accumulation, enabling teams or organizations to get a variety of benefits including decision-making, reduction of reinventing the wheel, innovation, performance, and other competitive advantages [11, 22, 25]. Therefore, knowledge sharing attracts more and more attention. Several enablers and barriers of knowledge sharing have been identified, such as the motivations and capacities of knowledge sources and receivers, trust, culture, leadership, the categories of knowledge, and so on [26–28]. In general, these influencing factors mainly come from the characteristics of sources and receivers, the characteristics of the relationship between sources and receivers, and the characteristics of knowledge [15]. As a kind of property of the relationship between sources and receivers, proximity has been given a growing concern.

Cohesion is regarded as "a dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its instrumental objectives and/or for the satisfaction of member affective needs" [29], emphasizes the resultant force formed by the individual's willingness of staying in the organization, and reflects the crossover process of individuals' commitment psychology resources. As a preeminent concern in psychology and team research, team cohesion has received a lot of attention and discussion, especially in sports teams and project teams. It is supposed to be a powerful predictor of a positive act, capability, and state, which will have a far-reaching influence on the effectiveness and overall performance of teams [5, 30]. Given this, scholars and practitioners have investigated the development of team cohesion [31]. Generally, the factors affecting team cohesion are organized in four aspects: interpersonal, structural, organizational, and situational factors. Among them, as one of the interpersonal factors, the similarities and attractions between team members are considered to be the most important factor in team cohesion.

3. Hypothesis Development

3.1. Nonspatial Proximity and Project Team Resilience. Social identity theory and similarity-attraction paradigm believe that high proximity enables individuals to communicate easily and cooperate effectively, which will contribute to a quick decision and action to crisis response. However, there are voices declaring proximity hinders creative, innovative ideas, and diversified solutions to adversities, and this negative effect is mainly reflected in job-related proximity [32–35]. It can be seen that cognitive proximity which relates to similar task-related knowledge and skills may have both positive and negative effects on resilience, while the impact of values proximity and social proximity on resilience may show a more positive side.

In project teams with lower cognitive proximity, the knowledge gap between team members will be shrinking with the increasing of cognitive proximity, but still large, which avoids quick common understanding for crisis response plans. Meanwhile, project teams' heterogeneous knowledge resources will be decreasing which is harmful to teams monitoring environmental changes from several insights, and coping with the adversities through various solutions. In other words, cognitive proximity is negatively correlated with project team resilience at lower levels. As cognitive proximity increases to a certain level, its advantages will become more and more obvious until it surpasses its negative effects. With similar knowledge backgrounds at higher cognitive proximity, team members can not only have a more professional and in-depth discussion on the dilemma but also reach an agreement on the contingency plans quickly, so that the duration of the adverse impact on project teams minimizes.

> Hypothesis 1a: cognitive proximity has a U-shaped effect on project team resilience

Brodsky et al. [36] identified shared values as one of the resilience processes at the organization level. Varajao et al. [21] indicated that common values can shape a group structure conducive to project team resilience. Consist with the above ideas, value proximity may positively affect project team resilience. Team members with similar values often hold strong beliefs for the development direction of the project and the project team. As such, project teams can effectively resist the negative impact of severe conditions on their goals and morale. Furthermore, value proximity avoids the prejudice introduced by inner dissimilarity and makes it easy for team members to identify with each other and form working tacit understanding in a short term [13]. This will help team members carry out emergency actions collectively, facilitating the efficiency of "bounce back".

> Hypothesis 1b: value proximity has a positive effect on project team resilience

Project teams are set up temporarily, and team members know each other well in advance and are conducive to projects surviving in the turbulent environment [37]. High social proximity often brings good relationship, because project team members with prior social connections show more trust with each other. High relationship quality has been recognized as the most evident condition to improve team resilience [38], as it not only provides emotional support for team members to resist pressure from adversities but also enhances mutual assistance between team members when facing hardship. Moreover, project team members in similar social networks prefer to interact. High social interactions density promotes the emergence of team resilience [37] since frequent communication produces effective teamwork and efficient problem-solving for addressing stressors. Subsequently, project team resilience may emerge from social proximity which is closely related to high social capital.

> Hypothesis 1c: social proximity has a positive effect on team resilience

3.2. Nonspatial Proximity, Knowledge Sharing, and Project Team Resilience

3.2.1. Nonspatial Proximity and Knowledge Sharing. The emergence of knowledge sharing is not easy because of

individuals' tendency of knowledge protection and the cost of exchanging knowledge. The similarity of knowledge base, values, and social network has a profound and lasting influence on removing these obstacles [15].

When the level of cognitive proximity is extremely low, highly heterogeneous knowledge is embedded in project participants. Project team members have no choice but to provide their own skills, techniques, and experiences and learn from each other because dealing with complex project tasks in a limited duration requires rapid integration of heterogeneous knowledge. Otherwise, the project cannot continue normally. With the increase in cognitive proximity, the passive force of knowledge sharing is decreasing. When cognitive proximity exceeds a certain level, although team members have less obligation to share knowledge, their willingness for sharing knowledge becomes gradually strong. The reason is that team members with similar educational or work backgrounds are more likely to resonate with technique or management difficulties, which enhances their desire to exchange information and ideas [15].

Hypothesis 2a: cognitive proximity has a U-shaped effect on knowledge sharing in project teams

Project team members tend to hide knowledge in their initial contact with others because of vigilance. Value proximity can help to solve this problem by breaking the defensive barriers between team members. According to the similarity-attraction paradigm, team members who share common goals, beliefs, and attitudes are more likely to attach and commit to each other, even willing to sacrifice their own interests for the other [39, 40]. That is, similar values produce a strong interpersonal attraction [41], with which team members are more likely to help their fellows by various means without regarding costs, including sharing their knowledge [42]. Furthermore, the similarity-attraction paradigm also asserted that people are eager to communicate and interact with someone who has inner similarities, which provides a good condition for knowledge sharing [43, 44].

Hypothesis 2b: value proximity has a positive effect on knowledge sharing in project teams

Christensen et al. [15] found the positive influence of social relationship on knowledge sharing frequency. Recently, Carmeli et al. [2] argued that experiential learning and access to knowledge are socially driven. Project team members may prefer to share knowledge with people they have known before. First, social connectedness involves trust is good for the reduction of social costs in the process of knowledge sharing. Second, project team members embedded in the same relation network know well with each other, and they can express their knowledge in a way that is easier for colleagues to understand; meanwhile, they know who possesses the knowledge they want and obtain it targeted, so as to reduce the time cost of knowledge sharing [15]. Third, team members with common experiences are more likely to associate with each other [45], which increases the probability of knowledge flow, especially the tacit knowledge (i.e., expertise, ideas, and opinions) that resides in individuals' minds [2].

Hypothesis 2c: social proximity has a positive effect on knowledge sharing

3.2.2. Knowledge Sharing and Project Team Resilience. Minimizing, managing, and mending adversities for a team depend on a lot of experiences and knowledge resources [7]. Different from traditional teams, the knowledge resources of project teams accumulate less because they are often established for a short time. Most of the knowledge resources are held by team members.

Knowledge sharing is an efficient crossover process to integrate knowledge from team members to project teams and create new knowledge [46], enabling project teams to stock and deploy knowledge resources to address adversities. First, knowledge sharing leads to knowledge collision and integration and, by extension, provides project teams a broader knowledge perspective to identify potential risks from outside and inside projects, and enriches project teams' innovative ideas to make accurate and efficient emergency measures. Secondly, the knowledge sharing process helps the project team understand and apply knowledge, so as to achieve high efficiency and performance of emergency preparedness and crisis solution. Zhang et al. [46] argued that sharing tacit knowledge contributes to construction project teams' flexibility and ensures that project teams can survive the challenge and dynamic conditions.

Hypothesis 3: knowledge sharing has a positive effect on project team resilience

3.2.3. The Mediation Role of Knowledge Sharing. Knowledge sharing is an essential means of team knowledge accumulation and innovation, which is of great significance for the project team to find, prevent, deal with, and recover from adversities. There are some hinders blocking the way of knowledge sharing, while nonspatial proximity provides a passageway for it. So, it is a possible path that nonspatial proximity acts on project team resilience through knowledge sharing.

Specifically, the passive power of heterogeneous knowledge interaction will gradually weaken under lower cognitive proximity, in turn, inhibiting project teams generate flexible and diverse solutions. With the increasing cognitive proximity, project team members actively share knowledge and make a deeper understanding of existing knowledge, which then promotes project teams' reaction efficiency and effectiveness. Value proximity produces attraction and frequent communication. These profits make up the costs of knowledge sharing and provide more possibilities for knowledge interaction, through which project teams have more ideas to deal with and a strong ability to carry out complex and dynamic tasks during the recovery process. Social proximity clears knowledge sharing obstacles by reducing transaction costs and improving contact and increasing knowledge sharing behavior which in turn enhances the capacity of project teams to bounce back from adversities. Hung et al. [11] indicated that knowledge sharing can mediate the relationship between nonspatial

proximity and team abilities such as innovation, which reinforce the hypothesis that knowledge sharing may play a mediation role between nonspatial proximity and project team resilience.

Hypothesis 4a: knowledge sharing plays a mediation role between cognitive proximity and project team resilience

Hypothesis 4b: knowledge sharing plays a mediation role between value proximity and project team resilience

Hypothesis 4c: knowledge sharing plays a mediation role between social proximity and project team resilience.

3.3. Nonspatial Proximity, Team Cohesion, and Project Team Resilience

3.3.1. Nonspatial Proximity and Team Cohesion. Project teams need to develop cohesion in a short time to promote team members' coordination on work as soon as possible. Cognitive, value, and social proximity between team members provide ecological conditions for team cohesion.

From the perspective of knowledge categorization, project teams with moderate cognitive proximity may have low teamwork and unity because of the easy appearance of subgroup formation, while very high and low proximity makes groups better cohesion as subgrouping is less likely to occur in such a state [17, 35]. From the perspective of knowledge itself, extreme low cognitive proximity brings project teams' diverse knowledge. In such a team, team members not only are respected for their own exclusive expertise but also can learn much new knowledge from their colleagues, which makes them feel included, valued, and satisfied, enhancing their commitment to the team [47]. Team members with extremely high cognitive proximity have smoother task-based communication and can resonate with the problems existing in the project, and this helps them stick together to finish project goals. However, team members with moderate cognitive proximity have neither enough affective needs satisfaction nor enough task-related needs satisfaction to keep united, and fall into the trap of being "stuck in the middle."

Hypothesis 5a: cognitive proximity has a U-shaped effect on team cohesion

The consistency of group members in values and goals plays an important role in promoting project team cohesion [48]. Firstly, according to social identity theory, value proximity is conducive to the improvement of interpersonal attraction, and a good relationship promotes team members to unite together. Secondly, members with similar values have much in common and can quickly establish emotional connections. This emotional dependence enhances team members to stick together. Thirdly, team members with similar beliefs and ideals often have common views about project objectives and tasks, which leads to less conflict and more coordination on the project tasks. The harmony at work contributes to the cohesion of project teams [41]. Webber et al. [17] indicated that the similarity values, beliefs, and attitudes positively affect workgroup cohesion, which also provides an argument for our inference.

Hypothesis 5b: value proximity has a positive effect on team cohesion

Project team members gather together temporarily for a specific project task, and they need to start work quickly after the team is formed. For them, there is less time for knowing and adapting to each other. It is difficult to build strong trust relationships with completely unfamiliar ones since the development of intimate relationships takes a certain amount of time [49]. Relational conflicts are more likely to appear among unfamiliar team members because of weak relationships, which harm the members' unity in accomplishing the project task goals. By contrast, team members with prior social relations have an attachment base. Conservation of resources theory pointed out that a solid resource base can promote the further spiral of this resource. Therefore, the existing social capital will further increase the connections and stickiness between team members, effectively and professionally, thus reinforcing project team cohesion.

Hypothesis 5c: social proximity has a positive effect on team cohesion

3.3.2. Team Cohesion and Project Team Resilience. Morgan et al. [38] regarded group cohesion as one of the resilient characteristics of elite sports teams. Compared with sports teams, project teams have shorter establishment time, less tacit understanding, greater work pressure, and more complex challenges. So, cohesion may be more necessary for project teams to struggle against adversities.

First, the heavy attacks brought by adversities often lead to low morale and make team members' emotions too exhausted to recover from the dilemma quickly. There is the more positive affective atmosphere in project teams higher in cohesion, from which team members can get emotional supplies and have more confidence and courage to fight against difficulties. Second, team members are psychologically loving and committed to each other in cohesive project teams, and they support and depend on each other rather than malign each other, which enables them to be capable of uniting to cross difficult barriers. Third, Braun et al. [30] believed that high cohesion contributes to a common version and teamwork. Based on this view, project teams with high cohesiveness share a more unified objective and schematization for how to rebound from adversities. Further, they can implement emergency measures more efficiently and resist adversities together better.

Hypothesis 6: team cohesion has a positive effect on project team resilience

3.3.3. The Mediation Role of Team Cohesion. Team cohesion emphasizes the psychological crossover of team members, which is mainly reflected in the close social-emotional

bonding and the consistency of task objectives. It is crucial for project team members who have just gathered together to unite against adversities, while the similarity of knowledge, values, and social embeddedness between team members provides the soil for the growth of team cohesion. Thus, team cohesion may be another mediation variable between nonspatial proximity and project team resilience.

In particular, when cognitive proximity is moderate, subgroups will appear in project teams. Furthermore, team members will possess less emotional commitment brought by knowledge uniqueness and less team identity brought by knowledge similarity. At this time, project teams are loose, full of conflicts, and have low emergency capacity. In contrast, when cognitive proximity is very low or high, subgroups are difficult to form, and team members satisfy with the team or communicate smoothly, which enables them to make efforts to project recovery and hang together to defeat adversities. Value proximity contributes to better intrateam relationships, team members' resonance, and a common version of project tasks, further enhancing team members to make a quick decision on crisis response scheme and coordinate on actions to fight against stressors. Team members with social proximity communicate and interact more frequently, which will produce more intrateam connections and stickiness. As such, project teams get more determination to overcome difficulties and the ability to break the dilemma quickly.

Hypothesis 7a: team cohesion plays a mediation role between cognitive proximity and project team resilience

Hypothesis 7b: team cohesion plays a mediation role between value proximity and project team resilience

Hypothesis 7c: team cohesion plays a mediation role between social proximity and project team resilience.

As shown in Figure 1, we built a research model based on the above hypotheses. In this model, cognitive proximity, value proximity, and social proximity are considered as independent variables, and project team resilience is regarded as a dependent variable, while knowledge sharing and team cohesion are represented as mediating variables.

4. Method

We tested the above hypotheses by questionnaire survey method, and structural equation modeling (SEM) except for the U-shaped indirect effect test since there is no widely accepted SEM for it. SEM incorporates unobservable variables and can effectively control the measurement error, thus estimating the direct and indirect effects more accurately [50].

4.1. Sample and Data Collection. We chose Chinese construction project teams as a data source. Construction project teams are formed temporarily, in which team members' knowledge structure and values may be similar or heterogeneous [51], and they may have known each other before or not. Construction project teams have a high demand for resilience to bounce back from lots of challenges such as natural disasters and time pressure. We distributed surveys online and face-to-face to construction project participants by the nonprobabilistic sampling method. We sent 340 and received 298 questionnaires with a recovery rate that is 87.65%. After excluding the invalid samples such as the missing answers and the same answers, we got 256 valid questionnaires with a valid response rate that is 75.29%. The details of the samples can be seen in Table 1.

4.2. Measures. Most of the items were selected from the existing research. The sources of the constructs and items are displayed in Table 2 (see Appendix for measure details). We modified the wording of the items to make them more suitable for the project context. Participants should answer each item with a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Then, we invited three experts in the field of project management, two experts who specialized in organizational behavior, and nine construction project practitioners with more than five years of working experience to check and revise the items. After that, we distributed 65 questionnaires for preinvestigation and further improved the items according to the response results, so that the respondents could better understand what we want to ask.

Finally, cognitive proximity is measured by three items that are similar educational backgrounds, similar work backgrounds, and similar function/domains. Similar educational backgrounds refer to the similar major or learning environment. Team members with similar work backgrounds tend to have similar professional experience. Similar function/domains mean close functional area.

Value proximity is developed by four items that are similar life values, similar work values, similar goals, and agreeing on what is important to the team. Similar life values refer to team members holding similar fundamental views when recognizing and evaluating the value attributes of life activities. Similar work values mean that team members have similar value preferences for work and work-related aspects of the team. Similar goals mean team members have a close intended purpose. Team members agree on what is important to the team further reflects the similarity of their ideas and orientation.

Social proximity measures assess team members who have common experiences previously, know each other previously, have friendship previously, trust each other previously, and have heard of each other's stories previously, and each item reflects the previous embedded relations between project team members.

Knowledge sharing is measured by five items. Project team members should answer if they frequently share official documents or manuals, project knowledge, technical skills, managerial expertise, communication, or negotiation skills with teammates. Project knowledge refers to project implementation-related knowledge, such as site conditions, project status, and client requirements. Technical skills refer to methods, procedures, processes, or skills specific to a task. Managerial expertise, communication, or negotiation skills

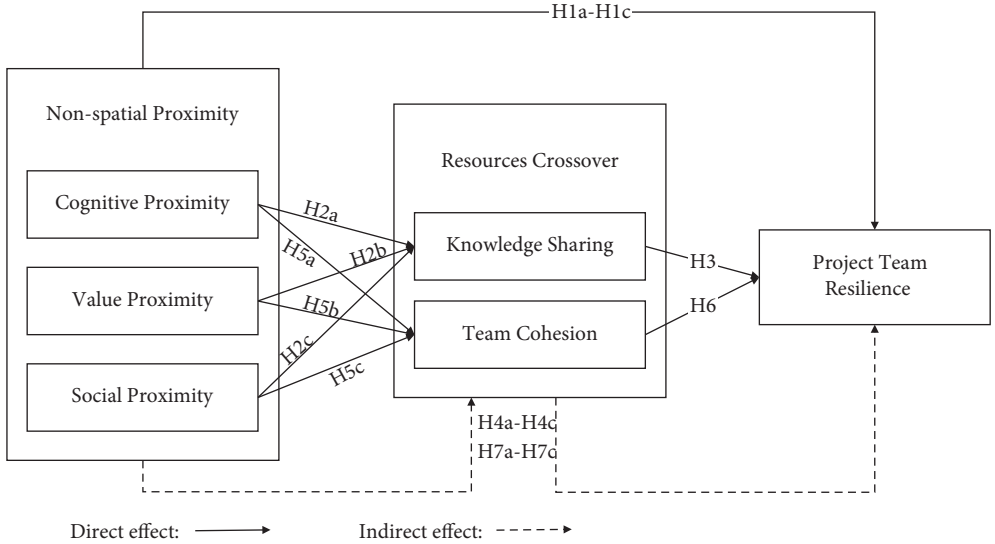


Figure 1: Research model.

Table 1: Sample description.

Category	Classification	Number of samples	Proportion (%)
Age	24 or less	22	8.59
	25–30	121	47.27
	31–40	85	33.20
	41–50	20	7.81
	51 or more	8	3.13
Position	Senior managers	68	26.56
	Middle managers	114	44.53
	Common employees	74	28.91
Project classification	Housing construction	84	32.81
	Railway projects	58	22.66
	Highway project	42	16.41
	Municipal engineering	49	19.14
	Other	23	8.98
Project team size	1–15 team members	94	36.72
	16–50 team members	104	40.63
	More than 50 team members	58	22.66
Planned duration	0-1 years	36	14.06
	1–3 years	153	59.77
	3–5 years	57	22.27
	More than 5 years	10	3.91

are presented in soft skills, such as progress control expertise.

Team cohesion is developed by five items. Project team members should answer if they contribute to the discussion and cooperate to get the work done, if there is an atmosphere of unity and fraternity in their project team, if they believe that teammates will do their fair share of the work, and if they enjoy working with teammates. The first two items reflect the unity in terms of members' behavior, the third one is involved in a team context, and the fourth and fifth items assess team cohesion from the perspective of members' beliefs.

Project team resilience is measured by seven items. Project team members should answer if their team can maintain high situational awareness at all times, if they cope well with the conflicts, pressures experienced at work, if they can provide a quick response to tensions or crises events, if their team always manages to find effective solutions, can maintain the main functions of the project, and quickly return to normal work. The first item emphasizes prevention before adversities. The next five items focus on defending during adversities. The last item emphasizes recovery after adversities.

4.3. Data Analysis

4.3.1. Common Method Biases. We carried out the method named controlling for the effects of an unmeasured latent methods factor [60] to assess the risk of common method

Table 2: Variables and their sources.

Variable	Item number	References
Cognitive proximity (CP)	3 (CP1-CP3)	Jaiswal and Dyaram [47], Cristian et al. [52]
Value proximity (VP)	4 (VP1-VP4)	Jehn et al. [53]
Social proximity (SP)	5 (SP1-SP5)	Cristian et al. [52]
Knowledge sharing (KS)	5 (KS1-KS5)	Zhang et al. [54]
Team cohesion (TC)	5 (TC1-TC5)	Hogg [55], Michalisin et al. [56], Chiniara et al. [57], Wendt et al. [58]
Team resilience (TR)	7 (TR1-TR7)	Pavez et al. [4], Ambulkar et al. [59]

bias by Amos21.0. We loaded all items on theoretical constructs, as well as on a latent common methods variance factor, and compared its structural parameters with the model with items on theoretical constructs only. As a result, the difference between the latter ($\chi 2 = 781.552$, df = 362, $\chi 2/\text{df} = 2.159$, CFI = 0.93, RMSEA = 0.067) and the former ($\chi 2 = 633.76$, df = 333, $\chi 2/\text{df} = 1.903$, CFI = 0.95, RMSEA = 0.060) is not significant, which means that the common method bias was not a concern in this study [60].

4.3.2. Confirmatory Factor Analysis. To assess the model quality, we carried out a confirmatory factor analysis using Mplus8.0. As shown in Table 3, the factor loadings of all items are greater than 0.6, the Z-values are greater than 1.96, and the P values are less than 0.001. The constructs have a strong explanatory ability to their items (R-square>0.36). The items of every construct have strong internal consistency, with the composite reliability (CR) being more than 0.7, and the average interpretation ability of all constructs being strong, with the average variance extracted (AVE) being more than 0.5 [61]. It can be seen that all constructs have good reliability and convergence validity.

To test discriminate validity, a construct correlations table was constructed in which the items on the diagonal represent the square root of AVE (see Table 4). The square root of AVE exceeds the correlations between constructs, which means that there is no multicollinearity between dimensions, and the discriminate validity is good [62].

4.4. Hypotheses Test

4.4.1. Linear Effect Test

(1) Linear direct effect test. A structural equation model 1 of the linear effect between value proximity, social proximity, knowledge sharing, team cohesion, and project team resilience in Mplus8.0 is built. The model fit is so good, with $\chi 2/\text{DF} = 2.4148$, CFI = 0.928, TLI = 0.920, RMSEA = 0.074, SRMR = 0.045, and that model 1 is acceptable. The test results are shown in Table 5. The positive effects of value proximity, social proximity on knowledge sharing, team cohesion, and project team resilience are significant, as well as the effect of knowledge sharing and team cohesion on project team resilience. H1b, H1c, H2b, H2c, H5b, H5c, H3, and H6 are accepted.

(2) Linear indirect effect test. We used bootstrap by Mplus8.0 to test the mediating effect of knowledge sharing and team cohesion. As shown in Table 6, the corresponding P values of the mediating effect of knowledge sharing and team cohesion between value proximity, social proximity, and project team resilience are less than 0.01 or 0.001, respectively. The Z-values are all greater than 1.96.0 which is not included in the confidence interval in the bias and percentile test, so the mediating effects of knowledge sharing and team cohesion between value proximity, social proximity, and project team resilience are significant. H4b, H7b, H4c, and H7c are supported.

4.4.2. U-Shaped Effect Test

(1) U-shaped direct effect test. The square of cognitive proximity was generated by the means of latent moderate structural equations provided by Klein et al. [63]. We used Mplus8.0 to construct model 2 including cognitive proximity and its square, project team resilience, knowledge sharing, and team cohesion. It is necessary to investigate the model 2 fit before the hypotheses test. However, Mplus8.0 cannot provide commonly used fitting index values such as RMSEA, CFI, and TLI if LMS is executed. To solve this problem, Sardeshmukh and Vandenberg [64] suggested building a benchmark model 2^* without square terms and investigating its fit. If model 2^* fit is acceptable and the AIC value is larger or equal than the AIC value of model 2, model 2 is acceptable. Model 2^* fit this study is accepted with $\chi 2/\text{DF} = 2.241$, CFI = 0.951, TLI = 0.944, RMSEA = 0.070, SRMR = 0.039, and its AIC value (9344.176) is larger than model 2 (9324.473), which proved model 2 is acceptable. In model 2, the positive effects of the square of cognitive proximity on team resilience, knowledge sharing, and team cohesion are significant as shown in Table 5. We then preliminarily judged that the U-shaped effect exists.

To further verify our judgment, we followed a three-step U-test procedure proposed by Lind et al. [65] to test the U-shaped effect using STATA 16.0, and the results can be seen in Table 7. We tested the relationship between cognitive proximity and project team resilience, knowledge sharing, team cohesion. As a result, (a) the square term's $P > |t|$ values are less than 0.0001; (b) the slopes are negative and positive numbers at a minimum and maximum data of cognitive proximity and are significant in the 95% confidence interval; (c) the turning points of cognitive proximity locate in the data ranges, which proves that the U-shaped relationships between cognitive proximity and project team

Table 3: Reliability and convergence validity.

Dim.	Item	Parameters of significant test			Item reliability		Composite reliability	Convergence validity
		Estimate	S.E.	Z-value	*P*-value	R-square	CR	AVE
Cognitive proximity	CP1	0.716	0.038	18.671	***	0.513	0.837	0.634
	CP2	0.767	0.036	21.402	***	0.588		
	CP3	0.895	0.032	28.287	***	0.801		
Value proximity	VP1	0.814	0.028	28.964	***	0.663	0.874	0.635
	VP2	0.879	0.025	35.298	***	0.773		
	VP3	0.764	0.035	21.778	***	0.584		
	VP4	0.722	0.039	18.728	***	0.521		
Social proximity	SP1	0.855	0.021	40.921	***	0.731	0.913	0.677
	SP2	0.825	0.024	34.991	***	0.681		
	SP3	0.887	0.018	49.470	***	0.787		
	SP4	0.793	0.027	29.544	***	0.629		
	SP5	0.746	0.031	23.903	***	0.557		
Knowledge sharing	KS1	0.787	0.027	28.725	***	0.619	0.912	0.675
	KS2	0.801	0.026	30.714	***	0.642		
	KS3	0.892	0.017	51.539	***	0.796		
	KS4	0.883	0.018	48.821	***	0.780		
	KS5	0.733	0.032	22.986	***	0.537		
Team cohesion	TC1	0.799	0.030	26.626	***	0.638	0.921	0.701
	TC2	0.857	0.024	35.652	***	0.734		
	TC3	0.826	0.027	30.328	***	0.682		
	TC4	0.801	0.030	26.699	***	0.642		
	TC5	0.900	0.019	46.196	***	0.810		
Project team resilience	TR1	0.715	0.033	21.904	***	0.511	0.942	0.698
	TR2	0.825	0.022	37.007	***	0.681		
	TR3	0.873	0.017	49.900	***	0.762		
	TR4	0.850	0.020	43.181	***	0.723		
	TR5	0.874	0.017	50.964	***	0.764		
	TR6	0.839	0.021	39.867	***	0.704		
	TR7	0.860	0.019	45.278	***	0.740		

Note: ***means that *P* values are less than 0.001.

Table 4: Construct correlations.

	CP	VP	SP	KS	TC	TR
CP	0.796					
VP	−0.096	0.797				
SP	−0.097	0.490	0.823			
KS	−0.061	0.561	0.649	0.821		
TC	−0.118	0.616	0.650	0.636	0.837	
TR	−0.122	0.628	0.656	0.672	0.780	0.835

Note: the diagonal elements are the square root of the AVE of a respective construct.

resilience, knowledge sharing, team cohesion are significant, and H1a, H2a, and H5a are accepted.

(2) Instantaneous indirect effect. The widely accepted method to test the nonlinear mediating effect is calculating the θ value of the instantaneous indirect effect proposed by Hayes et al. [66]. Following this, we calculated the instantaneous mediating effect of knowledge sharing and team cohesion between cognitive proximity and team resilience, when cognitive proximity was the average value and its plus or minus standard deviation, respectively. That is, we tested the significance of the instantaneous mediation effect by calculating the indirect change rate θ of $\partial \mathrm{M}(\mathrm{X})/\ \partial \mathrm{X} \times \partial \mathrm{Y}(\mathrm{X}, \mathrm{M})/\partial \mathrm{M}$ when X is $\overline{x} - \sigma$, $\overline{x}$, and $\overline{x} + \sigma$, respectively.

Table 5: Linear direct effect test.

Hypothesis	Estimate	S.E.	Est./S.E.	*P*-value
VP-TR (H1b)	0.163	0.059	2.746	**
SP-TR (H1c)	0.153	0.065	2.371	*
VP-KS (H2b)	0.329	0.06	5.504	***
SP-KS (H2c)	0.497	0.056	8.947	***
VP-TC (H5b)	0.396	0.056	7.103	***
SP-TC (H5c)	0.465	0.054	8.642	***
KS-TR (H3)	0.196	0.064	3.048	**
TC-TR (H6)	0.461	0.064	7.173	***
CP2-TR (H1a)	0.302	0.067	4.496	***
CP2-KS (H2a)	0.303	0.084	3.612	***
CP2-TC (H5a)	0.226	0.075	3.028	**
CP2-TR (H1a)	0.302	0.067	4.496	***

Note. *** means that *P* values are less than 0.001, ** means that *P* values are less than 0.01, and *means that *P* values are less than 0.05.

Table 8 shows that when cognitive proximity changes from $\overline{x} - \sigma$ to $\overline{x}$, and knowledge sharing's θ value changes from -0.219 to −0.01, the confidence interval appears "cross-zero", indicating that the reverse instantaneous intermediary role of knowledge sharing has experienced a process of "from presence to absence." When cognitive proximity increases from $\overline{x}$ to $\overline{x} + \sigma$, knowledge sharing's θ value changes from -0.01 to 0.2, and the confidence intervals are greater than 0,

Table 6: Linear indirect effect test.

Hypothesis	Point estimate	Product of coefficient			Bootstrap 1000 times 95%CI			
		S.E.	Est./S.E.	P-value	Bias corrected		Percentile	
					Lower	Upper	Lower	Upper
VP-KS-TR (H4b)	0.092	0.035	2.653	**	0.039	0.178	0.038	0.175
VP-TC-TR (H7b)	0.212	0.054	3.895	***	0.116	0.340	0.115	0.337
TOTAL	0.304	0.066	4.624	***	0.196	0.457	0.196	0.454
SP-KS-TR (H4c)	0.125	0.039	3.233	**	0.059	0.214	0.056	0.210
SP-TC-TR (H7c)	0.224	0.049	4.606	***	0.145	0.335	0.140	0.328
TOTAL	0.348	0.061	5.668	***	0.239	0.480	0.231	0.469

Note: ***means that P values are less than 0.001, and **means that P values are less than 0.01.

Table 7: U-test.

Hypothesis	$P > \lvert t \rvert$ value	T-value	Slopes (95%CI)		Turning point	Data range
CP2-TR (H1a)	***	4.14	−0.692***	0.567***	3.197	[2.922, 3.622]
CP2-KS (H2a)	***	5.00	−0.874***	0.863***	3.012	[2.774, 3.275]
CP2-TC (H5a)	***	4.12	−0.861***	0.732***	3.161	[2.883, 3.569]

Note. ***means that $P > \lvert t \rvert$ values are less than 0.001.

Table 8: Test of the instantaneous indirect effect.

Dim.	X (instantaneous indirect effect value θ)	Bootstrap (times)	90% CI		95% CI	
			Lower 5%	Upper 5%	Lower 2.5%	Upper 2.5%
Knowledge sharing	$\overline{x} - \sigma$ (−0.219)	1000	−0.321	−0.133	−0.339	−0.116
		2000	−0.315	−0.131	−0.335	−0.113
		5000	−0.315	−0.130	−0.334	−0.112
	$\overline{x}$ (−0.01)	1000	−0.053	0.036	−0.065	0.041
		2000	−0.055	0.036	−0.065	0.043
		5000	−0.053	0.036	−0.064	0.044
	$\overline{x} + \sigma$ (0.2)	1000	0.113	0.281	0.097	0.296
		2000	0.114	0.282	0.098	0.296
		5000	0.115	0.282	0.097	0.297
Team cohesion	$\overline{x} - \sigma$ (−0.251)	1000	−0.382	−0.126	−0.406	−0.100
		2000	−0.374	−0.123	−0.395	−0.097
		5000	−0.367	−0.116	−0.389	−0.091
	$\overline{x}$ (−0.043)	1000	−0.104	0.013	−0.116	0.024
		2000	−0.102	0.012	−0.11	0.023
		5000	−0.103	0.013	−0.113	0.024
	$\overline{x} + \sigma$ (0.164)	1000	0.052	0.259	0.032	0.275
		2000	0.065	0.264	0.044	0.281
		5000	0.065	0.263	0.045	0.280

indicating that knowledge sharing has an obvious positive instantaneous mediating effect between cognitive proximity and team resilience. Therefore, H4a is partially supported. Involving team cohesion, the changing trend of θ value is consistent with knowledge sharing (see Table 8 for details), so H7a is partially supported.

5. Discussion

Through the analysis above, we found that cognitive proximity has a U-shaped effect on project team resilience, knowledge sharing, and team cohesion. Value proximity, social proximity, knowledge sharing, and team cohesion positively influence project team resilience, and knowledge sharing and team cohesion mediate the relationships between nonspatial proximity and project team resilience. The findings make rich theoretical and practical contributions.

5.1. Theoretical Implications. First, compared with individual resilience and organizational resilience, there are still fewer studies on team resilience, let alone project team resilience. Pavez et al. [4] called for developing team resilience research in the project context. The project-based environment and conditions are unique, can exacerbate, neutralize, or restrict theories [4]. Accordingly, the development of team resilience theory should attach importance to the project context. This study responds to their suggestions and explored team resilience in the project-based

environment, enriching the research on project team resilience.

Second, current researches mostly studied proximity at a cross-organizational level, whereas few studies systematically discussed it between individuals. This study responds to the call of Christensen and Pedersen [15] to expand the proximity theory from the cross-organizational level to the cross-individual level. Based on the focus of team theory, we divided the dimensions of nonspatial proximity of project teams into cognitive proximity, value proximity, and social proximity, giving them new connotations. This provides individual insights for expanding proximity theory.

Third, we followed the suggestion of Pavez et al. [4] regarding project team resilience as a kind of ability, which is mainly reflected in good preparation before adversities, the efficient reaction in adversities, and recovery even improvement after adversities. Based on this, we explored the influence of cognitive proximity, value proximity, and social proximity on project team resilience. The results show that strong project team resilience occurs with low or high cognitive proximity, while moderate cognitive proximity makes project team resilience weak. Values and social proximity predict high project team resilience, as similar values and social embedding produce relationship attraction and frequent communication, to ensure the project team fights against adversities efficiently. This is a pioneering attempt to study team resilience with proximity theory, complements the research perspective of project team resilience from team composition, and broadens the theoretical boundary of team resilience and proximity research.

Fourth, we echoed the call to clarify how resources crossover uses a specific passageway and cultivates team resilience [14]. From the perspective of knowledge resource crossover, the results integrate the negative and positive arguments, indicating that the negative and positive effects of cognitive proximity on knowledge sharing are conditional. Value proximity is shown benefiting knowledge sharing, which confirms the significance of value proximity from the perspective of knowledge. Our results also support the views of Christensen and Pedersen [15] and Carmeli et al. [2] that social proximity is conducive to knowledge sharing because project team members who interact temporarily for a short time are hardly "locked in" a relationship network, and in turn, the quick trust and strong communication willingness brought by social proximity are the keys for knowledge sharing in project teams. Moreover, the results indicate that knowledge sharing stimulated or suppressed by nonspatial proximity helps project teams to develop new ideas and efficient solutions to bounce back from adversities.

From the perspective of psychology resource crossover, we found the U-shaped effect of cognitive proximity on team cohesion, which confirmed the guess of Webber and Donahue [17]. It is proved that value proximity and social proximity are positive antecedents of team cohesion, as they create high interpersonal attraction and stickiness, further promoting unity and cooperation among team members to achieve project goals. In the project context, we proved the predictor role of team cohesion in the emergence of project team resilience, which followed the suggestions of Bowers et al. [20] (2018) to study team resilience from the perspective of team cohesion, and confirmed their inference that team cohesion can improve team resilience. That is to say, either preparation before adversities, the reaction to adversities, or recovery after adversities, psychological resources crossover is indispensable. Moreover, similar to knowledge sharing, team cohesion also plays a partial intermediary role between nonspatial proximity and project team resilience; that is, nonspatial proximity can also affect project team resilience through team cohesion. In conclusion, this study described how nonspatial proximity influences project team resilience through knowledge sharing and team cohesion and provided support for the ideas of Hobfol et al. (2018) using the crossover model on COR theory to explain how individuals' resources contribute to team resilience.

5.2. Practical Implications. Nonspatial proximity is not only one of the resources of team resilience but also an important passageway of knowledge resource crossover and psychology resource crossover. A project team may encounter accidents from the beginning to the end of the project, and we suggest that resources should be ensured throughout the project life cycle [4].

The U-shaped role of cognitive proximity provides a conditional path for team formation. Managers should screen team members according to the needs of the project for heterogeneous knowledge. For example, when the project is relatively simple and does not involve much heterogeneous knowledge, individuals with similar knowledge base can be selected to form a project team, so that they can make quick decisions and reach consensus quickly in case of difficulties, instead of setting up a highly heterogeneous team to sacrifice decision-making efficiency for diversifying ideas. When the project is more complex and involves tasks in multiple fields, managers had better select individuals from different majors and work experience to set up a project team, to ensure that the project team can deal with complex emergencies with diverse knowledge. If the project team has been established, managers should give full play to the advantages of low proximity or high proximity and make up for their disadvantages, such as improving communication and strengthening learning within and outside the team.

High value and social proximity are in favor of knowledge sharing, team cohesion, and project team resilience. Accordingly, the employees' values model should be established through the psychological test, behavioral test, and other means. It is also necessary for managers to learn about the social connections between employees. During the formation of the project team, managers should give priority to selecting employees with similar values and social connections to participate in the project work, on the premise of ensuring the basic needs of the project. This also explains the practical phenomenon that many employees are required to take psychological tests when applying for jobs, and team members in some projects will be sent to another project as a whole after finishing one project. If the project team has been

established, team members' values should be integrated, and the relationship should be strengthened. Holding meets of exchange, organizing various "league building" activities, building communities of practice, etc. are possible ways to shrink the value gap and develop friendships between team members.

Knowledge sharing and team cohesion are significant for project teams curbing adversity or recovering from difficulties, and they are bridges connecting nonspatial proximity and project team resilience. We put forward some practical strategies from the perspective of stimulating knowledge sharing and team cohesion. The first suggestion is to keep an open communication, which is the key to improving relationship quality and enhancing ideological interaction. The methods to implement this practice include setting a flat organizational structure, holding regular meetings, developing team shared leadership, etc. The second suggestion for project managers is to inject emotional care. Projects are often pressed for time, so project team members are under great pressure and prone to emotional exhaustion, which is very unfavorable to knowledge flow and team unity. To mitigate this problem, project managers should keep abreast of the emotional dynamics of the team members, strengthen spiritual motivation, and create a positive emotional atmosphere for team members. The third suggestion is to create a safe atmosphere, encourage team members to speak freely, boldly try, and make mistakes. In such an atmosphere, team members will not be criticized even if they say something wrong; instead, they will be respected for sharing these contents. As such, team members can put forward their views and opinions without reservation and share their experiences and lessons actively, enhancing knowledge sharing and team cohesion.

5.3. Limitations. There are some limitations in this study that should be overcome in future research. First, we collected cross-sectional data for analysis, which is hard to solve the problem of common method bias perfectly though we tried our best. Future research should carry out longitudinal analysis to further explore project team resilience from the perspective of proximity, consolidating our conclusions. Second, we measured variables at the team level from the individual views. The results contributed to an initial understanding of the relationship between nonspatial proximity and project team resilience rather than totally solid proof. Future studies should measure these team-level variables from the team insight to confirm our conclusions. Third, we only used two mediators (knowledge sharing and team cohesion) between nonspatial proximity and project team resilience, whereas there may be other important mediating variables such as collective potency and team psychological safety, which should be considered in the future. Fourth, we collected questionnaires within the scope of Chinese construction projects, lacking data support from other countries or regions and other project types. Future research should further expand the scope of data collection so that the research conclusions can be more widely understood. [67].

Data Availability

The data supporting the results of this paper are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors would like to express their sincere thanks to the experts who helped us improve the measures and are very grateful to the respondents for their support to the questionnaire. This research was funded by the National Natural Science Foundation of China (grant no. 71302025).

Supplementary Materials

The supplementary Appendix displays the details of the measures of cognitive proximity, value proximity, social proximity, knowledge sharing, team cohesion, and team resilience in project teams. (*Supplementary Materials*)

References

[1] J. Mueller, "Formal and informal practices of knowledge sharing between project teams and enacted cultural characteristics," *Project Management Journal*, vol. 46, no. 1, pp. 53–68, 2015.

[2] A. Carmeli, A. Levi, and R. Peccei, "Resilience and creative problem-solving capacities in project teams: a relational view," *International Journal of Project Management*, vol. 39, no. 5, pp. 546–556, 2021.

[3] A. C. Stoverink, B. L. Kirkman, S. Mistry, and B. Rosen, "Bouncing back together: toward a theoretical model of work team resilience," *Academy of Management Review*, vol. 45, no. 2, pp. 395–422, 2020.

[4] I. Pavez, H. Gómez, L. Laulié, and V. A. González, "Project team resilience: the effect of group potency and interpersonal trust," *International Journal of Project Management*, vol. 39, no. 6, pp. 697–708, 2021.

[5] B. J. West, J. L. Patera, and M. K. Carsten, "Team level positivity: investigating positive psychological capacities and team level outcomes," *Journal of Organizational Behavior*, vol. 30, no. 2, pp. 249–267, 2009.

[6] M. Vera, A. M. Rodríguez-Sánchez, and M. Salanova, "May the force Be with you: looking for resources that build team resilience," *Journal of Workplace Behavioral Health*, vol. 32, no. 2, pp. 119–138, 2017.

[7] D. F. Gucciardi, M. Crane, N. Ntoumanis et al., "The emergence of team resilience: a multilevel conceptual model of facilitating factors," *Journal of Occupational and Organizational Psychology*, vol. 91, no. 4, pp. 729–768, 2018.

[8] K. M. Brykman and D. D. King, "A resource model of team resilience capacity and learning," *Group & Organization Management*, vol. 46, no. 4, pp. 737–772, 2021.

[9] S. Hartmann, M. Weiss, M. Hoegl, and A. Carmeli, "How does an emotional culture of joy cultivate team resilience? A sociocognitive perspective," *Journal of Organizational Behavior*, vol. 42, no. 3, pp. 313–331, 2021.

[10] I. Meneghel, I. M. Martinez, and M. Salanova, "Job-related antecedents of team resilience and improved team performance," *Personnel Review*, vol. 45, no. 3, pp. 505–522, 2016.

[11] S.-W. Hung, M.-J. Cheng, C.-E. Hou, and N.-R. Chen, "Inclusion in global virtual teams: exploring non-spatial proximity and knowledge sharing on innovation," *Journal of Business Research*, vol. 128, pp. 599–610, 2021.

[12] R. Saundry, V. Fisher, and S. Kinsey, "Disconnected human resource? Proximity and the (Mis)Management of workplace conflict," *Human Resource Management Journal*, vol. 31, no. 2, pp. 476–492, 2021.

[13] G. M. Alliger, C. P. Cerasoli, S. I. Tannenbaum, and W. B. Vessey, "Team resilience: how teams flourish under pressure," *Organizational Dynamics*, vol. 44, no. 3, pp. 176–184, 2015.

[14] S. E. Hobfoll, J. Halbesleben, J.-P. Neveu, and M. Westman, "Conservation of resources in the organizational context: the reality of resources and their consequences," *Annual Review of Organizational Psychology and Organizational Behavior*, vol. 5, pp. 103–128, 2018.

[15] P. H. Christensen and T. Pedersen, "The dual influences of proximity on knowledge sharing," *Journal of Knowledge Management*, vol. 22, no. 8, pp. 1782–1802, 2018.

[16] R. Boschma, "Proximity and innovation: a critical assessment," *Regional Studies*, vol. 39, no. 1, pp. 61–74, 2005.

[17] S. S. Webber and L. M. Donahue, "Impact of highly and less job-related diversity on work group cohesion and performance: a meta-analysis," *Journal of Management*, vol. 27, no. 2, pp. 141–162, 2001.

[18] T. Sheafer, S. R. Shenhav, J. Takens, and W. Van Atteveldt, "Relative political and value proximity in mediated public diplomacy: the effect of state-level homophily on international frame building," *Political Communication*, vol. 31, no. 1, pp. 149–167, 2014.

[19] J. J. Dose and R. J. Klimoski, "The diversity of diversity: work values effects on formative team processes," *Human Resource Management Review*, vol. 9, no. 1, pp. 83–108, 1999.

[20] C. Bowers, C. Kreutzer, J. Cannon-Bowers, and J. Lamb, "Team resilience as a second-order emergent state: a theoretical model and research directions," *Frontiers in Psychology*, vol. 8, 2017.

[21] J. Varajao, G. Fernandes, A. Amaral, and A. M. Goncalves, "Team resilience model: an empirical examination of information systems projects," *Reliability Engineering & System Safety*, vol. 206, 2021.

[22] A. A.-B. Kamla and O. Lorne, "Knowledge sharing through inter-organizational knowledge sharing systems," *Article Options and Tools*, vol. 47, no. 1, p. 26, 2017.

[23] S. Senaratne, X.-H. Jin, and K. Balasuriya, "Exploring the role of networks in disseminating construction project knowledge through case studies," *Engineering Construction and Architectural Management*, vol. 24, no. 6, pp. 1281–1293, 2017.

[24] J. N. Cummings, "Work groups, structural diversity, and knowledge sharing in a global organization," *Management Science*, vol. 50, no. 3, pp. 352–364, 2004.

[25] F. Nooshinfard and L. Nemati-Anaraki, "Success factors of inter-organizational knowledge sharing: a proposed framework," *The Electronic Library*, vol. 32, no. 2, pp. 239–261, 2014.

[26] G. Evers and M. M. H. Chappin, "Knowledge sharing in smart grid pilot projects," *Energy Policy*, vol. 143, Article ID 111577, 2020.

[27] H. Lee, J.-G. Park, and J. Lee, "Knowledge sharing in isd projects: role of task interdependence and social capital," *International Journal of Managing Projects in Business*, vol. 14, no. 3, pp. 580–599, 2020.

[28] S. H. Bhatti, S. K. Kiyani, S. B. Dust, and R. Zakariya, "The impact of ethical leadership on project success: the mediating role of trust and knowledge sharing," *International Journal of Managing Projects in Business*, vol. 14, no. 4, pp. 982–998, 2021.

[29] A. V. Carron, L. R. Brawley, and W. N. Widmeyer, *The Measurement of Cohesiveness in Sportgroups*, 1998.

[30] M. Braun, S. Kozlowski, T. Brown, and R. DeShon, "Exploring the dynamic team cohesion–performance and coordination–performance relationships of newly formed teams," *Small Group Research*, vol. 51, Article ID 104649642090715, 2020.

[31] Q. Zheng and L. Wang, "Teammate conscientiousness diversity depletes team cohesion: the mediating effect of intra-team trust and the moderating effect of team coaching," *Current Psychology*, vol. 40, no. 6, 2021.

[32] K. A. Bantel and S. E. Jackson, "Top management and innovations in banking: does the composition of the top team make a difference?" *Strategic Management Journal*, vol. 10, no. S1, pp. 107–124, 1989.

[33] T. R. Zenger and B. S. Lawrence, "Organizational demography: the differential effects of age and tenure distributions on technical communication," *Academy of Management Journal*, vol. 32, no. 2, pp. 353–376, 1989.

[34] L. H. Pelled, "Demographic diversity, conflict, and work group outcomes: an intervening process theory," *Organization Science*, vol. 7, no. 6, pp. 615–631, 1996.

[35] D. van Knippenberg, C. K. W. De Dreu, and A. C. Homan, "Work group diversity and group performance: an integrative model and research agenda," *Journal of Applied Psychology*, vol. 89, no. 6, pp. 1008–1022, 2004.

[36] A. E. Brodsky, E. Welsh, A. Carrillo, G. Talwar, J. Scheibler, and T. Butler, "Between synergy and conflict: balancing the processes of organizational and individual resilience in an Afghan women's community," *American Journal of Community Psychology*, vol. 47, no. 3-4, pp. 217–235, 2011.

[37] I. Giannoccaro, G. F. Massari, and G. Carbone, "Team resilience in complex and turbulent environments: the effect of size and density of social interactions," *Complexity*, vol. 2018, Article ID 1923216, 11 pages, 2018.

[38] P. B. C. Morgan, D. Fletcher, and M. Sarkar, "Defining and characterizing team resilience in elite sport," *Psychology of Sport and Exercise*, vol. 14, no. 4, pp. 549–559, 2013.

[39] D. M. Amodio and C. J. Showers, ""Similarity breeds liking" revisited: the moderating role of commitment," *Journal of Social and Personal Relationships*, vol. 22, no. 6, pp. 817–836, 2005.

[40] J. Zhang and J. Bloemer, "Impact of value congruence on affective commitment: examining the moderating effects," *Journal of Service Management*, vol. 22, no. 2, pp. 160–182, 2011.

[41] D. J. Woehr, L. M. Arciniega, and T. L. Poling, "Exploring the effects of value diversity on team effectiveness," *Journal of Business and Psychology*, vol. 28, no. 1, pp. 107–121, 2013.

[42] R. M. Montoya and R. S. Horton, "A meta-analytic investigation of the processes underlying the similarity-attraction effect," *Journal of Social and Personal Relationships*, vol. 30, no. 1, pp. 64–94, 2013.

[43] L. Zhang and J. He, "Critical factors affecting tacit-knowledge sharing within the integrated project team," *Journal of Management in Engineering*, vol. 32, no. 2, 2016.

[44] X. Ren, X. F. Deng, and L. H. Liang, "Knowledge transfer between projects within project-based organizations: the project nature perspective," *Journal of Knowledge Management*, vol. 22, no. 5, pp. 1082–1103, 2018.

[45] C. Omobhude and S.-H. Chen, "The roles and measurements of proximity in sustained technology development: a literature review," *Sustainability*, vol. 11, no. 1, 2019.

[46] L. Zhang, J. He, and S. Zhou, "Sharing tacit knowledge for integrated project team flexibility: case study of integrated project delivery," *Journal of Construction Engineering and Management*, vol. 139, no. 7, pp. 795–804, 2013.

[47] A. Jaiswal and L. Dyaram, "Towards well-being: role of diversity and nature of work," *Employee Relations*, vol. 41, no. 1, pp. 158–175, 2019.

[48] M. Pratt, "To Be or not to Be: central questions in organizational identification," *Identity in Organizations: Building Theory through Conversations*, Sage Publications, Inc, California, CL, USA, 1998.

[49] A. C. Costa, K. Bijlsma-Frankema, and B. De Jong, "The role of social capital on trust development and dynamics: implications for cooperation, monitoring and team performance," *Social Science Information*, vol. 48, no. 2, pp. 199–228, 2009.

[50] J. Sun, X. Ren, and C. J. Anumba, "Analysis of knowledge-transfer mechanisms in construction project cooperation networks," *Journal of Management in Engineering*, vol. 35, no. 2, pp. 1–13, 2019.

[51] X. Ren, Z. Yan, Z. J. Wang, and J. W. He, "Inter-project knowledge transfer in project-based organizations: an organizational context perspective," *Management Decision*, vol. 58, no. 5, pp. 844–863, 2020.

[52] G. Cristian, F. Christian, T. Ekaterina, and D. Aurelia, "How does proximity affect interfirm marketing cooperation? A study of an agribusiness cluster," *Journal of Business Research*, vol. 68, no. 2, pp. 263–272, 2015.

[53] K. A. Jehn, G. B. Northcraft, and M. A. Neale, "Why differences make a difference: a field study of diversity, conflict and performance in workgroups," *Administrative Science Quarterly*, vol. 44, no. 4, pp. 741–763, 1999.

[54] P. Zhang and F. Fai Ng, "Attitude toward knowledge sharing in construction teams," *Industrial Management & Data Systems*, vol. 112, no. 9, pp. 1326–1347, 2012.

[55] M. A. Hogg, *The Social Psychology of Group Cohesiveness: From Attraction to Social Identity*, New York University Press, New York, NY, USA, 1992.

[56] M. D. Michalisin, S. J. Karau, and C. Tangpong, "Top management team cohesion and superior industry returns: an empirical study of the resource-based view," *Group & Organization Management*, vol. 29, no. 1, pp. 125–140, 2004.

[57] M. Chiniara and K. Bentein, "The servant leadership advantage: when perceiving low differentiation in leader-member relationship quality influences team cohesion, team task performance and service ocb," *The Leadership Quarterly*, vol. 29, no. 2, pp. 333–345, 2018.

[58] H. Wendt, M. C. Euwema, and I. J. H. van Emmerik, "Leadership and team cohesiveness across cultures," *The Leadership Quarterly*, vol. 20, no. 3, pp. 358–370, 2009.

[59] S. Ambulkar, J. Blackhurst, and S. Grawe, "Firm's resilience to supply chain disruptions: scale development and empirical examination," *Journal of Operations Management*, vol. 33-34, pp. 111–122, 2015.

[60] P. M. Podsakoff, S. B. MacKenzie, J. Y. Lee, and N. P. Podsakoff, "Common method biases in behavioral research: a critical review of the literature and recommended remedies," *Journal of Applied Psychology*, vol. 88, no. 5, pp. 879–903, 2003.

[61] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.

[62] D. Gefen and D. Straub, "A practical guide to factorial validity using pls-graph: tutorial and annotated example," *Communications of the Association for Information Systems*, vol. 16, pp. 91–109, 2005.

[63] A. Klein and H. Moosbrugger, "Maximum likelihood estimation of latent interaction effects with the lms method," *Psychometrika*, vol. 65, no. 4, pp. 457–474, 2000.

[64] S. R. Sardeshmukh and R. J. Vandenberg, "Integrating moderation and mediation: a structural equation modeling approach," *Academy of Management Proceedings*, vol. 20, no. 1, p. 11839, 2013.

[65] J. T. Lind and H. Mehlum, "With or without U? The appropriate test for a U-shaped relationship," *Oxford Bulletin of Economics & Statistics*, vol. 72, no. 1, pp. 109–118, 2010.

[66] A. F. Hayes and K. J. Preacher, "Quantifying and testing indirect effects in simple mediation models when the constituent paths are nonlinear," *Multivariate Behavioral Research*, vol. 45, no. 4, pp. 627–660, 2010.

[67] N. Bart, *Learning and Innovation in Organizations and Economies*, Oxford University Press, Oxford, UK, 2000.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7844524, 6 pages
https://doi.org/10.1155/2022/7844524

Research Article

An Entropy Weight-TOPSIS Based Model for Partner Selection of Strategic Alliance of Prefabricated Construction Enterprises

Bin Guo,[1,2] Shengyue Hao,[1] Yi Zhang,[3] Guangmei Cao,[1] Honghu Gao,[4] and Mingyang Zhang[5]

[1]*School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China*
[2]*Century College, Beijing University of Posts and Telecommunications, Beijing 102101, China*
[3]*School of Logistics, Beijing Wuzi University, Beijing 101149, China*
[4]*School of Management Engineering, Zhengzhou University of Aeronautics, Henan 450046, China*
[5]*School of Economics and Management, Beijing Forestry University, Beijing 100083, China*

Correspondence should be addressed to Guangmei Cao; 1910177971@qq.com

Received 6 February 2022; Accepted 24 February 2022; Published 9 April 2022

Academic Editor: Lele Qin

Selecting the right partner is a key factor for the successful construction of the strategic alliance of prefabricated construction enterprises in China. Based on the summarization of domestic and foreign studies, combined with the characteristics of the strategic alliance of prefabricated construction enterprises, the paper has constructed an evaluation indicator system of the partner selection of the strategic alliance of prefabricated construction enterprises in China. The paper also has conducted an empirical study on the evaluation model of partner selection of the strategic alliance of prefabricated construction enterprises in China by using the method Entropy Weight-TOPSIS. The research results show that the five most influential second-level indicators are commercial housing sales capability, property management capability, commitment of capital, commitment of talents, and product innovation capability. The model constructed in the paper can comprehensively evaluate and select the strategic alliance partners of prefabricated construction enterprises in China.

1. Introduction

At present, Chinese governments at all levels have launched regulatory policies for the development of prefabricated buildings. Continuous regulation has accelerated the differentiation of prefabricated construction enterprises in China. Prefabricated construction enterprises in China have overall ended the model of simple scale expansion and rapid development with huge profits. Getting bigger and stronger has become an important means for prefabricated construction enterprises in China to obtain resources such as land and capital, maintain government relations, avoid risks, and reduce costs. Making strategic alliances has become an important way for prefabricated construction enterprises in China to promote their development. Although the number of alliances has increased significantly, 30%–70% of alliances ended in failure [1, 2]. Studies have found that defects in partner selection are an important reason for failure [3, 4]. Because the prefabricated construction enterprises in China face complex and changeable market environment, selecting the appropriate alliance partner is the key to the construction of strategic alliances for prefabricated construction enterprises in China, which also needs to be further studied.

2. Literature Review

In the aspects of factors affecting the selection of strategic alliance partners, Badaracco [5] held the view that it is necessary to carefully study the compatible values, commitments, and complementary capability of the alternative partners when selecting them as alliance members. Similarly, when choosing partners, enterprises tend to choose familiar

or similar enterprises to cooperate. They seek enterprises with rare or valuable resources and hope to learn from partners who are willing to share their expertise. The best partner is the enterprise that can satisfy all these requirements. In the process of choosing partners, influence factors such as the size, management style and corporate culture of the alternative partner, the enterprise's profitability, challenges brought by the previous successful partnerships, other alliances that the alternative partner used to join in, strategy types to reduce cooperation risks, and the current internal capability of the enterprise should be considered. Hutt et al. [6] found that three important factors, trust, commitment, and compatibility, should be considered particularly in partner selection. Sierra [3] suggested using three indicators of compatibility, capability, and commitment to select partners. Shah and Swaminathan [7] also believed that three indicators of complementarity, compatibility, and commitment can be used to select partners.

To sum up, the selection of strategic alliance partners in the present mainly concentrates on the importance of strategic alliance partners and the factors affecting the selection of strategic alliance partners. Studies on the selection of strategic alliance partners of prefabricated construction enterprises in China are still rare. Based on this context, the paper has proposed a selection model of strategic alliance partners of prefabricated construction enterprises in China and analyzed their selection indicators. The paper also uses the method of Entropy Weight-TOPSIS to optimize selection, so as to determine the optimal strategic alliance partners of prefabricated construction enterprises in China.

Based on the selection practice of strategic alliance partners and other related theoretical studies as well as the industry characteristics of the strategic alliance of prefabricated construction enterprises in China, the paper has analyzed the selection criteria of the strategic alliance of the prefabricated construction enterprises from three perspectives.

2.1. Capability. The capability of an enterprise is the ground and guarantee of alliance cooperation. Murray and Siehl [8] emphasized that strategic alliances require partners to have different and complementary contributions in terms of resources, technologies, and capabilities. Anslinger and Jenk [9]further pointed out that the capability of alternative partners should take the availability of key resources, the strategic capability of teamwork, and market demand into consideration.

In summary, an important factor influencing enterprises to select alliance partners is to make up for their lack of capabilities. In general, China has relatively developed economies and high land costs, and households have relatively high requirements for housing quality and property management. The capability of strategic alliance partners of prefabricated construction enterprises in China can be evaluated in terms of the investment planning capability, land obtaining capability, product innovation capability, commercial housing sales capability, and property management capability of enterprises.

2.2. Compatibility. To evaluate the compatibility of alliance partners, the consistency of the background, goals, organization culture, resources, and values of alliance partners can be considered. Sarkar et al. [10] further pointed out that strategy and culture compatibility have a positive impact on the success of strategic alliances, and lack of culture and business compatibility may be the main reason for the failure of partnerships. Enterprises need to avoid cooperation with partners whose strategies, compatibility, character, experience, and motivation are incompatible; otherwise, alliance cooperation cannot be formed [8].

If the compatibility of the alliance partners is not good, the differences and contradictions between partners will increase as soon as the external market and environment change, which can easily lead to the collapse of the alliance. Generally, the compatibility of strategic alliance partners of prefabricated construction enterprises in China is surveyed mainly in terms of strategic goals, corporate culture, management mode, organizational structure, and the amount of commercial housing sales.

2.3. Commitment. Morgan and Hunt [11] believed that commitment means that partners are willing to invest resources and provide help in the alliance and achieve the business goals of partners through fulfilling obligations and taking responsibilities among partners. Sierra [3] held the view that partners must be willing to invest time, energy, and resources to make the alliance successful. When government policies, markets, or technologies change, partners should show a commitment to the capability and willingness to adapt and persist [5]. Moran and Stripp [12] pointed out that partnership depends on the capability of members to maintain their commitments due to the mutual relationship of interests.

Therefore, commitment is an important factor affecting the selection of strategic alliance partners of prefabricated construction enterprises in China. Prefabricated construction enterprises in China have to evaluate whether alternative partners have a sufficient degree of commitment to the alliance. The commitments of strategic alliance partners of prefabricated construction enterprises in China generally include the commitment of capital, land, talents, and knowledge.

3. Modelling Processes

The partner selection of the strategic alliance of prefabricated construction enterprises in China requires not only to construct a complete selection evaluation indicator system but also to determine the weights of indicators. In information theory, entropy can measure the probability of uncertain values of discrete random variables. The higher the order of the indicators is, the lower the information entropy and the greater the indicator weight will be. In this paper, the entropy weight method is adopted to determine the weight of the index.

The method of TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), which is also called an

ideal solution, is a sorting method proposed by Hwang and Yoon in 1981 to identify the optimal solution from limited alternatives. The basic logic of TOPSIS is to define the positive ideal solution and negative ideal solution. When a solution is the closest to the positive ideal solution and the farthest to the negative ideal solution, it is determined as the optimal solution. TOPSIS can objectively evaluate various programs under multiple indicators, minimize the influence of human factors, and ensure the authenticity and reliability of evaluation results [13, 14]. Therefore, the paper adopts the method of Entropy Weight-TOPSIS to construct a partner selection model of strategic alliances of prefabricated construction enterprises in China.

3.1. Weights of Indexes

3.1.1. Structure of the Decision Matrix. Suppose evaluation set of multiattribute decision-making problem is $M = (M_1, M_2, \ldots, M_m)$, index set is $N = (N_1, N_2, \ldots, N_n)$, and the jth index's value in the ith alternative is x_{ij}; then, the decision matrix is $X = [x_{ij}]_{m\times n}$.

3.1.2. Normalization of the Decision Matrix. In order to eliminate the influence of index dimension and its variation range on evaluation results, it is necessary to normalize the original matrix to ensure that all the attributes are equivalent and in the same format; then, the normalized decision matrix is

$$\begin{aligned} Y &= \left(y_{ij}\right)_{m\times n}, \quad i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n, \\ y_{ij} &= \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \quad i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n. \end{aligned} \tag{1}$$

3.1.3. Calculation of the Index's Entropy. According to the definition of entropy, entropy of the jth index is determined by

$$e = -k\sum_{i=1}^{m} y_{ij} \ln\ y_{ij}, \quad 0 \le e \le 1, \tag{2}$$

wherein

$$k = (\ln\ m)^{-1}, \quad (i = 1, 2, \ldots m;\ j = 1, 2, \ldots n). \tag{3}$$

Calculation of the Index's Entropy Weight. Entropy weight of the jth index is determined by

$$w_j = \frac{h_j}{\sum_{j=1}^{n} h_j}, \quad j = 1, 2, \ldots n, \tag{4}$$

wherein

$$h_j = 1 - e_j. \tag{5}$$

3.2. TOPSIS Method

3.2.1. Determination of the Weighted Decision Matrix. The weighted decision matrix is determined by the normalized decision matrix multiplication with weights of indexes and shown by

$$Z = \left(r_{ij}\right)_{m\times n}, \quad i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n, \tag{6}$$

wherein

$$r_{ij} = w_j \cdot y_{ij}, \quad (i = 1, 2, \ldots m;\ j = 1, 2, \ldots n). \tag{7}$$

3.2.2. Determination of the Ideal Solution. The ideal solution is composed of the optimal value of every attribute from the weighted decision matrix, and the negative ideal solution is composed of the worst value of every attribute from the weighted decision matrix, which are shown by

$$\begin{aligned} Z^+ &= z_1^+, z_2^+, \ldots z_n^+, \\ Z^- &= z_1^-, z_2^-, \cdots z_n^-, \end{aligned} \tag{8}$$

wherein

$$\begin{aligned} Z_j^+ &= \max\left\{z_{1j}, z_{2j}, \ldots, z_{mj}\right\}, \\ Z_j^- &= \min\left\{z_{1j}, z_{2j}, \ldots, z_{mj}\right\}, \quad j = 1, 2, \ldots, n. \end{aligned} \tag{9}$$

3.2.3. Calculation of the Distance. The distance of every feasible solution from the ideal solution and the negative ideal solution is calculated, respectively, by (10 and 11).

$$\begin{aligned} D_i^+ &= \left\|z^+ - z_i\right\| \\ &= \sqrt{\sum_{j=1}^{n}\left(z^+ - z_{ij}\right)^2}, \quad i = 1, 2, \ldots m, \end{aligned} \tag{10}$$

$$\begin{aligned} D_i^- &= \left\|z_i - z\right\| \\ &= \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z^-\right)^2}, \quad i = 1, 2, \ldots m. \end{aligned} \tag{11}$$

3.2.4. Calculation of the Relative Degree of Approximation. The relative degree of approximation is determined by

$$B_i = \frac{D_i^-}{D_i^+ + D_i^-}, \quad i = 1, 2, \ldots m. \tag{12}$$

The evaluation object is ranked according to the value of the relative degree of approximation. The bigger the value is, the better the evaluation object is.

3.3. Evaluation Indicators of Partner Selection. According to the previous research results, the evaluation indicators of partner selection of strategic alliances of prefabricated

Table 1: Evaluation indicator system of partner selection of strategic alliances of prefabricated construction enterprises in China.

First-level indicator	Second-level indicator
Capability C_1	Investment planning C_{11}
	Land acquisition C_{12}
	Product innovation C_{13}
	Commercial house sales C_{14}
	Property management C_{15}
Compatibility C_2	Strategic goal C_{21}
	Corporate culture C_{22}
	Management model C_{23}
	Organizational structure C_{24}
	Amount of commercial house sales C_{25}
Commitment C_3	Capital C_{31}
	Land C_{32}
	Talents C_{33}
	Knowledge C_{34}

Table 2: The indicators' evaluation values of six alternative partners.

First-level indicator	Second-level indicator	P1	P2	P3	P4	P5	P6
Capability C_1	Investment planning C_{11}	7.4	7.6	8.3	8.6	7.8	8.2
	Land acquisition C_{12}	8.3	8.8	8.2	9.1	7.9	7.6
	Product innovation C_{13}	7.6	8.1	7.6	8.4	8.8	9.0
	Commercial house sales C_{14}	5.8	6.7	7.4	6.5	7.0	5.9
	Property management C_{15}	8.8	8.5	7.2	9.4	7.8	8.6
Compatibility C_2	Strategic goal C_{21}	8.5	8.2	9.0	7.8	8.3	9.1
	Corporate culture C_{22}	8.8	8.1	8.5	7.8	8.2	8.8
	Management model C_{23}	9.1	8.7	8.6	9.2	8.5	8.9
	Organizational structure C_{24}	7.8	8.7	8.5	7.8	7.6	7.9
	Amount of commercial house sales C_{25}	7.7	8.9	7.6	8.5	7.8	8.4
Commitment C_3	Capital C_{31}	6.9	6.7	7.6	8.3	7.8	7.4
	Land C_{32}	8.7	7.5	7.9	7.4	8.2	7.6
	Talents C_{33}	7.8	7.4	7.2	6.7	8.3	7.5
	Knowledge C_{34}	7.8	8.6	9.4	9.1	8.6	8.8

construction enterprises in China are constructed as shown in Table 1.

4. Model Evaluation and Results

4.1. Research Object Selection and Data Collection. The paper has selected JA real estate enterprise (hereinafter referred to as JA Company) as the research sample to verify the feasibility and rationality of the method of partner selection of strategic alliances of prefabricated construction enterprises in China.

JA Company is one of the earliest real estate companies engaged in real estate development in China. JA Company has formed strategic alliances with many prefabricated construction enterprises. JA Company selects elites from various departments within the company to form a selection team of strategic alliance partners to be responsible for the selection of strategic partners, which covers all aspects of the enterprise from design to sales, as well as all internal management and operation aspects of the enterprise. Based on the previously studied selection indicator system of strategic alliances of prefabricated construction enterprises in China, the paper has finally selected a total of 6 prefabricated construction enterprises in China as alternative partners, which are P1, P2, P3, P4, P5, and P6, respectively, and conducted empirical analysis on the selection method of strategic alliances of prefabricated construction enterprises in China.

According to the evaluation indicator system (shown in Table 1), the indicators' evaluation values of those six alternative partners are shown in Table 2.

4.2. Evaluation Results

4.2.1. Calculation of the Entropy Weight and the Ideal Solution. The entropy weights are calculated according to equations (2)–(5). The positive ideal value and the negative ideal value are obtained by equations (6)–(9). The results are shown in Table 3.

4.2.2. Determination of Evaluation Ranks. The distance of every feasible solution from the positive ideal solution and the negative ideal solution is obtained according to (10) and (11). The relative degree of approximation is determined according to (12). The queuing indicator value of six alternative partners could be ranked by the relative degree of approximation and is shown in Table 4.

Table 3: The entropy weights and the ideal solutions of six alternative partners.

First-level indicator	Second-level indicator	Entropy weights	Positive ideal value	Negative ideal value
Capability C_1	Investment planning C_{11}	0.0515	0.0093	0.0080
	Land acquisition C_{12}	0.0699	0.0128	0.0107
	Product innovation C_{13}	0.0808	0.0147	0.0124
	Commercial house sales C_{14}	0.1416	0.0267	0.0209
	Property management C_{15}	0.1358	0.0254	0.0194
Compatibility C_2	Strategic goal C_{21}	0.0535	0.0096	0.0082
	Corporate culture C_{22}	0.0365	0.0064	0.0057
	Management model C_{23}	0.0158	0.0027	0.0025
	Organizational structure C_{24}	0.0467	0.0084	0.0073
	Amount of commercial house sales C_{25}	0.0646	0.0118	0.0100
Commitment C_3	Capital C_{31}	0.0979	0.0182	0.0147
	Land C_{32}	0.0612	0.0113	0.0096
	Talents C_{33}	0.0821	0.0152	0.0123
	Knowledge C_{34}	0.0621	0.0112	0.0093

Table 4: The distance, the relative degree of approximation, and evaluation ranks.

Alternative partners	Positive ideal solution	Negative ideal solution	Relative degree of approximation	Evaluation ranks
P1	0.0078	0.0053	0.4021	5
P2	0.0059	0.0058	0.4927	2
P3	0.0073	0.0068	0.4836	3
P4	0.0051	0.0081	0.6117	1
P5	0.0100	0.0065	0.3931	6
P6	0.0069	0.0055	0.4411	4

5. Discussion

According to the evaluation results and based on the weights of each indicator, it can be concluded that the weights of capability, compatibility, and commitment are 47.96%, 21.70%, and 30.33%, respectively. The findings of evaluation results indicate that capability has the greatest influence on the partner selection of strategic alliance of prefabricated construction enterprises. The five most influential second-level indicators are commercial housing sales capability(14.16%), property management capability (13.58%), commitment of capital (9.79%), commitment of talents (8.21%), and product innovation capability (8.08%).

The outcomes of applying the TOPSIS approach revealed the ranking of the alternative partners. The bigger the relative degree of approximation is, the better the partner is. As can be seen from Table 4, evaluation ranks of six alternative partners are as follows: P4 >P2 > P3> P6> P1> P5. The results obtained by this method are consistent with reality. P4, P2, and P3 are the top three alternative partners, and P4 is the most promising alternative partner. In total, the method of Entropy Weight-TOPSIS provides an opportunity for partner selection of strategic alliance of prefabricated construction enterprises.

6. Conclusion and Limitations

The paper has constructed an evaluation indicator system of partner selection of strategic alliances of prefabricated construction enterprises in China, which is composed of 3 first-level indicators of capability, compatibility, and commitment and 14 second-level indicators. The paper has also constructed an evaluation model of partner selection of strategic alliances of prefabricated construction enterprises in China based on the method of Entropy Weight-TOPSIS. Six alternative partners of JA Company have been selected as research samples to conduct empirical study. The model constructed in the paper can comprehensively evaluate and select the strategic alliance partners of prefabricated construction enterprises in China.

A drawback sometimes arises with Entropy Weight-TOPSIS which is associated with the relative nature of the judgments involved. Here, changing the set of alternatives changes the ranking of all alternatives. Further research studies can focus on designing more reasonable evaluation methods.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (NSFC) under grant numbers 72002015 and 71901027.

References

[1] P. Kale and H. Singh, "Managing strategic alliances: what do we know now, and where do we go from here?" *Academy of Management Perspectives*, vol. 23, no. 3, pp. 45–62, 2009.

[2] A. Rahman, "Challenges in privately joint-ventured project: a case study," *Journal of Logistics, Informatics and Service Science*, vol. 6, no. 2, pp. 90–107, 2019.

[3] M. C. de la Sierra, *Managing Global Alliances: Key Steps for Successful Collaboration*, Addison-Wesley Publishing Company, Boston, MA, USA, 1995.

[4] P. Bierly and S. Gallagher, "Explaining alliance partner selection: fit, trust, and strategic expediency," *Long Range Planning*, vol. 40, no. 2, pp. 134–153, 2007.

[5] J. L. Badaracco, *The Knowledge Link: How Firms Compete through Strategic Alliances*, Harvard Business School Press, Boston, MA, USA, 1991.

[6] M. D. Hutt, E. R. S. Ord, B. A. Walker, and P. H. Reingen, "Case study-defining the social network of a strategic alliance," *MIT Sloan Management Review*, vol. 41, no. 2, pp. 51–62, 2000.

[7] R. H. Shah and V. Swaminathan, "Factors influencing partner selection in strategic alliances: The moderating role of alliance context," *Strategic Management Journal*, vol. 29, no. 5, pp. 471–494, 2008.

[8] A. I. Murray and C. Siehl, *Joint Ventures and Other Alliances: Creating A Successful Cooperative Linkage*, Financial Executives Foundation, Morristown, NJ, USA, 1989.

[9] P. Anslinger and J. Jenk, "Creating successful alliances," *Journal of Business Strategy*, vol. 25, no. 2, pp. 18–22, 2004.

[10] M. Sarkar, R. Echambadi, S. T. Cavusgil, and P. S. Aulakh, "The influence of complementarity, compatibility, and relationship capital on alliance performance," *Journal of the Academy of Marketing Science*, vol. 29, no. 4, pp. 358–373, 2001.

[11] R. M. Morgan and S. D. Hunt, "The commitment-trust theory of relationship marketing," *Journal of Marketing*, vol. 58, no. 3, pp. 20–38, 1994.

[12] R. T. Moran and W. G. Stripp, *Dynamics of Successful International Business Negotiations*, Gulf Publishing Company, Houston, TX, USA, 1991.

[13] H.-Y. Wu, a. Tsai, and H.-S. Wu, "A hybrid multi-criteria decision analysis approach for environmental performance evaluation: An example of the TFT-LCD manufacturers in Taiwan," *Environmental Engineering and Management Journal*, vol. 18, no. 3, pp. 597–616, 2019.

[14] V. Zemlickienė, "Using TOPSIS method for assessing the commercial potential of biotechnologies," *Journal of System and Management Sciences*, vol. 9, no. 1, pp. 117–140, 2019.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 3953464, 11 pages
https://doi.org/10.1155/2022/3953464

Research Article

Risk Evaluation of Urban Integrated Pipe Corridor Operation and Maintenance Based on Improved AHP-CIM Model

Shuai Wang and Shaochuan Fu

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China

Correspondence should be addressed to Shuai Wang; 16113139@bjtu.edu.cn

Received 22 February 2022; Accepted 8 March 2022; Published 7 April 2022

Academic Editor: Lele Qin

In order to scientifically and objectively evaluate the risk in the operation and maintenance process of the urban integrated pipe corridor, and then prevent the occurrence of urban integrated pipe corridor operation and maintenance accidents, this paper combines AHP analysis and CIM model to propose a new model for the risk assessment of pipe corridors: AHP-CIM model, and uses the model to conduct a verification of the operation and maintenance risk evaluation of the Beijing Tongzhou Canal Core Area North Ring Tunnel Integrated Pipe Corridor. Using a combination of qualitative and quantitative methods, the risk factors in the operation and maintenance process of the integrated urban pipe corridor were first identified and their weights determined, and then the CIM model was used to calculate the probability distribution of the levels of risk factors at each level of the hierarchical model, and finally the risk assessment set of the risk probability distribution of this integrated pipe corridor was obtained. The results show that the overall O&M risk level of this integrated pipe corridor is high, and its probability is 69.47%.

1. Introduction

In recent years, due to the increasing scarcity of land resources, integrated pipe corridors have gradually become the main choice for the construction of municipal facilities in cities due to their superiority in terms of resource integration and convenient maintenance. With the policy support of the State Council, the construction scale of urban underground integrated pipeline corridors in China is also gradually expanding.

A comprehensive urban underground pipeline corridor is a municipal underground pipeline complex that integrates municipal pipelines such as electric power, communication, gas, water supply and drainage, heating and other engineering pipelines in a common underground tunnel space, and achieves its unified planning, operation, maintenance and management by setting up special lifting, maintenance ports, control and testing supporting systems, etc. As a public service infrastructure for cities, the construction of underground integrated urban corridors is of great significance in solving urban diseases, promoting the improvement of the carrying capacity of cities and meeting the needs of people's livelihood.

However, in general, the construction of urban underground integrated corridors in China is still in its infancy, and although the level of control of China's corridor operation and maintenance contractors has improved considerably in recent years, the level of operation and maintenance management of integrated corridors is still inadequate, and the risk assessment methods for corridor operation and maintenance are not yet perfect, with disasters and accidents occurring from time to time. There is still a lack of more scientific and objective methods to evaluate the overall risk of integrated corridor operation and maintenance.

In this paper, based on the analysis of risk factors of urban underground integrated pipeline corridors, a new risk evaluation of integrated pipeline corridor O&M will be established using the improved AHP analysis method and CIM model, and applied to practical cases.

2. Literature Review

At present, underground integrated pipeline corridors are under construction or in operation in several cities in China. Safety issues are crucial in the operation and maintenance of integrated pipe corridors, and in recent years, scholars at home and abroad have conducted a lot of research on this.

2.1. Current Status of Domestic Research. More ideas have been put forward by domestic scholars on the risk evaluation of integrated pipeline corridors, covering various stages such as investment, construction, operation and maintenance, and the whole life cycle. The existing literature is categorized into three types: specialized disaster and accident risk evaluation studies, coupled risk evaluation studies, and comprehensive risk evaluation studies.

Specialized disaster-incident risk evaluation research: Zhao [1] and Wang [2] conducted a comprehensive risk identification and evaluation of natural gas leakage accidents in integrated pipeline corridors using the accident tree analysis method as well as the Kent method, respectively; Xiangling et al. selected five aspects based on hierarchical analysis and fuzzy comprehensive evaluation method, including integrated pipeline corridor situation, firefighting facilities, evacuation facilities, safety management, and escape personnel skills, as the main influencing factors affecting the fire risk of integrated pipeline corridors, and evaluated the fire risk of integrated pipeline corridors [3]; Huang and Lin established a fire safety evaluation index system for integrated pipeline corridors and proposed to evaluate the fire safety level of integrated pipeline corridors using an evaluation model based on AHP-evidence theory [4]; Shen used the fuzzy fault tree analysis method to assess, from the perspective of risk research The failure probability of gas pipeline leakage in urban integrated pipeline corridors, identified the main risk points in them, developed a dedicated emergency plan and evaluated its completeness [5].

Coupled risk evaluation study. Wang et al. established hazard evaluation indicators for a single disaster that may occur in the integrated pipeline corridor, and applied fuzzy mathematical methods to establish a coupling degree model so as to obtain the coupling relationship between multiple disasters, and finally proposed a risk evaluation method for the coupling of disasters caused by multiple disasters in the integrated pipeline corridor [6]; Qiu et al. proposed a coupled evaluation method for the construction safety risk of the integrated pipeline corridor based on CM and information entropy method, using information entropy to quantify the weight of each index, and quantitatively evaluated the safety risk state of integrated pipe corridor construction based on coupling degree model with coupling degree value [7]; Chai and Liu designed a multi-hazard coupled prediction model of integrated pipe corridor based on fuzzy clustering analysis, implemented clustering based on variable fuzzy clustering method, and then applied the use of fuzzy mathematics to obtain the coupling relationship between multiple hazards, and finally The multi-hazard coupled prediction of integrated pipeline corridor was realized [8].

Comprehensive risk evaluation research: Chen et al. constructed a fuzzy comprehensive assessment model for disaster risk of comprehensive pipeline corridors based on Bayesian networks and achieved ratings for disaster risk [9]; Liu et al. constructed an evaluation model based on grey clustering method to evaluate the operational risk of underground comprehensive pipeline corridor projects [10]. Zhang and Zhang established a whole-life cycle risk assessment index system and applied fuzzy hierarchical analysis to risk assessment [11]; Lu et al. constructed a risk evaluation model for operation and maintenance of underground integrated pipeline corridor projects based on information entropy combination of empowerment and topologizability theory [12]; Cai et al. established a construction safety risk based on improved D-S evidence theory evaluation model for a comprehensive evaluation of the first phase of the construction of the comprehensive pipe corridor in Kaizhou, Chongqing [13]; meanwhile, literature [14] and literature [15] also made relevant studies on comprehensive risk evaluation of underground comprehensive pipe corridors from different perspectives, involving issues such as the comparison of comprehensive pipe corridor operation and maintenance in different regions and comprehensive pipe corridor operation and maintenance disasters.

2.2. Status of Research abroad. Although the construction of foreign integrated pipe corridor compared to the domestic advancement, foreign scholars on the integrated pipe corridor risk evaluation research is relatively mature, but simply for the integrated pipe corridor risk evaluation research literature compared to the domestic is less, involving there are related domain tube tunnel risk evaluation more. Therefore, the existing literature is grouped into two categories: risk evaluation studies of integrated pipeline corridors, and other related risk evaluation studies.

Canto-Perello et al. proposed an expert system combining colour-coded, Delphi and hierarchical analysis methods to analyse the criticality and threat of integrated pipe corridors, which was used to support the planning of safety policies for urban underground facilities [16]; Jang and Jung investigated gas leaks and unknown ignitions in integrated pipe corridors due to gas explosions [17]; Wang and Fang constructed a risk evaluation model for integrated pipe corridor PPP projects, identified risk factors for utility based on a questionnaire survey, and then designed a risk evaluation index system and used an optimized fuzzy integrated rating method for risk evaluation [18]; He et al. proposed a new fire risk assessment method within integrated pipe corridors in In the absence of historical cable fire data, fuzzy theory was used to calculate the failure probability of the main events of cable fires, and fuzzy inference was performed using a weighted fuzzy Petri net, and a numerical simulation method was used to quantify the losses caused by cable fires so as to quantify the risk of cable fires [19]; Ding et al. applied a fault tree model to influence the

urban underground integrated pipeline corridor project PPP model risks were analyzed, resulting in factors that have a greater impact on project risks, and found that the application of the PPP model in integrated underground corridors is more suitable for developed regions [20]; while the literature [21, 22] analyzed the key risks of urban integrated corridors and their ratings from the actual situation of Chinese as well as Korean cities, respectively.

Other related risk rating studies: as early as 2011, Rita and Herbert proposed a method to systematically assess and manage tunnel-related risks by combining a geological prediction model with a construction strategy decision model to predict the geology prior to tunnel construction to select the least risky construction strategy among different construction strategies [23]; Golam et al. proposed a Bayesian belief network for assessing the risk of failure of metal water pipes model that can rank water supply trunk pipes in distribution networks to identify vulnerable and sensitive pipes for rational water supply management [24]; Zhang et al. proposed a method for tunnel fire safety risk analysis based on fuzzy Bayesian networks [25]; Khwaja Mateen et al. proposed a new public-private partnership based on fuzzy integral infrastructure project (PPP project) risk assessment method to help stakeholders make risk management decisions [26]; Wu et al. developed a cloud model-based risk assessment model for metro tunnel shield construction, which effectively addressed the stochastic uncertainty and fuzzy uncertainty of indicator factors [27]; in addition to these, Kang, Marian et al. Martinka et al. have also implemented dynamic analysis of risks in underground tunnels, sub-sea tunnels, and cables, respectively [28–30]. Han et al. through the combination of the classical AHP method and DSM method effectively manage its risks in operation and maintenance management [31].

2.3. Shortcomings of Existing Studies

(1) The existing studies are more concerned with the impact of these special disasters such as gas leaks and fires in urban integrated pipeline corridors and their prevention and control, and there are relatively few studies on the overall risk assessment of the operation and maintenance of urban integrated pipeline corridors

(2) Existing research is relatively more focused on the investment, design and construction of integrated pipeline corridors, and relatively less on the analysis and study of the operation and maintenance risks of integrated pipeline corridors

(3) In the process of research on the operation and maintenance risks of integrated pipeline corridors, most of the studies tend to be qualitative, and there is a lack of reliable quantitative and comprehensive evaluation methods for operation and maintenance risks

(4) In the process of ranking the importance of risks, subjective weighting methods such as hierarchical analysis are mostly used, which makes it difficult to fully consider the information contained in the risk evaluation indicators and has certain limitations

3. Research Methodology

3.1. Improving the AHP Hierarchical Analysis. The AHP hierarchical analysis method is an effective approach to complex problems proposed by American scholar T. L. Saaty. It is the process of decomposing a complex problem into multiple influencing factors, establishing a hierarchy based on the logical relationship between the factors, calculating qualitative and quantitative calculations for each level, and finally summing up the levels according to the weights to achieve a comprehensive decision-making process. The specific steps of the application of the method are as follows:

(1) Establish a hierarchical structure model. According to different attributes, each factor is decomposed into target layer, criterion layer, and indicator layer.

(2) Construct a comparative judgement matrix. Starting from the second level of the hierarchical model, the comparison method and the scaling method are used to compare the importance of factors between the same levels, so as to construct a comparison matrix, as

$$\left(B_{ij}\right)_{n\times n} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}. \quad (1)$$

At present, the improvement of the AHP method by domestic scholars mainly focuses on the comparison matrix, the construction of the scale and the solution of the weights of the feature vectors, among which the scale is the focus of the research on the construction problem. In this paper, we choose to improve the AHP method in terms of the design of the scale.

Table 1 below shows the assignment rules of the traditional "nine-scale method" for constructing the comparison matrix. The analysis shows that the method is highly subjective and inconvenient in practice, and requires the use of seat differences between words, such as "slightly important", "more important", "extremely important" and "extremely important" " and "extremely important" to construct a comparison matrix. This is particularly difficult in practice for sets of factors that are less distinct in terms of impact and have a larger base.

In view of the shortcomings of the "nine-scale method," a new "five-scale method" is established to make judgments, converting the nine numbers from 1 to 9 in the nine-scale method into five numbers of 1/4, 1/2, 1, 2 and 4, thus constructing a new judgement matrix as shown in Table 2 below. The new judgement matrix is shown in Table 2. The

Table 1: Two-by-two comparison of the "nine-scale method."

Numerical values	Level of importance
1	Element i and element j are more important than equally
3	The i and j elements are slightly more important than the
5	Element i is more important than element j
7	The i element is much more important than the j element
9	Element i is significantly more important than element j
2, 4, 6, 8	The mutual importance of elements i and j lies between the two adjacent judgement scales above

Table 2: Two-by-two comparison of the improved "five-scale method."

Numerical values	Level of importance
4	Factor i is absolutely more important than factor j
2	Factor i is marginally more important than factor j
1	Factor i is equally important than factor j
1/2	Factor j is slightly more important than factor i
1/4	The j-factor is definitely more important than the i-factor

improved "five-scale method" distinguishes to a certain extent from the vague expressions in the text of the "nine-scale method" by not focusing on "slightly," "obviously," "very" and so on. and "very," which reduces the subjectivity of the artificiality and makes it less difficult and more efficient to implement. In addition to this, because the five numbers are chosen in proportion to each other, the final weight allocation ratio can be quickly obtained without the need for a consistency test

(3) Normalize the comparison matrix to obtain the standard two-by-two comparison matrix, as

$$\left(\overline{B}_{ij}\right)_{n\times n} = \begin{bmatrix} \overline{b}_{11} & \overline{b}_{12} & \cdots & \overline{b}_{1n} \\ \overline{b}_{21} & \overline{b}_{22} & \cdots & \overline{b}_{2n} \\ \vdots & \vdots & \vdots & \\ \overline{b}_{n1} & \overline{b}_{n2} & \cdots & \overline{b}_{nn} \end{bmatrix}. \tag{2}$$

Calculation of risk factor weights for the criterion level as well as the indicator level. The elements of each row of the standard two-by-two comparison matrix are summed to obtain a sum value, and each element of that row is divided by this sum value separately to calculate the weight of that element, as

$$w_i = \frac{\overline{b_i}}{\sum_{i=1}^{n} b_i}. \tag{3}$$

A weight matrix is constructed from the weight values of each indicator layer, as

$$W = \left(w_1 \;\; w_2 \;\; \cdots \;\; w_1 \right). \tag{4}$$

3.2. CIM Model. The CIM model is a memory assessment model for control intervals, divided into 2 types of series corresponding models and parallel corresponding models, and is an effective method for analyzing the superposition of complex risk factor probability distributions. It replaces the integral of the risk factor probability function directly with the sum of the histograms of the risk factor probability distribution, which simplifies the calculation of the risk factor probability and has significant advantages in handling complex and variable information.

In the urban integrated pipeline corridor operation and maintenance safety risk, the probability of accidental risk is greater, the emergence of risk factors levels is random, and there are more uncertainty factors, and they interact and influence each other, resulting in diversified influences between risk factors, when the factors causing risk change, it will inevitably lead to changes in the risk itself or associated factors, at this time, the risk factors at the same level can be simplified to parallel relationship, so this paper selects the probability superposition method of multiplication to apply the CIM parallel response model for research.

In the calculation of the probability of risk superposition, we set the decision target as X, there are n randomly occurring risk factors that affect each other, noted as $X_1, X_2, \ldots, X_n$, then its combined response probability calculation formula is as follows:

$$\begin{aligned} P\left(X_a = x_a\right) = &\sum_{i=1}^{n} P\left(X_1 = x_a, X_2 \le x_a\right) \\ &+ \sum_{i=1}^{n} P\left(X_1 < x_a, X_2 = x_a\right), \end{aligned} \tag{5}$$

where $a = 1, 2, \ldots, n$, x_a denotes the interval being divided into groups of n.

When there are two or more risk factors, we apply the model to the probability distribution superposition calculation, as shown in Figure 1 for the CIM parallel response model risk specific superposition process: the first and second risk factor probability distribution is superimposed to obtain the new probability distribution superposition value, this superposition value and the third risk factor probability distribution for the second probability distribution superposition, and so on, after n - 1 superposition

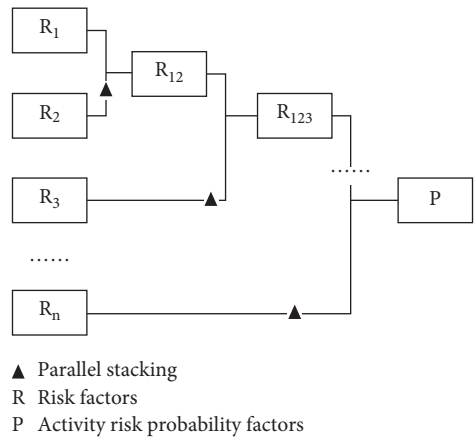


Figure 1: Risk overlay process for the CIM parallel response model.

calculation, until the last factor probability distribution superposition value, that is, the main risk level of the probability distribution.

3.3. Improved AHP-CIM Model Construction. The AHP hierarchical analysis method is systematic, concise and practical, and is able to analyse things qualitatively, but its subjectivity affects the accuracy of decision making problems. By combining AHP-CIM, the qualitative indicators in the CIM model are quantified by the AHP analysis method, which overcomes the problem of the CIM model not being able to deal with qualitative indicators well when applied alone, while compensating for the shortcomings of the AHP model being influenced by subjective factors and realising the combination of qualitative and quantitative.

The specific procedure for evaluating the O&M risk of the integrated corridor using the improved AHP-CIM model is shown in Figure 2 below:

4. Case Study

In this paper, the Beijing Tongzhou Canal Core Area North Ring Ring Tunnel Integrated Corridor is chosen as an example to analyse and validate the constructed model.

The Beijing Tongzhou Canal Core Area Beiruan Tunnel Integrated Corridor is located underneath the Tongzhou Canal Beiruan Traffic Ring Tunnel and is the first underground three-level ring corridor in Beijing that combines urban road traffic and municipal functions. The Beiluan Ring Tunnel is buried deep beneath Beiguan North Street, Xinhua East Road, Yongshun South Street and Beiguan Middle Road in Tongzhou District. The main tunnel is 1.5 km long, with a total structural width of 16.55 m and a height of 12.9 m, containing a carriageway layer, an equipment mezzanine layer and a comprehensive pipe corridor layer. The integrated pipe corridor is a double-layered structure, coconstructed with the circular tunnel. The section of the pipe corridor is arranged in three compartments, electric, water letter and thermal, with a total length of approximately 2.3 km.

4.1. Building an Integrated Corridor Operation and Maintenance Risk Evaluation Index System. As there are relatively few studies on the risks in the operation and maintenance of integrated pipeline corridors, in order to obtain a more comprehensive picture of the risk factors in the process of operation and maintenance of integrated pipeline corridors, we used the literature analysis method to read and combine the existing literature and information data in the literature review section to summarize and identify the risk factors in the process of operation and maintenance of integrated pipeline corridors.

Initially, six risk sources were identified: management factors, corridor body, corridor pipelines, infrastructure, internal and external environment and information technology, with a focus on the causes of accidents that have occurred in natural gas pipelines, water supply and drainage pipelines, electricity pipelines, oil pipelines and corridor bodies. The preliminary list of risks is shown in Table 3, based on a review of such literature and the relevant standards and regulations in each region of China.

Based on the preliminary list of risk factors for further generalization, a comprehensive evaluation index system for the operation and maintenance risks of urban integrated pipeline corridors is established in accordance with the basic principles of the hierarchical analysis method, and the system is divided into three layers according to the model construction principles of the AHP hierarchical analysis method, namely the target layer, the criterion layer and the indicator layer, as shown in Figure 3.

4.2. Determining the Weighting of Risk Factors. Combined with the actual situation of the Beijing Tongzhou Canal Core Area North Ring Tunnel, Figure 3 above was used as the risk factor hierarchy model for the comprehensive evaluation system of the operation and maintenance risk of the integrated pipeline corridor, and in accordance with the "five

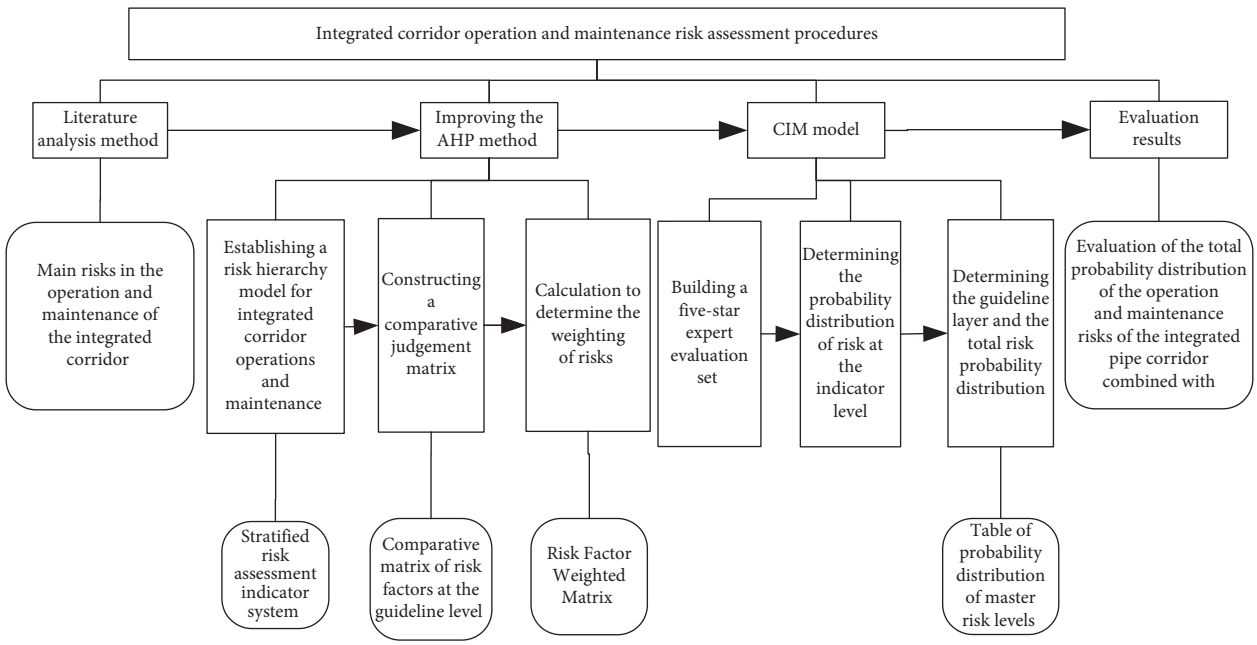


Figure 2: AHP-CIM model evaluation procedure.

Table 3: Literature collection on the main risk factors of the integrated corridor O&M management process.

Serial number	Risk category	Literature sources
1	Unclear management responsibilities and poor safety awareness	Literature [10]
2	The many management units make coordination difficult	Literature [11, 12]
3	File management in disarray	Literature [12]
4	Inadequate and unregulated management standards	Literature [13, 14]
5	Improper handling by personnel	Literature [14]
6	Invasion by persons, theft	Literature [14]
7	Inadequate routine maintenance	Literature [32]
8	Poor O&M equipment and facilities	Literature [32]
9	Technical immaturity	Literature [33]
10	External forces, third party construction damage	Literature [34]
11	Corroded pipes, substandard pipe welding	Literature [35]
12	Leaking pipes	Literature [34, 35]
13	Quality of products and installations such as valves and fittings	Literature [36]
14	Uneven settlement of pipe corridor, structural stability	Literature [37]
15	Interaction between pipelines and dangerous pipeline build-up	Literature [37]
16	Fires, explosions, etc. caused by oil, gas, etc.	Literature [38]
17	Natural disasters such as earthquakes, floods and mudslides	Literature [39]
18	Urban construction, road excavation	Literature [40, 41]
19	Air humidity, oxygen and toxic gas levels inside the corridor	Literature [38, 41]
20	Waterproofing of pipe galleries, density of drainage outlets	Literature [42]
21	Inadequate ventilation, lighting and firefighting facilities	Literature [43]
22	Dynamic update of underground pipeline information is not timely	Literature [44, 45]
23	No linkage of information above and below ground	Literature [45]
24	Insufficient intelligent control	Literature [45]
25	Poor communication	Literature [45]

scale method" described in Table 2 above, the experts of the integrated pipeline corridor were asked to compare the degree of influence of each risk factor on the project at the criterion level to obtain the relative importance between them and give the corresponding scale values, so as to construct a two-by-two comparison matrix as shown in Table 4.

A two-by-two comparison matrix of the main risk factors for this integrated corridor is obtained from Table 3 and is

$$\begin{bmatrix} 1 & 2 & 2 & 4 & 2 \\ 0.5 & 1 & 0.5 & 2 & 0.5 \\ 0.5 & 2 & 1 & 2 & 0.5 \\ 0.25 & 0.5 & 0.5 & 1 & 0.5 \\ 0.5 & 2 & 2 & 2 & 1 \end{bmatrix}. \tag{6}$$

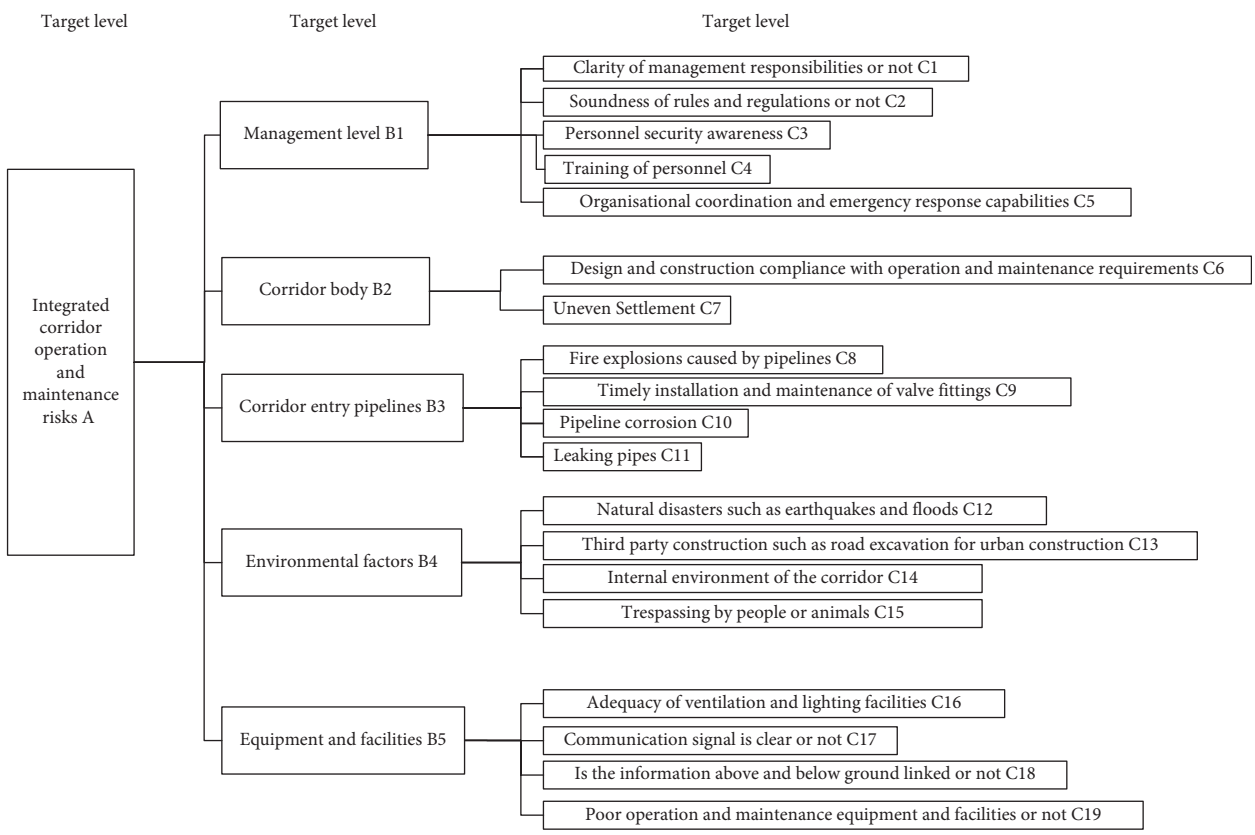


Figure 3: Integrated corridor operation and maintenance risk evaluation index system.

Table 4: Comparison matrix of risk factors for criterion level B.

A	B_1	B_2	B_3	B_4	B_5
B_1	1	2	2	4	2
B_2	1/2	1	1/2	2	1/2
B_3	1/2	2	1	2	1/2
B_4	1/4	1/2	1/2	1	1/2
B_5	1/2	2	2	2	1

Normalizing (6) gives the standard two-by-two comparison matrix:

$$\begin{bmatrix} 0.3636 & 0.2667 & 0.3333 & 0.3636 & 0.4444 \\ 0.1818 & 0.1333 & 0.0833 & 0.1818 & 0.1111 \\ 0.1818 & 0.2667 & 0.1667 & 0.1818 & 0.1111 \\ 0.0909 & 0.0667 & 0.0833 & 0.0909 & 0.1111 \\ 0.1818 & 0.2667 & 0.3333 & 0.1818 & 0.2222 \end{bmatrix}. \quad (7)$$

A modified five-scalar method was used, eliminating the need for consistency testing. The weights of the main risk factors at the criterion level are obtained according to (7) combined with the algorithm of (2) in MATLAB:

$$\begin{aligned} W &= \left(w_1 \;\; w_2 \;\; w_3 \;\; w_4 \;\; w_5 \right) \\ &= \left(0.3543 \;\; 0.1383 \;\; 0.1816 \;\; 0.0886 \;\; 0.2372 \right). \end{aligned} \quad (8)$$

4.3. Calculating the CIM Model Probability Distribution

4.3.1. Build an Expert Evaluation Set and Determine the Risk Probability Distribution for Indicator Layer C. Based on the hierarchical structure model given in Figure 1, the subrisk factors (i.e., the indicator layer) of each main risk are rated by 10 experts in five aspects: management level, corridor body, entry pipeline, environmental factors and equipment and facilities, and the evaluation results are in a five-level manner, namely high risk, relatively high risk, moderate risk, relatively low risk and low risk. Let the evaluation set be V, then it is expressed as

$$\begin{aligned} V &= \left(V_1 \;\; V_2 \;\; V_3 \;\; V_4 \;\; V_5 \right) \\ &= ((\textit{large large moderate small small}). \end{aligned} \quad (9)$$

We set the evaluation level given by an expert to the ith risk factor as j, the number of experts who give evaluation level j to risk factor i by N_j, and N is the total number of experts, then Pij denotes the probability of the risk level of that risk factor, which is calculated by

$$P_{ij} = \frac{N_j}{N}. \quad (10)$$

Accordingly, the rank probabilities for all subrisks of the indicator layer were obtained as shown in Table 5.

Table 5: Risk rating probability table for the operation and maintenance of the northern ring tunnel integrated corridor in the Tongzhou canal core area.

Risk indicators		Risk level probability				
		Small	Smaller	Moderate	Larger	Large
Management levelB_1	Clarity of management responsibilitiesC_1	0.0	0.0	0.3	0.2	0.5
	Soundness of rules and regulationsC_2	0.0	0.0	0.2	0.5	0.3
	Personnel security awarenessC_3	0.0	0.0	0.2	0.4	0.4
	Training of personnelC_4	0.1	0.1	0.2	0.3	0.3
	Organizational coordination and emergency response capabilitiesC_5	0.0	0.0	0.3	0.3	0.4
Corridor bodyB_2	Compliance of design and construction with O&M requirementsC_6	0.0	0.1	0.1	0.3	0.5
	Uneven SettlementC_7	0.2	0.0	0.5	0.2	0.1
Corridor entry pipelinesB_3	Explosive fires caused by pipelinesC_8	0.3	0.1	0.3	0.2	0.1
	Timely installation and maintenance of valve fittingsC_9	0.1	0.0	0.1	0.2	0.6
	Pipeline corrosionC_{10}	0.1	0.1	0.4	0.2	0.2
	Leaking pipesC_{11}	0.2	0.1	0.5	0.1	0.1
Environmental factorsB_4	Natural disasters such as earthquakes, floods and mudslidesC_{12}	0.5	0.1	0.3	0.1	0.0
	Third party construction such as road excavation for urban constructionC_{13}	0.4	0.2	0.4	0.0	0.0
	Internal environment of the corridorC_{14}	0.0	0.1	0.6	0.2	0.1
	People, animals trespassingC_{15}	0.5	0.1	0.3	0.1	0.0
Equipment and facilitiesB_5	Adequacy of ventilation, lighting and fire-fighting facilitiesC_{16}	0.1	0.0	0.2	0.4	0.3
	Is the communication signal clear?C_{17}	0.1	0.0	0.5	0.2	0.2
	Is the information above and below ground linkedC_{18}	0.1	0.0	0.6	0.1	0.2
	Is the equipment and facilities poorC_{19}	0.0	0.1	0.4	0.3	0.2

4.3.2. Parallel Stacking Calculates the Probability Distribution of the Principal Risk Level of the Criterion Layer B. Using the parallel response model of CIM, the probability distribution of the main risk of the guideline layer is calculated for the probability of the subrisk levels of indicator layer C in the table above. The following is an example of the algorithmic process for the probability distribution of the occurrence of each of the risk levels for criterion layer B3 into the corridor pipeline risk with a moderate number of subrisks.

(1) 1st overlay: the B_3 subrisk C_8 and C_9 risk level probabilities of the primary risk are overlaid according to (5).

Lower risk level V1 probability stack: $0.3 \times 0.1 = 0.03$

Lower risk level V2 probability stack: $0.1 \times (0.1 + 0) + 0 \times 0.3 = 0.01$

Medium risk level V3 probability stack: $0.3 \times (0.1 + 0 + 0.1) + 0.1 \times (0.3 + 0.1) = 0.1$

Higher risk level V4 probability stack: $0.2 \times (0.1 + 0 + 0.1 + 0.2) + 0.2 \times (0.3 + 0.1 + 0.3) = 0.22$

High risk level V5 probability stack: $0.1 + 0.6 \times (0.3 + 0.1 + 0.3 + 0.2) = 0.64$

The results of the 1st overlay, C89, were concatenated with the subrisk C10 to obtain Table 6, ready for the 2nd overlay.

(2) 2nd overlay: calculated by overlaying the C_{89} and C_{10} risk class probabilities based on (5).

Lower risk level V1 probability overlay: $0.03 \times 0.1 = 0.003$

Lower risk level V2 probability overlay: $0.01 \times (0.1 + 0.1) + 0.1 \times 0.03 = 0.005$

medium risk level V3 probability stack: $0.1 \times (0.1 + 0.1 + 0.4) + 0.4 \times (0.03 + 0.01) = 0.076$

Higher risk level V4 probability overlay: $0.22 \times (0.1 + 0.1 + 0.4 + 0.2) + 0.2 \times (0.03 + 0.01 + 0.1) = 0.204$

High risk level V5 probability overlay: $0.64 + 0.2 \times (0.03 + 0.01 + 0.1 + 0.22) = 0.712$

The results of the 2nd overlay, C_{8910}, were concatenated with the subrisk C_{11} to obtain Table 7 below, ready for the 3rd overlay.

(3) 3rd overlay: calculated by overlaying the C_{8910} and C_{11} risk class probabilities based on (5).

Lower risk level V1 probability overlay: $0.003 \times 0.2 = 0.0006$

Lower risk level V2 probability overlay: $0.005 \times (0.2 + 0.1) + 0.1 \times 0.003 = 0.0018$

Medium risk level V3 probability stack: $0.076 \times (0.2 + 0.1 + 0.5) + 0.5 \times (0.003 + 0.005) = 0.0648$

Higher risk level V4 probability overlay: $0.204 \times (0.2 + 0.1 + 0.5 + 0.1) + 0.1 \times (0.003 + 0.005 + 0.076) = 0.192$

High risk level V5 probability overlay: $0.712 + 0.1 \times ((0.003 + 0.005 + 0.076 + 0.204) = 0.7408$

The probability distribution of the occurrence of each risk level of the main risk B_3 at the guideline level can be obtained by concatenating the results of the 3rd overlay calculation, as shown in Table 8.

Similarly, the risk level probability distributions for B_1, B_2, B_4 and B_5 are calculated by overlaying (5) in MATLAB to

Table 6: Probability distribution of the 1st superimposed parallel risk level.

Risk indicators		Overall rating				
		Small	Smaller	Moderate	Larger	Large
B_3	C_{89}	0.03	0.01	0.1	0.22	0.64
	C_{10}	0.1	0.1	0.4	0.2	0.2
	C_{11}	0.2	0.1	0.5	0.1	0.1

Table 7: Probability distribution of the 2nd superimposed parallel risk level.

Risk indicators		Overall rating				
		Small	Smaller	Moderate	Larger	Large
B_3	2nd superimposed valueC_{8910}	0.003	0.005	0.076	0.204	0.712
	C_{11}	0.2	0.1	0.5	0.1	0.1

Table 8: Probability distribution of risk level B3 for the main risk at the guideline level.

Primary risk	Overall rating				
	Small	Smaller	Moderate	Larger	Large
B_3	0.0006	0.0018	0.0648	0.192	0.7408

Table 9: Probability distribution of risk levels for master risk at guideline level.

Code level B risk factors	Comprehensive risk assessment rating				
	Small	Smaller	Moderate	Larger	Large
B_1	0.0000	0.0000	0.0014	0.0868	0.9118
B_2	0.0000	0.0200	0.1200	0.3100	0.5500
B_3	0.0006	0.0018	0.0648	0.1920	0.7408
B_4	0.0000	0.0216	0.5454	0.3330	0.1000
B_5	0.0001	0.0000	0.0629	0.2954	0.6416

obtain Table.9 below.9 From this table, the matrix B of the main risk level probability distribution for the guideline layer is constructed and is.

$$B = \begin{bmatrix} 0.0000 & 0.0000 & 0.0014 & 0.0868 & 0.9118 \\ 0.0000 & 0.0200 & 0.1200 & 0.3100 & 0.5500 \\ 0.0006 & 0.0018 & 0.0648 & 0.1920 & 0.7408 \\ 0.0000 & 0.0216 & 0.5454 & 0.3330 & 0.1000 \\ 0.0001 & 0.0000 & 0.0629 & 0.2954 & 0.6416 \end{bmatrix}. \tag{11}$$

Multiply this risk probability distribution matrix with the weight matrix to calculate the risk assessment set V for this integrated corridor O&M risk probability distribution.

$$V = B^T \times W^T = \begin{bmatrix} 0.0000 & 0.0000 & 0.0006 & 0.0000 & 0.0001 \\ 0.0000 & 0.0200 & 0.0018 & 0.0216 & 0.0000 \\ 0.0014 & 0.1200 & 0.0648 & 0.5454 & 0.0629 \\ 0.0868 & 0.3100 & 0.1920 & 0.3330 & 0.2954 \\ 0.9118 & 0.5500 & 0.7408 & 0.1000 & 0.6416 \end{bmatrix} \times \begin{bmatrix} 0.3543 \\ 0.1383 \\ 0.1816 \\ 0.0886 \\ 0.2372 \end{bmatrix}, \tag{12}$$

$$V = \left(0.0001 \quad 0.0050 \quad 0.0921 \quad 0.2081 \quad 0.6947 \right).$$

From the results of this evaluation set, it can be seen that the ranking probability of the occurrence of risk in this urban integrated pipeline corridor is in the following order from high risk > higher risk > medium risk > lower risk > low risk, and the probability of occurrence of each risk level is 69.47%, 20.81%, 9.21%, 0.5% and 0.01% respectively, and the total risk level is mainly concentrated in the medium and high risk level.

Focusing on the main risk factors at the indicator level, it can be seen that the city's integrated pipeline corridor: management factors, corridor body factors, into the corridor pipeline factors, equipment and facilities factors risk level is high probability; corridor environmental factors risk level is moderate probability; the overall risk of corridor operation and maintenance is high.

5. Conclusions and Outlooks

In this paper, the AHP method is improved from the perspective of scalar design, and the CIM model is introduced to combine the advantages of both, and an improved AHP-CIM risk evaluation model is constructed to realize a qualitative and quantitative combined risk evaluation method for the operation and maintenance of the integrated pipeline corridor.

Based on the literature, a comprehensive analysis of the risk factors of the integrated pipeline corridor was carried out, and a hierarchical model consisting of 5 secondary and 19 tertiary indicators was established. The calculation results show that the probability of O&M risks in this integrated pipeline corridor is high that probability of 69.47%, and the focus is on four aspects: management level, corridor body, pipelines into the corridor, equipment and facilities.

In response to the findings of the study, several outlooks are given for the prevention and control of the O&M risks of the integrated pipe corridor.

(1) The government as well as the corridor O&M contractor should speed up the improvement of the regulations on the O&M of the integrated corridor, clarify the O&M content and technical requirements, unify and standardize the preparation and presentation of files and information, and speed up the standardization of O&M management.

(2) Clarify the allocation of responsibilities for O&M activities, strengthen training, improve the professional quality and safety awareness of management personnel, and try to cooperate with professional management and maintenance units or with the government to form more professional and reliable management and maintenance teams.

(3) Pay attention to and speed up the handling of emergency incidents in the corridor itself and in the part of the pipeline entering the corridor, further improve the regulations for handling emergency incidents, and reasonably allocate the composition of the personnel of the main construction body, the personnel of the pipeline entering the corridor unit and the operation and maintenance personnel in the management team.

(4) Improve the internal equipment and facilities of the integrated pipeline corridor, monitor and maintain valves, fittings and other products in a timely manner, regularly overhaul and update key infrastructure such as lighting, ventilation and fire-fighting, keep communication signals open, and pay attention to the density of water-proofing and drainage outlets in the corridor.

(5) Accelerate the construction and improvement of the information platform of the integrated pipe corridor to achieve intelligent operation and maintenance management, so as to link up information on the underground, achieve visualization of the urban underground integrated pipe corridor, and achieve intelligent control and emergency decision-making.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Y. Zhao, *Risk Assessment on Natural Gas Pipelines in an Urban Utility Tunnel[D]*, South China University of Technology, Guangzhou, 2018.

[2] Ni. Wang, *Risk Assessment of Natural Gas Pipeline in Urban Utility Tunnel[D]*, Southwest Petroleum University, Chengdu, 2018.

[3] D. Xiangling, Z. Bai, Y. Li, Li. Lei, and Z. Wang, "AHP-FCEM based fire risk evaluation of integrated pipe corridors[J]," *China Science and Technology Information*, vol. 3, no. 4, pp. 113–116, 2019.

[4] P. Huang and Q. Lin, "Fire safety evaluation of integrated pipe corridors based on AHP evidence theory[J]," *Journal of Safety and Environment*, vol. 20, no. 1, pp. 1–8, 2020.

[5] Y. Shen, "Fuzzy fault tree analysis of gas leakage and emergency response plan in urban integrated pipeline corridor [J]," *Journal of Anhui Electronic Information Vocational Technology College*, vol. 19, no. 4, pp. 24–30, 2020.

[6] S. Wang, Ze. Zhang, W. Hou et al., "A multi-hazard coupled disaster risk evaluation method for integrated pipe corridors [J]," *Journal of Northeastern University*, vol. 39, no. 6, pp. 902–906, 2018.

[7] S. Qiu, Z. Huang, W. Zhonghua, N. Nan, and Y. Chen, "Research on the coupled evaluation of safety risks of integrated pipe corridor construction based on CM and information entropy[J]," *Industrial Safety and Environmental Protection*, vol. 45, no. 5, pp. 17–22, 2019.

[8] K. Chai and X. Liu, "A coupled multi-hazard prediction model for integrated pipe corridors based on fuzzy cluster analysis [J]," *Disaster Science*, vol. 35, no. 4, pp. 206–209, 2020.

[9] Y. Chen, H. Li, W. Wang, Bo. Xue, and G. Li, "Bayesian network-based disaster risk analysis of integrated pipe corridor operation and maintenance[J]," *Safety and Environmental Science*, vol. 18, no. 6, pp. 2109–2114, 2018.

[10] Y. Liu, B. Guo, C. Zhang, M. Xiao, and Yu. Wang, "Research on the evaluation of operational risk of underground integrated pipe corridor projects based on grey clustering [J]," *Value Engineering*, no. 26, pp. 121–125, 2018.

[11] Y. Zhang and R. Zhang, "Risk assessment and analysis of the whole life cycle of underground integrated pipe corridors [J]," *Journal of Xi'an University of Architecture and Technology*, vol. 51, no. 2, pp. 294–300, 2019.

[12] T. Lu, A. Jiang, Y. Dong, Q. Xiong, and Ji. Liu, "Risk evaluation of operation and maintenance of integrated pipeline corridor projects based on information entropy combined empowerment-topology model[J]," *Journal of Water Resources and Construction Engineering*, vol. 18, no. 2, pp. 52–58, 2020.

[13] M. L. Cai, Q. G. Hu, and Z. M. He, "Safety risk evaluation of integrated pipe corridor construction based on fuzzy set and improved evidence theory," *J]. Road and steam transportation*, no. 2, pp. 161–166, 2020.

[14] X. Yuan, S. Xu, Li. Lei, R. Xu, and S. Jiya, "Comparative analysis of integrated pipe corridor operation and maintenance management in Taiwan and mainland China [J]," *Municipal Technology*, vol. 37, no. 1, pp. 172–174, 2019.

[15] J. Guo, Y. Qian, Z. Wang, Z. Dong, and X. Liu, "Research on common operation and maintenance disasters and countermeasures of urban underground integrated pipe corridors [J]," *Disaster Science*, vol. 34, no. 1, pp. 27–33, 2019.

[16] J. Canto-Perello, J. Curiel-Esparza, and V. Calvo, "Criticality and threat analysis on utility tunnels for planning security policies of utilities in urban underground space," *Expert Systems with Applications*, vol. 40, no. 11, pp. 4707–4714, 2013.

[17] Y. Jang and S. Jung, "Quantitative risk assessment for gas-explosion at buried common utility tunnel," *Journal of the Korean Institute of Gas*, vol. 20, no. 5, pp. 89–95, 2016.

[18] W. Wang and J. Fang, *Study on the Risk Evaluation Model of Utility Tunnel Project under a PPP Mode[C]*, ICCREM, 2017.

[19] L. He, G. Ma, Q. Hu et al., "A novel method for risk assessment of cable fires in utility tunnel," *Mathematical Problems in Engineering*, vol. 2019, pp. 1–14, 2019.

[20] X. Ding, K. Liu, S. Shi et al., *Risk Assessment of PPP Model Based on Fault Tree Model for Urban Underground Utility Tunnel[C]*, CEMMS, 2019.

[21] X. Zhou, H. Pan, and Y. Shen, *China's Underground Comprehensive Utility Tunnel Project of PPP Mode Risk Identification[C]*, ICCREM, 2017.

[22] J.-H. Seong and M.-H. Jung, "Study on key safety hazards and risk assessments for small section utility tunnel in urban areas [J]," *Journal of Korean Tunnelling and Underground Space Association*, vol. 20, no. 6, pp. 931–946, 2018.

[23] L. Rita and H. Herbert, "Risk analysis during tunnel construction using Bayesian Networks: porto Metro case study [J]," *Tunnelling and Underground Space Technology*, vol. 27, no. 2012, pp. 86–100, 2011.

[24] K. Golam, T. Solomon, and F. Alex, "Evaluating risk of water mains failure using a Bayesian belief network model[J]," *European Journal of Operational Research*, vol. 240, no. 2015, pp. 220–234, 2014.

[25] L. Zhang, X. Wu, Y. Qin, M. J. Skibniewski, and W. Liu, "Towards a fuzzy bayesian network based approach for safety risk analysis of tunnel-induced pipeline damage," *Risk Analysis*, vol. 36, no. 2, pp. 278–301, 2016.

[26] M. Khwaja Mateen, P. Albert, C. Chan, Z. Hafiz et al., "Fuzzy integral–based risk-assessment approach for public–private partnership infrastructure projects," *Journal of Construction Engineering and Management*, vol. 144, no. 12, Article ID 04018111, 2018.

[27] H. Wu, M. Wang, and J. Wang, *Shield Construction Safety Risk Assessment of Metro Tunnels Based on Cloud Model[C]*, ICUEMS, 2020.

[28] L. Kang, "Risk assessment of urban underground utility tunnel based on fuzzy analytic hierarchy process[J]," *Operations Research and Fuzziology*, vol. 9, no. 2, pp. 131–139, 2019.

[29] W. K Marian, G. Beata, and K. Adam, *Modelling with Bayesian Networks - Case Study: Construction of Tunnel under the Dead Vistula River in Gdansk[C]*, Creative Construction Conference, 2017.

[30] J. Martinka, P. Rantuch, J. Sulová, and F. Martinka, "Assessing the fire risk of electrical cables using a cone calorimeter," *Journal of Thermal Analysis and Calorimetry*, vol. 135, no. 6, pp. 3069–3083, 2019.

[31] B. J. Han, Y. S. Jiang, Z. Wang et al., "Analysis of the risk path of the pipeline corridor based on system dynamics[J]," *Shock and Vibration*, p. 2021, 2021.

[32] Li. Qian and W. Duan, "Research on risk factors of integrated corridor operation and maintenance management based on DEMATEL [J]," *Tunnel Construction (in Chinese and English)*, vol. 39, no. 1, pp. 31–39, 2019.

[33] K. H. Liu, "Analysis and management of hidden dangers of underground pipelines [J]," *Modern occupational safety*, no. 9, p. 25, 2017.

[34] Y. Liu, "Problems and countermeasures in the construction and management of urban underground lifeline system archives [J]," *Engineering and Construction*, vol. 29, no. 6, p. 875, 2015.

[35] S. Wang, *Analysis and Study on Subsidence Mechanisms of Road Caused by Leakage of Urban Underground Pipeline [D]*, Zhengzhou University, Zhengzhou, 2017.

[36] J. H. Lu, Y. H. Yang, and D. Zhao, "Risk analysis and response of setting gas pipe compartments in underground integrated pipe corridors," *[J], Gas and Heat*, vol. 36, no. 8, p. 1, 2016.

[37] D. Wu, M. Zuo, and Q. Wu, "Construction and practice of integrated pipe corridor project," *[J], Science and Technology Innovation*, no. 32, p. 97, 2017.

[38] Ye. Zhang, "Exploration on the construction of underground integrated urban wisdom corridor," *J]. Housing and real estate*, no. 33, p. 216, 2017.

[39] J. Wang, H. Zhang, and R. Lu, "Hazard analysis of underground pipelines in petrochemical enterprises," *J]. Safety, Health and Environment*, vol. 15, no. 1, p. 23, 2015.

[40] W. Zhou, W. Ruijuan, L. Pan et al., "Comprehensive management of urban underground pipelines [J]," *Urban construction theory research (electronic version)*, no. 28, p. 172, 2017.

[41] J. Chang, "Feasibility analysis of municipal pipelines into the comprehensive pipeline corridor [J]," *Tianjin Construction Science and Technology*, vol. 27, no. 5, p. 73, 2017.

[42] C. Chen and H. Jiang, "Analysis of structural design elements of integrated pipe corridor [J]," *Sichuan Cement*, no. 11, p. 96, 2017.

[43] J. H. Ni, X. Xiang, and J. J. Lai, "Study on temporary ventilation and lighting facilities in the electromechanical installation stage of integrated pipe corridor [J]," *Construction Technology*, vol. 46, no. 21, p. 33, 2017.

[44] Y. J Liu and L. U Yuan, "Evaluation study on the degree of synergy in the operation phase of integrated pipe corridor [J]," *Engineering Economics*, vol. 27, no. 9, p. 69, 2017.

[45] L. Yang, J. Zhu, C. Li et al., "Safety risk identification analysis of urban integrated pipeline corridor based on Kent method [J]," *Urban Development Research*, vol. 25, no. 8, pp. 19–25, 2018.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 7720250, 8 pages
https://doi.org/10.1155/2022/7720250

Research Article

The Prediction of Sports Economic Development Prospect in Different Regions by Improved Artificial Bee Colony Algorithm

Lei Liu and Guangda Song

Physical Education Institute of Jimei University, Xiamen 361021, China

Correspondence should be addressed to Lei Liu; 200661000205@jmu.edu.cn

Received 9 February 2022; Accepted 4 March 2022; Published 28 March 2022

Academic Editor: Lele Qin

In order to study the development of the sports economy in different regions and analyze the future development prospect of sports economy, this paper uses the k-clustering method to improve the artificial bee colony algorithm and further improve the clustering degree of the bee colony. Among them, the improved artificial bee colony algorithm reduces the incidence of local extreme and improves the accuracy of calculation by setting the weight and threshold of indicators. MATLAB simulation results show that the prediction accuracy of the improved artificial bee colony algorithm for the development prospect of sports economy is 96–99%, and the calculation time is 0–17 seconds. Therefore, the improved artificial bee colony algorithm can best predict the development of the sports economy in different regions, and its accuracy, periodicity, and calculation time are better than those of the original artificial bee colony algorithm.

1. Introduction

With the rapid development of social economy, there is a gap in the sports economy between different regions [1]. To promote the development of sports economy, the national sports department put forward the strategy of sports competitive balance [2]. However, existing sports economic evaluation methods have the problems of poor accuracy and long evaluation time, which cannot achieve the purpose of economic prediction. Scholars at home and abroad have increased the regional prediction of sports economy, and they especially introduced quantitative analysis methods and comprehensive analysis methods to evaluate and predict sports economy. At present [3], the domestic prediction of the development of sports economy is only limited to the theoretical level, or the quantitative analysis method is directly transplanted to the sports economy [4], without improving the original methods, such as Bayesian algorithm, genetic algorithm, and particle swarm optimization algorithm [5]. Therefore, the main research direction is to apply quantitative analysis method and improve it to improve the prediction accuracy of sports economic development. Among them, the artificial bee colony method is widely used in sports economic prediction. However, there are deficiencies in data processing of artificial bee colony, which cannot meet the needs of sports economic development prediction at this stage. The above algorithm mainly has the problem of regional extrema, resulting in large deviation in the calculation. To realize the rational planning of national sports economy, this paper proposes an improved artificial bee colony algorithm and judges the prediction of the sports economy in different regions.

2. Literature Review

Artificial bee colony algorithm is a multidimensional data analysis and calculation method used to solve the selection problem of distinct combination schemes. In the process of collecting honey, bees should traverse distinct honey sources, judge the concentration of honey sources, and finally lead the bee colony to select the optimal honey source. In this process, it involves honey source traversal, source judgment path optimization, and so on [6]. Similar analysis shows that the prediction of sports economic development

in regions is the honey source selection process of bee colonies. Artificial bee colony algorithm can effectively traverse regions. Stone et al. [7] found the reasons for the differences between sports in different regions and put forward solutions according to the prediction results. In addition, in the process of sports economic prediction, the threshold and weight should be calculated to eliminate the data that have no impact on the judgment results. From the above analysis, it can be seen that there are many research studies on the artificial bee colony algorithms in China. At the same time, domestic scholars also believe that the artificial bee colony algorithm has shortcomings and cannot adapt to the analysis of sports economic development in different regions, especially large-scale data analysis. At present, the artificial bee colony algorithm has been improved and applied to the field of sports in China, but it has not been applied to the prediction of the development prospect of sports economy [8]. Therefore, it is an urgent problem to study and improve the role of the artificial bee colony algorithm in the development of sports economy and the prediction effect.

This paper improves the artificial bee colony algorithm, integrates k-cluster analysis, and uses European clustering to reduce the occurrence rate of extrema, to improve the accuracy of calculation. In addition, it can reduce the amount of data preprocessing of the artificial bee colony algorithm to shorten the calculation time. At the same time, k-clustering can adjust the relationship between local extreme value and global value, avoid optimal solution, and improve the accuracy of calculation. When the artificial bee colony algorithm processes data, there will be a problem of regional extrema, resulting in low accuracy of calculation. In order to meet the prediction requirements of the sports economy in different regions, it is necessary to reduce the impact of massive data on the calculation results. By clustering massive data, k-clustering reduces the amount of data processing, reduces the initial amount from data of artificial bee colony, and improves the accuracy of calculation. This paper uses empirical analysis and simulation to verify the effectiveness of the improved artificial bee colony model and tries to provide case and theoretical support for sports economic development planning.

3. Method

3.1. The Description of the Artificial Bee Colony Algorithm. The artificial bee colony algorithm is an optimization method proposed to imitate the behavior of bees. The algorithm searches the honey source target in multiple dimensions, judges distinct combination schemes, and selects the target that is most conducive to the bee colony. Artificial bee colony can reduce the search dimension, improve the search accuracy, and select the target according to the advantage of honey source target. At the same time, the artificial bee colony algorithm can change the search role, and the same bee can play the role of leader and follower. Artificial bee colony algorithm can solve the path selection problem between distinct targets, reduce the complexity between different targets, and is suitable for the calculation of large amount of data. However, the artificial bee colony algorithm has the problem of regional extrema, which affects the accuracy of search results. At present, artificial bee colony algorithms have a wide range of applications and belong to a common comprehensive analysis method. Compared with other analysis methods, artificial bee colony algorithms can reduce the impact of data on the results, improve the calculation efficiency of data, and predict the future development trend according to the existing data. Based on Liang's research [9], this paper attempts to introduce the k-clustering method to improve the artificial bee colony algorithm to solve the problem of inaccurate prediction of sports economic development in different regions [10]. The principle of the artificial bee colony algorithm is shown in Figure 1.

3.2. Determination of the Input Index of the Artificial Bee Colony Algorithm. The index determination of the artificial bee colony algorithm is an important work, which plays a forward-looking role in the prediction of sports economic development trend and affects the accuracy of later calculation results. The indexes in the artificial bee colony algorithm are divided into three kinds: existing indexes, prediction indexes, and transfer indexes, which are not only related to the development potential of sports competition but also related to the influence points of sports economy and the development of sports economy in the future. Different indicators change through transfer factors and show complex indicator relationships. Artificial bee colony algorithm is suitable for large-scale data of calculation and can realize cross regional data analysis. The development of sports economy is not only related to local economic policies, economic development potential, and infrastructure construction but also related to the development environment of domestic sports economy, the market potential of sports economy, and the future development strategy for the region. To realize the prediction of sports economic development in different regions, it is necessary to integrate various indicators and data and establish the dynamic relationship.

Due to the large amount of data collected, it is necessary to preprocess the data in the early stage and eliminate the data that have a little impact on the results, to improve the accuracy of data analysis. In this paper, the k-clustering method is used to cluster the data of 1 ~ 6 regions P I A, I A P, Plav et al. [11]. At the same time, transfer factors are added between different data, integrating the influence of space, time, and policy, to realize the comprehensive analysis of sports economic development. The artificial bee colony algorithm is an analysis method often used in the sports economy, but it requires analysis of large-scale data. The algorithm may have regional extrema problems, which will reduce the accuracy of analytical results. Therefore, after incorporating the k-clustering methods, the occurrence rate of regional extrema can be reduced. Hypothesis 1: the input index of the artificial bee colony algorithm is xi, the transfer factor is yj, the output result is Pij, and i, j belong to set $(1,\ldots,n)$; subsequently, the calculation formula with the result is shown in the following:

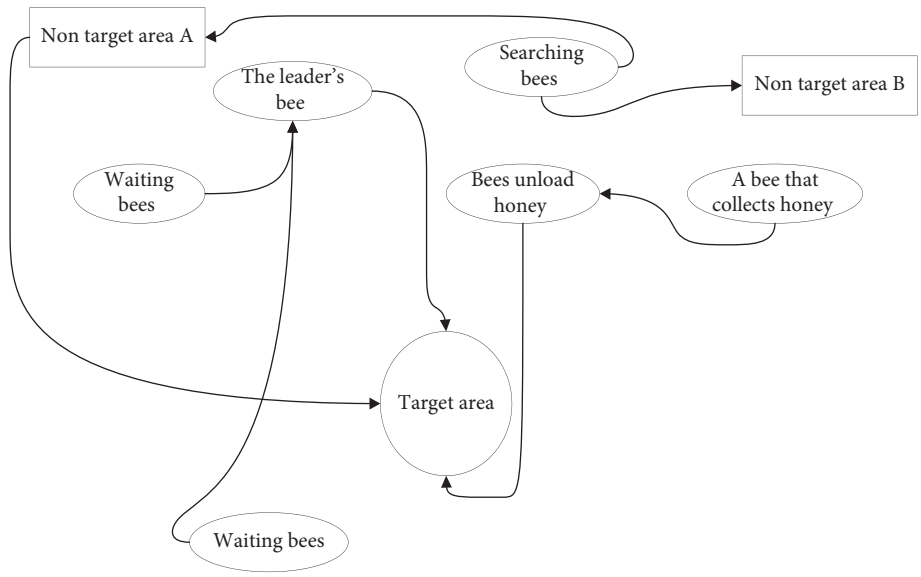


Figure 1: The principle of the artificial bee colony algorithm.

$$P_{ij} = \begin{cases} x_i y_j - \sum_{i,j=1}^{n} \frac{\overline{x}_i \overline{y}_i}{\mu, x_i} < x_{i+1}, \\ \\ \overline{y}_j = \frac{1}{\mu} \sum_{i=1}^{n} x_i, y_j < y_{j+1}, \end{cases} \quad (1)$$

where μ is the expected optimal result of artificial bee colony, $x_i < x_{i+1}$ is the advanced condition of the input index, $y_j < y_{j+1}$ is the advanced condition of transfer between indexes, $\overline{x}_i$ is the local average of an index, and $\overline{y}_i$ is the local average of any transfer factor.

3.3. The k-Clustering Algorithm. Due to the large number of transfer factors and input indexes of the artificial bee colony algorithm, it is necessary to improve and optimize it and put forward irrelevant data [12]. When artificial bee colony algorithm traverses different regions, it should pass through sports cities as much as possible and analyze the corresponding sports economy [13]. Hypothesis 2: if the Euclidean distance between any index is S; subsequently, the distance between two points is the shortest, and any point between xi and xi + 2 will be eliminated. Therefore, the artificial bee colony algorithm only needs to judge the distance between any two points. If the minimum requirement is met, the mean place shall be excluded; in other respects, it shall be included in the mean place [14]. In addition, the distance between any two points should be directional; in other respects, repeated calculation will occur and increase the amount of calculations.

Hypothesis 3: Si is the Euclidean distance between any two points and St is the direction of the distance between any two points; subsequently, the distance between any two points is divided equally by K and calculated accordingly [15]. The formula is

$$\begin{cases} S_i(x, y) = \frac{\sqrt{p(x_i y_j)^2 - q(x_i y_j)^2}}{\max\{q(x_i y_j), p(x_i y_j)\}}, \\ \\ S_t(x, y) = \frac{1}{\xi} \sum_{i,j=1}^{n} S_t(x_i y_j), \end{cases} \quad (2)$$

where $p(x_i y_j)$ is the abscissa of xi and yj, $q(x_i y_j)$ is the abscissa of xi and yj, and ξ is the optimal expected time [16]. Hypothesis 4: the threshold is P_E and the index weight is ω_{ij}. In order to ensure the accuracy of calculation, the threshold and weight shall be set. The calculation formula is

$$P_E = \sqrt{\sum_{i,j=1}^{m} \omega_{ij} \left[P_{ij} - min(P_{ij})\right]^2} + \tau, \quad (3)$$

where ω_{ij} is the weight of i input index, j is the transfer factor [17], min (P_{ij}) is the minimum output result, and τ is the adjustment coefficient of local threshold (the coefficient is the GDP of the sports economy in different regions). In k-clustering, the value of the initial cluster is 0 and increases gradually. After Si and St are calculated, they are k equally divided and arranged in the corresponding order [18]. If the results of Si and St are less than P_E, they will be rejected; in other respects, they will be included.

3.4. The Construction of the Improved Artificial Bee Colony Algorithm. Using the objective function, the artificial bee colony algorithm can solve the complex calculation problem of regional economic differences. By traversing the data from different regions, this paper forecasts the development of sports economy [19]. However, with the increase of the number of economic data, the results will fall into regional extrema value, which will affect the accuracy of the calculation results. At the same time, the application of big data,

cloud computing, and other methods also increases the amount of data of zonal sports economy and improves the occurrence rate of local extreme values [20]. Based on the literature at home and abroad, this paper improves the artificial ant colony algorithm, preprocesses the input data and transfer factors through k-clustering, and reduces the dimension of the analysis data with the help of bee routing. In the process of improved artificial bee colony calculation [21], the threshold and weight of input indexes are increased to make the iterative calculation move forward in the specified direction. Since the threshold and weight are positive, the tangent is between 0 and 1 [22]. When there is a negative value in the calculation result of artificial bee colony, the weight will reduce the value and the overall result [23]. If negative values continue to increase and fall below the threshold, they will be eliminated. Therefore, the setting of threshold and weight can put forward negative values and make the calculation results develop in a positive direction. Hypothesis 5: the actual development of the sports economy in different regions is Oij, and the predicted economy is Pij. When the input indicators and transfer factors are the same, the difference is DIJ; subsequently, the calculation formula is

$$d_{ij} = \begin{cases} O_{ij} = f\left[\sum_{i,j=1}^{n}\left(w_{ij}x_i + y_j\right)\right], \\ P_{ij} = f\left[\sum_{i,j=1}^{n}\left(w_{ij}x_i + y_j\right)\right] + \psi, \end{cases} \tag{4}$$

where $f(\cdot)$ is the improved artificial bee colony algorithm and ψ is the adjustment function of the actual value. In the above analysis process, the improved artificial bee colony algorithm is used to judge the target result. If the result meets the threshold [24], the calculation result is output; in other respects, the threshold will be adjusted. In addition, ψ is the interference factor in sports economic judgment, which belongs to the dynamic variable. ψ representative policy, culture, strategy, and other influencing factors [25]; the calculation formula is

$$\psi = \frac{1}{\mu}\sum_{i,t=1}^{n}\{[g(x) - S_i] - [z(x) - S_t]\}, \tag{5}$$

where $g(\cdot)$ is the subjective influencing factor and $z(\cdot)$ is the object influencing factor. Distinct input vectors get distinct output values, so we should adjust the threshold of sports economic prediction index to make it infinitely close to the actual requirements of Kondratenko et al. [26]. Therefore, Fourier series is integrated into the analysis of interference factors, and the specific calculation formula is

$$\lim_{x\longrightarrow\infty}\psi = \frac{1}{\mu}\sum_{i,t=1}^{n}\left\{\left[\triangle g(x)^T - S_i\right] - \left[\triangle z(x)^T - S_t\right]\right\}, \tag{6}$$

where the specialization of $\triangle g(x)^T$ and $\triangle z(x)^T$ is the increment of $g(x)$ and $z(x)$. Formula (6) can realize the standardized treatment of influencing factors, reduce the influence of non important factors that is ψ on the results, and improve the calculation accuracy. Under distinct colony targets, distinct analytical results are obtained by improving artificial bee colony [27]. Further analysis is carried out on the further requirements of the bee colony objective, further calculation steps, and design indicators. Therefore, for sports economic analysis in different regions, appropriate input indicators and thresholds should be selected to improve the accuracy of calculation. Since the eigenvalue of the located and the global thresholds are consistent, the calculation direction of the index shall be constrained, and the calculation direction shall be positive. Before the improved artificial bee colony calculation, all sports economic data are processed for public welfare, the corresponding data values are projected between [0, 1], and the located and global extreme values are set. Hypothesis 6: the located extreme value is Em and the global extreme value is EC; subsequently, the calculation formula of the extreme value is

$$\begin{cases} E_m = \dfrac{\left[\sum_{i,j=1}^{n}\left(x_i - y_j\right)^2\right]}{\lim\limits_{x\longrightarrow\infty} f(x)} w_{ij}, \\ E_C = \dfrac{S_i - S_t}{x_i y_j} \times 100\%. \end{cases} \tag{7}$$

The regional extrema E_m are greater than the threshold but less than 1; the global extrema E_C are positive and less than 1. According to the above analysis, the flow of the improved artificial bee colony algorithm can be obtained, which is shown in Figure 2.

4. Results and Discussion

In this paper, the improved artificial ant colony algorithm is used to analyze the sports economy in different regions, and the accuracy and effectiveness of the algorithm are verified in the MATLAB environment. Before analysis, you need to set the weight and threshold of the input indicators. At the same time, 100 iterations of the algorithm are carried out to verify the overall calculation results. Among them, after referring to relevant domestic literature, the number of iterations is determined to be 100. Too many iterations will increase the system burden, and few iterations will reduce the calculation accuracy.

4.1. The Sample Objects. Taking the sports economy of 16 regions as the research object, this paper analyzes the development of the sports economy in different regions. Among them, 2 places are selected in Northeast China, 3 places are selected in North China, one place is selected in Northwest China, one place is selected in Southwest China, five places are selected in Southeast China, and four places are selected in East China. The selected input indicators are economic development potential x1 (unit: none), the proportion of sports economy in GDP x2 (unit: %), the development speed of sports economy x3 (unit: none), and the growth proportion of sports economy x4 (unit: %), the transfer factors y1 (unit: none), indicator function transfers y2 (unit: none), and indicator influence degree transfers y3

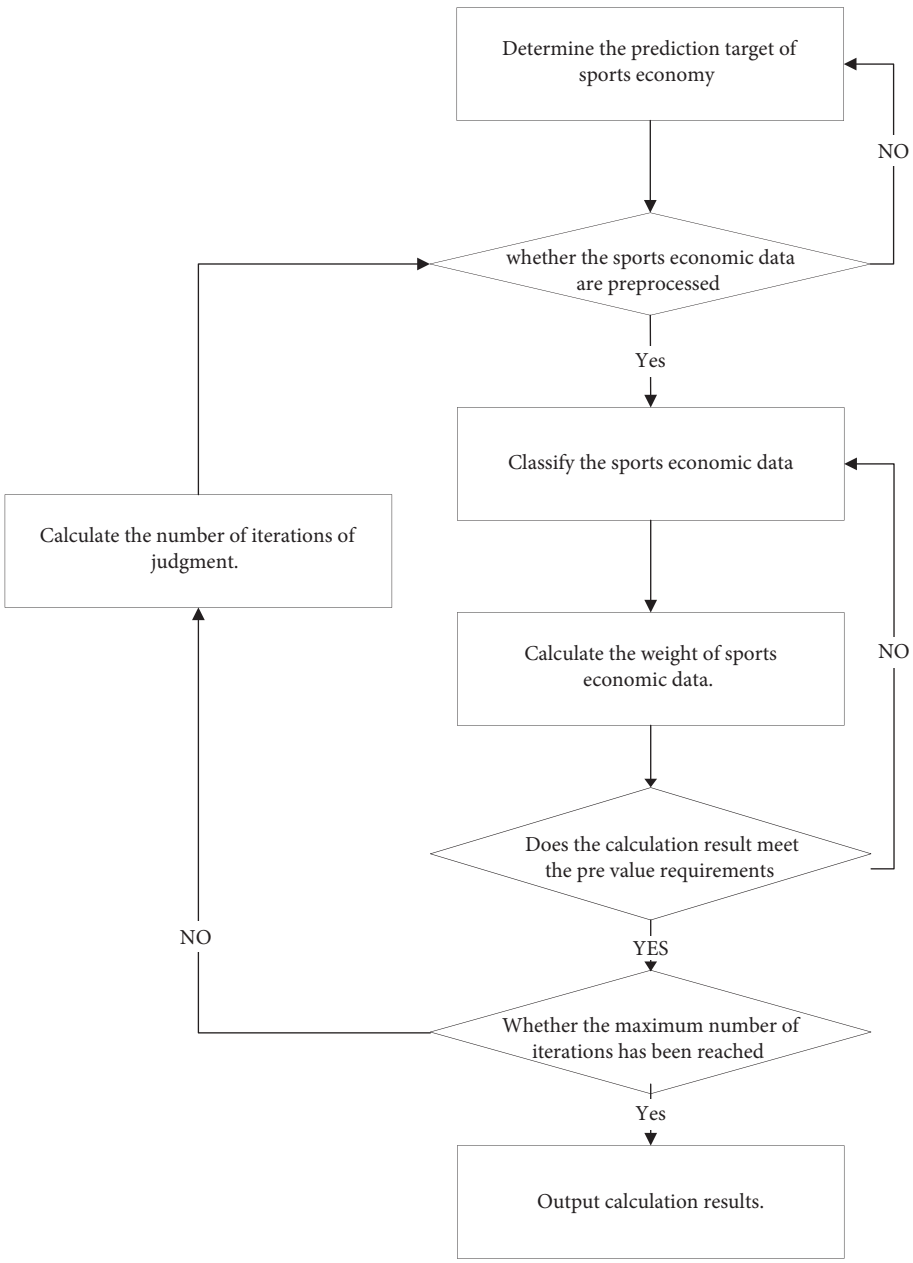


Figure 2: The flowchart of the improved artificial bee colony algorithm.

(unit: %). The k-clustering results of sample objects are shown in Table 1.

It can be seen from Table 1 that the clustering degree of different input indicators and transfer factors is greater than 95% and higher than the global threshold of 0.98, so the sports economical industry data meet the specific requirements and can be analyzed and calculated [28].

4.2. The Accuracy of Prediction of an Economic Development Prospect of the Sports Industry. Compared with the original bee colony algorithm, the calculation accuracy of the improved artificial bee colony algorithm is higher, which can reach more than 95%, which is shown in Figure 3.

It can be seen from Figure 3 that the accuracy of the improved artificial bee colony algorithm is between 96% and 99%. The accuracy of the existing bee colony algorithm in predicting the development prospect of sports economy is only 94%–96%. Therefore, the improved artificial bee colony algorithm has higher accuracy [29]. The reason is that k-clustering is used to make the calculation results iterate in the same direction, which effectively reduces the occurrence rate of local extreme values. The results are shown in Figure 4.

It can be seen from Figure 4 that the iterative data do not change in different directions at the same time. In the projection of sports economic data, the direction of data has always been the same direction. Therefore, the improved artificial bee colony algorithm can ensure the data changes in

Table 1: The sample clustering.

The number of samples	Initial cluster center (%)						$E_C = 0.78$
	x1	x2	x3	x4	y1	y2	
12	97.98	98.91	97.98	95.96	98.93	96.90	0.88
15	97.94	95.96	98.97	98.92	98.91	96.97	0.83
10	95.92	96.91	98.99	97.98	98.94	96.93	0.81
14	96.93	96.93	96.97	95.96	96.92	98.92	0.87
15	98.97	96.92	98.99	96.97	95.93	96.99	0.82

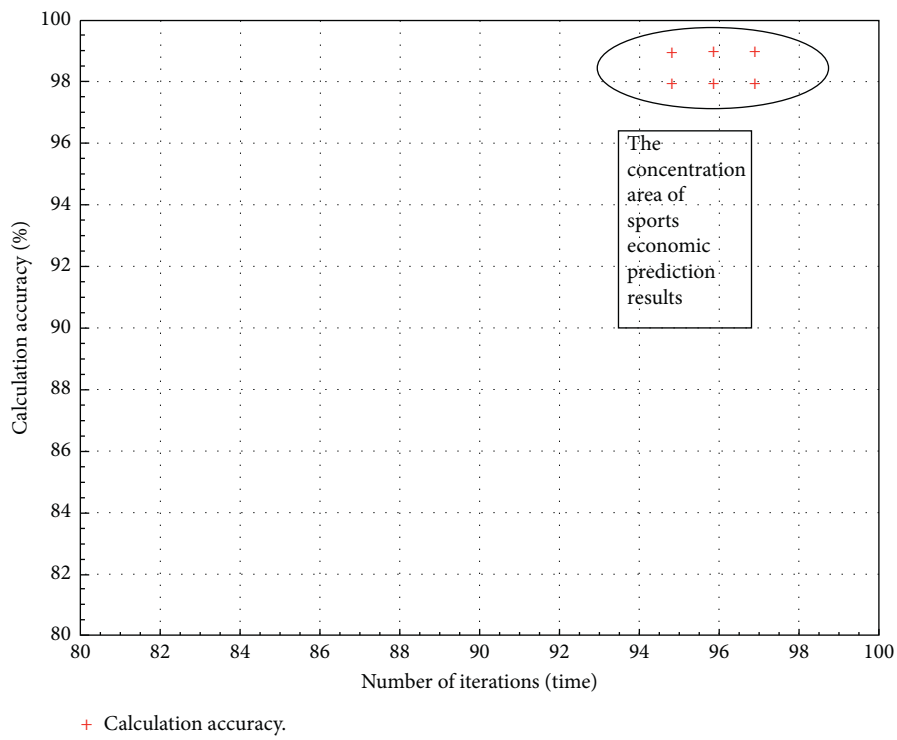


Figure 3: The concentration area of the sports economy calculation results.

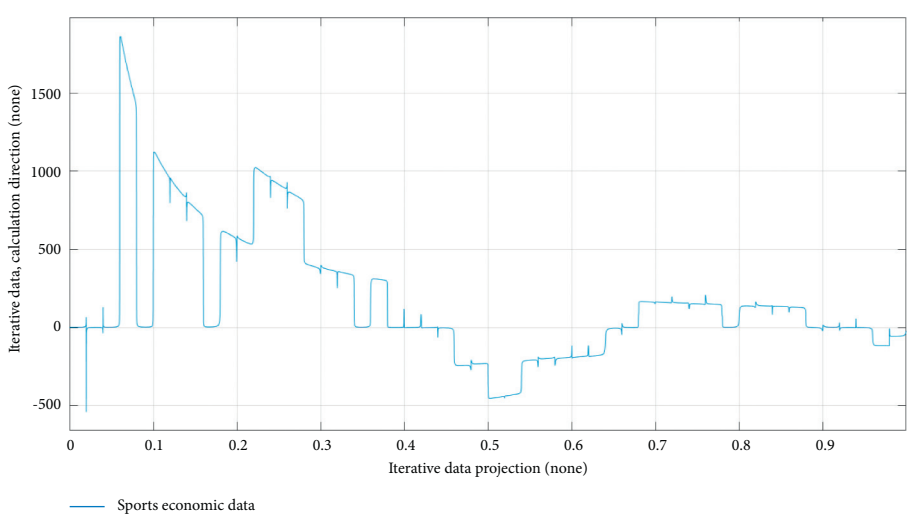


Figure 4: The calculation direction of the improved artificial bee colony algorithm.

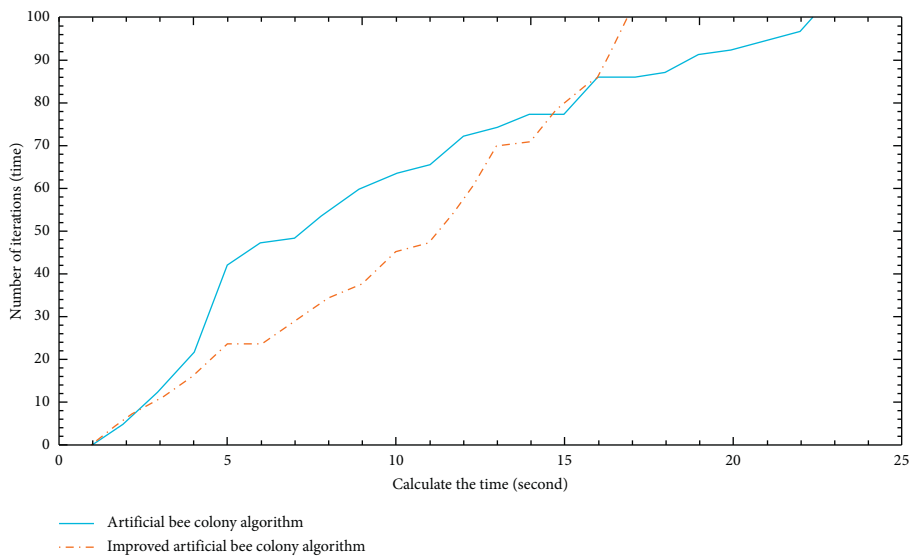


Figure 5: Comparison of calculation time of economic development forecast of sports industry.

the direction. Compared with the original artificial bee colony algorithm, the improved artificial bee colony algorithm has significant advantages in data iteration direction, high accuracy of calculation, and low probability of regional extrema.

4.3. The Forecast Time of Economic Development Prospect of the Sports Industry. In terms of computing time, the improved artificial bee colony algorithm can effectively compare data, propose redundant data, and greatly reduce the amount of data processing [30]. Under the same sports economic data, the calculation time of the clustering algorithm is shorter, and the results are shown in Figure 5.

It can be seen from Figure 5 that the calculation time of the improved artificial bee colony algorithm is 0–17 seconds, and the calculation time of the original bee colony algorithm is 0–21 seconds. There is a significant difference between the two. The main reason for the above problems is that the artificial bee colony algorithm has been improved, and the conclusions are obtained by using the k-clustering method for data preprocessing and the Fourier series for continuous threshold analysis. Therefore, the improved artificial bee colony algorithm has more advantages in computing time.

In the early stage of data processing, the data direction vector is high and shows a downward trend in the later stage. The reason is that the postprocessing volume of data is reduced. The latter data vector is relatively stable without significant change, which further shows that the data processing effect is better.

The change range of the improved artificial bee colony algorithm is small, and it has reached the extreme value after 18 iterations, which shows that the calculation effect of this method is better and the processing effect of economic development data is better. In the future research process, we should pay attention to improving the change amplitude control of artificial bee colony algorithm to make the processing process more stable.

5. Conclusion

The improved artificial bee colony algorithm preprocesses the sports economy data through the k-clustering, compares the differences in region camps, and obtains the clustering of sports economic index data. Subsequently, accuracy and calculation time of sports prediction are compared. MATLAB simulation results show that all sports economic data are relatively concentrated, and the degree of clustering is 96~99%. At the same time, the calculation accuracy of the improved artificial bee colony algorithm is more than 98%, and the calculation time is 0–17 seconds, which are higher than those of the original artificial bee colony algorithm. Therefore, the improved artificial bee colony algorithm has significant advantages in calculation accuracy and time and can predict the development trend of the sports economy in different regions. However, in this paper, the correlation between regions is not deeply analyzed, and the transfer factor is only used as an intermediate value without detailed analysis. In the future research, we will focus on the analysis of regional differences and the role of transfer factors [31].

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by Physical Education Institute of Jimei University.

References

[1] T. Akifumi, "The role of myokine Irisin on Improving public Sports effect," *Journal of the Korea Society of Computer and Information*, vol. 24, no. 9, pp. 32-33, 2010.

[2] Z. Gaojie, "Effects of long-term physical exercise onMass sports and improving public sports effect in middle school girls," *International Journal of Education and Economics*, vol. 2, no. 2, pp. 32-33, 2019.

[3] R. I. D. Lima, "Estimating the production function for the Brazilian industrial sector: a Bayesian panel VAR approach," *Cogent Business & Management*, vol. 9, no. 1, pp. 202–205, 2022.

[4] H. Jia, H. Wang, L. Cao et al., "Genetic analysis of a SARS-CoV-2 Omicron variant from a Chinese traveller returning from overseas," *Emerging Microbes & Infections*, vol. 11, no. 1, pp. 306–309, 2022.

[5] L. Liu, N. Dai, K. W. Lao, and Y. Song, "Nonuniform power factor partial compensation for compensating current reduction using particle swarm optimization in traction power supply system," *IEEE Transactions on Industrial Electronics*, vol. 69, no. 6, pp. 6140–6151, 2022.

[6] N. Isao, T. Akifumi, and Y. Masafumi, "Evaluation of cartilage and improving public sports effect in collegiate athletes belonging to various sports clubs by analyzing type II collagen degradation and Synthesis,and type I collagen degradation," *Juntendo Medical Journal*, vol. 64, no. 1, pp. 32-33, 2018.

[7] T. M. Stone, J. E. Wingo, and J. C. Young, "An evaluation of select physical activity exercise classes on improving public sports effect," *International journal of exercise science*, vol. 11, no. 2, pp. 9-10, 20108.

[8] J. Iwamoto, "Calcium and Improving public Sports effect across women's life stages.Exercise and sport to increase body strength in accordance with female lifecycle," *Clinical Calcium*, vol. 27, no. 5, pp. 33-34, 2017.

[9] Y. Liang, "Research on composition and hardware connection design of VR based simulation welding method platform," *Journal of Suzhou University*, vol. 35, no. 8, pp. 72–75, 2020.

[10] H. Li, "Application of VR simulation method in moot court teaching," *Legal system and society*, vol. 32, no. 29, pp. 163-164, 2020.

[11] P. Šiđanin, J. Plavšić, I. Arsenić, and M. Krmar, "Virtual reality pp.VR simulation of a nuclear physics laboratory exercise," *European Journal of Physics*, vol. 41, no. 6, pp. 34–43, 2020.

[12] M. Zhang, J. ye, and M. Yu, "Physical modeling and VR simulation experiment of Mars probe earth sun transfer orbit," *University physics experiment*, vol. 33, no. 5, pp. 109–112, 2020.

[13] R. M. S. Campos, M. T. de Mello, and L. Tock, "Aerobic plus resistance training improves Improving public Sports effect and inflammation in adolescents who are obese," *The Journal of Strength & Conditioning Research*, vol. 28, no. 3, pp. 44–46, 2022.

[14] N. Isao, T. Akifumi, and Y. Masafumi, "Evaluation of cartilage and improving public sports effect in collegiate athletes belonging to various sports clubs by analyzing type II collagen degradation and Synthesis,and type I collagen Degradation; Poster sessions - musculoskeletal system," *Juntendo Medical Journal*, vol. 64, no. 11, pp. 22-23, 2019.

[15] Y. Masafumi, "Effects of long-term aerobic exercise on body breaking force and serum improving public sports effect markers in ovariectomized mice," *Journal of The Korean Society of Living Environmental System*, vol. 26, no. 1, pp. 32-33, 2019.

[16] L. T. Zungu, B. P. Makhoba, and L. Greyling, "A scrutiny into fiscal policy in the South African economy: a Bayesian approach with hierarchical priors," *Cogent Economics & Finance*, vol. 10, no. 1, pp. 102–104, 2022.

[17] N. Mallah, "Synergism interaction between genetic polymorphisms in drug metabolizing enzymes and NSAIDs on upper gastrointestinal haemorrhage: a multicenter case-control study," *Annals of Medicine*, vol. 54, no. 1, pp. 379–392, 2022.

[18] T. Zeng, "Artificial bee colony based on adaptive search strategy and random grouping mechanism," *Expert Systems with Applications*, vol. 12, no. 4, p. 192, 2022.

[19] T. Y. Ye, "Artificial bee colony algorithm with an adaptive search manner and dimension perturbation," *Neural Computing & Applications*, vol. 10, no. 10, p. 92, 2022.

[20] K. Thirugnanasambandam, "Directed Artificial Bee Colony algorithm with revamped search strategy to solve global numerical optimization problems," *Automated Software Engineering*, vol. 29, no. 1, 32 pages, 2022.

[21] C. Tang, W. Sun, M. Xue, X. Zhang, H. Tang, and W. Wu, "A hybrid whale optimization algorithm with artificial bee colony," *Soft Computing*, vol. 26, no. 5, pp. 2075–2097, 2022.

[22] H. Su, "Horizontal and vertical search artificial bee colony for image segmentation of COVID-19 X-ray images," *Computers in Biology and Medicine*, vol. 11, no. 4, p. 142, 2022.

[23] J. Sato, "Artificial bee colony for affine and perspective template matching," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 7, no. 3, p. 72, 2022.

[24] Q. M. Pu, C. Xu, H. Wang, and L. Zhao, "A novel artificial bee colony clustering algorithm with comprehensive improvement," *The Visual Computer*, vol. 13, no. 4, p. 102, 2022.

[25] X. L. Liu, J. Liang, D. Y. Liu, R. Chen, and S. M. Yuan, "Weapon-target assignment in unreliable peer-to-peer architecture based on adapted artificial bee colony algorithm," *Frontiers of Computer Science*, vol. 16, no. 1, p. 42, 2022.

[26] A. A. Kondratenko, M. Bergstorm, M. Suominen, and P. Kujala, "An Artificial Bee Colony optimization-based approach for sizing and composition of Arctic offshore drilling support fleets considering cost-efficiency," *Ship Technology Research*, vol. 26, no. 5, 42 pages, 2022.

[27] B. Gorkemli, "A new method based on artificial bee colony programming for the regional standardized intensity-duration-frequency relationship," *Arabian Journal of Geosciences*, vol. 15, no. 3, p. 407, 2022.

[28] U. Erkan, A. Toktas, and D. "Ustun, "Hyperparameter optimization of deep CNN classifier for plant species identification using artificial bee colony algorithm," *Journal of Ambient Intelligence and Humanized Computing*, vol. 12, no. 3, pp. 107–109, 2022.

[29] R. Danehchin, "Enhancing fault tolerance in vehicular ad-hoc networks using artificial bee colony algorithm-based spanning trees," *International Journal of System Assurance Engineering and Management*, vol. 4, no. 3, pp. 22–24, 2022.

[30] C. Ben Djaballah and W. Nouibat, "A new multi-population artificial bee algorithm based on global and local optima for numerical optimization," *Cluster Computing-the Journal of Networks Software Tools and Applications*, vol. 11, no. 3, 108 pages, 2022.

[31] M. Zapata-Cachafeiro, "Artificial bee colony algorithm with bi-coordinate systems for global numerical optimization," *International Journal of Intelligent Systems*, vol. 23, no. 3, p. 203, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 1711645, 14 pages
https://doi.org/10.1155/2022/1711645

Research Article

IPO Pricing, Investor Behavior, and IPO Underpricing of High-Tech Companies: Evidence from SSE STAR Market and Nasdaq Market

Yu Ma,[1,2] **Guiling Liu**,[1,2] **and Chaoping Qi**[3]

[1]*Department of Finance, University of Shandong Technology and Business, Yantai, Shandong 264005, China*
[2]*Shandong Provincial University Financial Service Transformation Collaborative Innovation Center, Yantai, 264005, China*
[3]*Department of Management, University of Shandong Technology and Business, Yantai, Shandong 264005, China*

Correspondence should be addressed to Chaoping Qi; qichaoping@163.com

Received 9 February 2022; Accepted 7 March 2022; Published 26 March 2022

Academic Editor: Lele Qin

There is a significant IPO underpricing phenomenon in the stocks of high-tech companies on China Science and Technology Innovation Board (STAR Market). In order to analyze the causes of high IPO underpricing on STAR Market, from the perspective of investor behavior, this paper uses the Two-tier Stochastic Frontier Model to decompose IPO underpricing into two parts, the pricing impact of the primary market and the transaction impact of the secondary market, and then studies the differences of the impact of different markets on IPO underpricing. The results show the following: (1) the primary market pricing of most stocks, that is, the difference between the issuance price of stocks and the real value of stocks is small, which shows that the primary market pricing has a weak impact on the IPO underpricing of the STAR Market, which in turn shows that the implementation of the registration system has significantly improved the IPO pricing efficiency of the STAR Market; (2) the closing price of most stocks fell on debut, that is, the trading price of stocks is significantly higher than its real value, which shows that the blind optimism of investors in the secondary market and the irrationality of investor structure are the main factors leading to the IPO underpricing of the STAR Market; and (3) through the variance decomposition and the robustness test of grouping the industry to which the enterprise belongs, the year of listing, and issuance and the size of the enterprise, we find that in different years and different industries, the impact of investor behavior in the secondary market on IPO underpricing is significantly higher than that in the primary market. In addition, the IPO underpricing of enterprises is not affected by the size of enterprises. This shows that the behavior of investors in the secondary market has always been the main means to affect the IPO underpricing of the STAR Market. This paper expands the analysis idea of IPO underpricing, which has a certain reference significance for the reform of STAR Market and the listing and financing of scientific and technological innovation enterprises.

1. Introduction

For a long time, initial underpricing, "hot issue" markets, and long-term underperformance, as the "three anomalies" associated with the initial public offering (IPO), widely existed in major stock markets all over the world, especially in China's stock market. Among them, IPO underpricing refers to the phenomenon that the price of new shares rises sharply on the first trading day, which is significantly higher than the stock offering price. The degree of IPO underpricing in China's stock market is significantly higher than that in other countries, which seriously restricts the effectiveness of resource allocation in China's stock market. Some scholars pointed out that the restrictions of China's stock issuance system are important factors causing the high degree of IPO underpricing in the stock market [1]. Based on the experience of the stock markets in Europe and the United States, the stock issuance registration system with the core function of disclosing issuers' information can effectively reduce IPO Underpricing and other issues [2–4]. On June 13, 2019, STAR Market was officially launched, and the registration system was piloted. Theoretically, with the implementation

of a registration system, the stocks' prices should gradually return to the real value in the stock market. However, through the analysis of the IPO data of enterprises listed on STAR Market, it is found that the IPO underpricing phenomenon of the STAR Market is still widespread and significantly higher than that of the stock market represented by the Nasdaq. The reason for this is that the listed enterprises on STAR Market are mainly scientific and technological innovation enterprises facing the world's scientific and technological frontier and serving the national strategy. Therefore, the secondary market investors would irrationally prefer the firms listed on the STAR Market easily. At present, the research on IPO underpricing of STAR Market mostly focuses on pricing efficiency, and there is less analysis on the causes of IPO underpricing. To study whether the IPO underpricing of scientific and technological innovation enterprises is mainly affected by the behavior of investors in the secondary market, the IPO underpricing is divided into two parts: the impact of offering pricing in the primary market and the impact of investor behavior in the secondary market. By comparing their impact factor to IPO underpricing, the part which mainly influences the IPO underpricing will be conducted. At the same time, as a control, the Nasdaq Market is selected to compare the differences between the IPO underpricing of high-tech companies in an emerging capital market and a developed capital market. Through the decomposition of IPO underpricing, we can get the main influencing factors of IPO underpricing of the STAR Market. The research conclusion is of great significance to ensure the smooth operation of STAR Market and improve the Chinese capital market system.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature on IPO underpricing. Section 3 presents the research methods, data, and methodology. Section 4 presents and interprets the empirical results. Section 5 is the robustness test. Section 6 concludes and discusses the policy implications.

2. Literature Review

The research on IPO underpricing has a long history, which can be traced back to the 1970s. Dennis [5] and others discovered IPO underpricing earlier in the process of studying the stock market but did not study this phenomenon further. Ibbotson [6] first put forward the concept of IPO underpricing when studying American-listed enterprises to describe the phenomenon that the trading price on the first day of IPO is higher than the offering price. The previous research was mainly based on the information asymmetry theory and analyzed the IPO underpricing phenomenon on the premise that the secondary market is effective. At this stage, scholars generally believed that the discount of the primary market is the main factor causing the IPO underpricing phenomenon. On this basis, they studied and formed the underwriter monopoly theory, "Winner's Curse" theory, and signal theory. The underwriter monopoly theory holds that the stock issuer lacks effective supervision over the underwriter, and the underwriter tends to bring the IPO pricing downward from the real value of the stock. On the one hand, IPO issued at discount can reduce the risk of underwriters and maintain their reputation; on the other hand, it can compensate the investors who are at a disadvantage of information and maintain the relationship with investors [7, 8]. The "Winner's Curse" theory was developed by Rock [9] based on the underwriter monopoly theory. Rock [9] believes that there is information asymmetry among investors in the secondary market. Investors with information can buy stocks with high investment value according to their information, while investors without information can only buy stocks with no investment value abandoned by investors with information, which eventually leads to investors without information exiting the market. To ensure the smooth issuance of shares, we must attract investors who do not have information through discount issuance. Allen and Faulhaberborad [10] put forward the signal theory of IPO underpricing by bringing the information mastery of stock issuers, underwriters, and investors into the same framework. This theory assumes that the information of the real value of the stock issuer is higher than that of the investor, so it is necessary to transmit the information of the real value of the stock through discount issuance. At the same time, to transmit the low-risk signal of stocks, stock issuers often entrust reputable underwriters to underwrite the stocks. With the continuous development of the capital market and economic theory, some scholars found that the effectiveness of the secondary market remains to be discussed. The traditional stock discount issuance theory is insufficient to explain many phenomena in the process of stock IPO, and the research focus began to shift to the behavior of investors in the secondary market [11], Jay and Lvo [12] pointed out that the irrational behavior of investors in the secondary market is the main reason for IPO underpricing. According to Jay and Lvo [12], combined with the theoretical support of behavioral finance, François [13] and Alexander et al. [14] proposed the mechanism of secondary market investors affecting IPO underpricing. They believed that individual investor sentiment in the secondary market is the main reason for IPO underpricing. The excessive optimism of individual investors will lead to the valuation of enterprise stocks in the secondary market being significantly higher than the real value of enterprise stocks. Therefore, in the process of stock pricing, underwriters can issue stocks at an issue price lower than the stock trading price in the secondary market but higher than the real value of enterprise stocks. In recent years, scholars have studied the influencing factors of IPO underpricing more widely. Baschieri et al. [15] pointed out that the preference of local investors for local IPO companies will significantly affect the IPO underpricing rate of the company. Boulton et al. [16] found that the IPO underpricing of enterprises with Wikipedia records was significantly higher than that of enterprises without Wikipedia records. At the same time, some scholars found that government risk management and market manipulation rules also have a significant impact on IPO underpricing by studying international samples [17, 18].

With the development of China's capital market, the researches on IPO underpricing in China gradually rose after 2000. Yang and Wang [19] first tested the explanatory

power of information asymmetry theory on IPO underpricing in China's stock market by studying the stocks issued in China's A-share market from 1998 to 2000. Different from foreign stock markets, China's stock market has the characteristics of short development time, low market effectiveness, imperfect infrastructure, etc. Therefore, China scholars' research on IPO underpricing focused more on the level of market effectiveness and regulation. Liu and Xiong [20] found that the market environment under the special system will distort the interest mechanism and lead to the heterogeneity of investors' behavior, resulting in the phenomenon of high IPO underpricing. Tian [21] pointed out that IPO underpricing in China is mainly affected by the regulatory policies of stock issuance, which is an institutional underpricing. Chu and Zhang [22] divided the reform of China's stock issuance system into seven stages to study the impact of the IPO issuance system on IPO underpricing. The results show that pricing regulation is an important reason for the high IPO underpricing in the process of IPO in China, and with the continuous reform of China's stock issuance system, the degree of IPO underpricing shows a downward trend. Another major feature of China's stock market is the large proportion of individual investors. Therefore, some China scholars studied its impact on IPO underpricing from the perspective of investor sentiment. Han and Wu [23] put forward a systematic research framework on the impact of investor sentiment on IPO underpricing for the first time. The results showed that high investor sentiment can significantly improve the level of IPO underpricing. Subsequently, the research conclusions of Song and Wang [24] and Shi et al. [25] further verified the impact of investor sentiment on IPO underpricing. In addition, the reform of the registration system is an important measure for the development of China's stock market. The impact of the implementation of registration system on IPO underpricing is also a popular research question. Zhang and Wu [26] and Lv et al. [27] studied the impact of the registration system of the science and Innovation Board on IPO underpricing from the aspects of the underwriter follow-up investment system and the sponsor's approval system and recommendation experience, and found that the implementation of the registration system can reduce the IPO underpricing level.

Based on the above analysis, the following assumptions are proposed:

(i) H1: registration-based system can improve IPO pricing efficiency and has a positive impact on reducing IPO underpricing level

(ii) H2: the irrational behavior of investors in the secondary market has a positive impact on improving the IPO underpricing level

To sum up, scholars at home and abroad have a long history of IPO Underpricing and have developed a series of theoretical hypotheses. The empirical research on IPO underpricing covers a wide range, and makes a more comprehensive analysis on the influencing factors of IPO underpricing from the perspectives of stock issuers, underwriters, and investors. In view of the reality of China, Chinese scholars' research on IPO underpricing focuses more on policy and system. Although the existing literature on IPO underpricing has been more comprehensive, most studies only focus on the unilateral impact of the primary market or the secondary market, and there are few studies on the joint impact of the two markets. Only Huang et al. [28] studied the IPO underpricing phenomenon of STAR Market by integrating the primary market impact and secondary market impact into the same framework with the help of two-tier stochastic frontier model. In addition, the existing research on IPO underpricing of science and innovation board is mostly theoretical analysis, which may be caused by the short establishment time and limited data of science and innovation board. However, so far, the scientific innovation board has been officially opened for more than two years, with more than 350 listed companies, and the amount of data is enough to support the empirical research on IPO underpricing. The main marginal contributions of this paper are as follows: (1) from the perspective of market classification, this paper makes a quantitative study on the IPO underpricing of scientific and technological innovation enterprises by using the two-tier stochastic frontier model, systematically analyzes the impact of the primary market and the secondary market on the IPO underpricing of scientific and technological innovation enterprises. It avoids the limitations of the study on the impact of a single market, and enriches the research ideas of IPO underpricing; (2) this paper compares the sci-tech innovation board and Nasdaq Market into the same research framework, and clearly points out the similarities and differences between the IPO underpricing in those two capital markets through comparative analysis, which provides empirical help for the construction of an international stock exchange market in China; and (3) through empirical research on the characteristics of IPO underpricing on the STAR board, this paper reveals the difference between IPO Underpricing on STAR Market and that on China's A-share market. This paper also provides some policy implications and suggestions for the construction of multi-level capital market in China.

3. Data and Methodology

3.1. Research Method. According to the efficient market hypothesis and other economic theories, under the condition of complete symmetry of information, the IPO pricing of listed enterprises should truly reflect the reasonable valuation of the real value of enterprises. However, neither the emerging capital market nor the capital market has reached a fully effective market, and there is a situation that the pricing of stock IPO deviates from the real value of enterprises. According to the analysis of the existing literature, IPO underpricing can be divided into two parts: primary market pricing and secondary market investor behavior. Under the idea of traditional econometrics, the multiple linear regression method can be used to study the impact of IPO underpricing on the pricing of the primary market and the behavior of investors in the secondary

market. However, Hunt-McCool et al. [29] pointed out that linear regression models such as OLS have great deficiencies in the ability to explain IPO underpricing. Therefore, the Two-tier Stochastic Frontier Model (SFA) is proposed for the following research and analysis. The Two-tier Stochastic Frontier Model (SFA) was first proposed by Meeusen and Den [30] and Aigner et al. [31] when studying the input-output efficiency of enterprises. After further development in the 1990s, it was widely used in economic research.

Since both the STAR Market and the Nasdaq Market adopt the registration system, in theory, the closing price on the first day of listing can fully reflect the information of the secondary market. Therefore, we can use the closing price on the first day of listing as an approximate substitute for the trading price in the stock market, and the expression of IPO underpricing is as follows:

$$\mathrm{UP}_i = \frac{CP_i - \mathrm{IP}_i}{\mathrm{IP}_i}, \tag{1}$$

where UP_i represents the IPO underpricing level of stock i, CP_i and IP_i represent the market trading price and issuance price of stock I, respectively. Algebraic Treatment of (1) shows that

$$\ln\left(\mathrm{UP}_i + 1\right) = \ln CP_i - \ln \mathrm{IP}_i. \tag{2}$$

In the above formula, replacing $\ln\mathrm{UP_i}$ with $\ln(UP_i + 1)$ has no significant impact on the research conclusion, and after processing, it ensures that the IPO underpricing level in the sample data is greater than 0, which is conducive to calculation. According to the idea of the Two-tier Stochastic Frontier Model, in theory, there is an effective boundary where there is no difference between the issue price and the market transaction price of the stock. On this boundary, the issue price and the market transaction price of the stock should be equal to the real value of the stock, that is,

$$CP_i^* = \ln_i^* = TP_i^*, \tag{3}$$

$$TP_i^* = f\left(X_i; \beta_i\right) + \rho_i, \tag{4}$$

where CP_i^* and IP_i^*, respectively, represent the trading price and issuing price of the stock market in the ideal state, IP_i^* represents the real value of the stock, X_i represents the enterprise and market characteristics that affect the real value of the stock, β_i represents the corresponding influence coefficient, and ρ_i represents the random error term. However, in reality, the issue price and market transaction price of stocks are affected by many factors and always deviate from the real value of stocks. Therefore, the actual stock market transaction price and issue price can be expressed as

$$\ln \mathrm{lP}_i = \ln \mathrm{lP}_i^* + \delta_i + \mu_i. \tag{5}$$

$$\ln CP_i = \ln CP_i^* + \varepsilon_i + \omega_i, \tag{6}$$

where ε and δ represent an unobservable random error term, μ_i and ω_i represent the deviation degree of the issue price and market transaction price relative to the real value of the stock, respectively. According to the previous analysis, μ_i and ω_i are greater than 0. The final expression of IPO underpricing can be obtained by combining formulas (2), (3), (4), (5), and (6):

$$\ln\left(\mathrm{UP}_i + 1\right) = g\left(X_i; \gamma_i\right) + \theta_i, \quad \theta_i = v_i + \omega_i - \mu_i. \tag{7}$$

(7) is the standard form of the Two-Tier Stochastic Frontier Model. Among them, γ_i represents the parameter to be estimated, X_i represents the influencing factors at the enterprise and market level, v_i represents the general random error term, μ_i represents the impact of stock issue price on IPO underpricing, and ω_i represents the impact of stock market transaction price on IPO underpricing. According to the theoretical analysis and the setting of model (7), μ_i and ω_i all obey unilateral distribution, assuming $\mu_i \sim EXP(\lambda_\mu, \lambda_\mu^2), \omega_i \sim EXP(\lambda_\omega, \lambda_\omega^2)$. For the general random error term v_i, it is generally assumed that it follows the standard normal distribution, that is, $v_i \sim N(0, \sigma^2)$. At the same time, it is assumed that the random error terms v_i, μ_i, and ω_i are independent of each other; so, the total random error term can be obtained as θ_i Probability density function of $f(\theta_i)$:

$$f\left(\theta_i\right) = \frac{\exp\left(a_i\right)\Phi\left(c_i\right) + \exp\left(b_i\right)\phi\left(d_i\right)}{\lambda_u + \lambda_\omega}. \tag{8}$$

Here,

$$\begin{aligned} a_i &= \frac{\sigma^2}{2\lambda_u^2} + \frac{\theta_i}{\lambda_\mu}, \\ b_i &= \frac{\sigma^2}{2\lambda_\omega^2} - \frac{\theta_i}{\lambda_\omega}, \\ c_i &= -\frac{\theta_i}{\sigma} - \frac{\sigma}{\lambda_\mu}, \\ d_i &= \frac{\theta_i}{\sigma} - \frac{\sigma}{\lambda_\omega}, \end{aligned} \tag{9}$$

where $\Phi(\cdot)$ and $\phi(\cdot)$ are cumulative distribution function and probability density function of standard normal distribution, respectively. Key research variables are λ_μ and λ_ω It only appears in the variables a_i, c_i and b_i, d_i, respectively, so it can be identified. According to (8), the natural function expression in logarithmic form can be obtained as

$$\ln L = -n \ln\left(\lambda_u + \lambda_\omega\right) + \sum_{i=1}^{n} \ln\left[e^{a_1}\Phi\left(c_i\right) + e^{b_1}\phi\left(d_i\right)\right]. \tag{10}$$

The maximum likelihood estimation of the correlation coefficient can be obtained by solving the log likelihood function. In view of the impact of primary market pricing and secondary market investor behavior on IPO underpricing, which this paper focuses on, we need to get the conditional distributions of μ_i and ω_i. After calculation, we can get

$$f(\mu_i|\theta_i) = \frac{\tau \exp(-\tau\mu_i)\Phi((\mu_i/\sigma) + d_i)}{\Phi(d_i) + \exp(a_i - b_i)\Phi(c_i)}, \quad (11)$$

$$f(\omega_i|\theta_i) = \frac{\tau \exp(-\tau\omega_i)\Phi((\omega_i/\sigma) + c_i)}{\exp(a_i - b_i)[\Phi(d_i) + \exp(a_i - b_i)\Phi(c_i)]}. \quad (12)$$

Including $\tau = 1/\mu_i + 1/\omega_i$. The conditional expectation functions of μ_i and ω_i can be further obtained according to (11) and (12):

$$E\left(1 - e^{-\mu_i} \mid \theta_i\right) = 1 - \frac{\tau}{1+\tau} \frac{\Phi(d_i) + \exp(a_i - b_i)\exp\left(\left(\sigma^2/2\right) - \sigma c_i\right)\Phi(c_i - \sigma)}{\Phi(d_i) + \exp(a_i - b_i)\Phi(c_i)}, \quad (13)$$

$$E\left(1 - e^{-\omega_i} \mid \theta_i\right) = 1 - \frac{\tau}{1+\tau} \frac{\Phi(c_i) + \exp(b_i - a_i)\exp\left(\left(\sigma^2/2\right) - \sigma d_i\right)\Phi(d_i - \sigma)}{\exp(a_i - b_i)[\Phi(d_i) + \exp(a_i - b_i)\Phi(c_i)]}. \quad (14)$$

For this paper, (13) and (14), respectively, represent the extent to which the stock issuance price and market transaction price deviate from the real value of the stock, which can reflect the impact of primary market pricing on IPO underpricing effect (FE) and the impact of secondary market investor behavior on IPO underpricing effect (SE). The difference between the two is the net effect (NE) = SE-FE. According to the above formula, we can analyze the IPO underpricing effect of different samples.

3.2. Data Source and Model Setting. As of October 28, 2021, STAR Market has issued 352 stocks. After excluding the stock samples with missing data and breaking on the first day of listing, we obtained a total of 322 sample data. We also selected the stocks issued in the Nasdaq Market as the control sample. After excluding the stock samples with missing data and breaking on the first day of listing, we obtained a total of 613 sample data.

In order to study the impact of IPO underpricing on the pricing of the primary market and the behavior of investors in the secondary market, based on the practice of Huang et al. [28], the total amount of IPO funds raised, underwriting sponsor fees and underwriter reputation are selected as the measurement indicators of the pricing of the primary market, and the stock turnover rate on the first day of listing price to book ratio and relative market rise and fall are used as indicators to measure the behavior of investors in the secondary market. Among them, the underwriter's reputation is a dummy variable. If the stock IPO underwriters rank among the top ten in that year, it is 1, otherwise it is 0. At the same time, based on the practices of Hu and Zhao [32], Qiu and Cao [33] and Zhang et al. [34], enterprise age, enterprise profitability, enterprise scale, and enterprise growth are selected as the measurement indicators at the enterprise level. Combined with the above analysis, the following regression model is constructed:

$$\begin{aligned} \mathrm{UP} = {} & \alpha_0 + \alpha_1 \mathrm{Age}_i + \alpha_2 \mathrm{ROE}_i + \alpha_3 \mathrm{Size}_i + \alpha_4 \mathrm{Growth}_i + \alpha_5 \mathrm{TFR}_i + \alpha_6 \mathrm{URF}_i \\ & + \alpha_7 \mathrm{UR}_i + \alpha_8 \mathrm{FT}_i + \alpha_9 \mathrm{PBR}_i + \alpha_{10} \mathrm{RRF}_i + v_i + \omega_i - \mu_i. \end{aligned} \quad (15)$$

Among them, the meanings of symbols v_i, μ_i, and ω_i are the same as those above. See Table 1 for other specific variable names, symbols, and definitions.

The selected variable data are from the Wind Financial Database and the CSMAR China stock database. Some enterprise-level measurement index variable data are manually collected through the prospectus. In the primary market measurement index, the underwriter reputation is calculated according to the ranking of the lead underwriter in the current year of stock IPO. In the empirical analysis, in order to avoid the impact of dimensionality and other problems on the results, and to ensure the reasonable interpretation of various variable coefficients, some data are logarithmicized. Tables 2 and 3 are the descriptive statistics of the processed data of STAR Market and Nasdaq Market, respectively. It can be found that the average IPO underpricing value of STAR Market is significantly higher than that of the Nasdaq Market, which is consistent with the later empirical research results.

4. Empirical Research

4.1. Benchmark Regression. Based on (15), this paper decomposes the IPO underpricing in STAR Market and the Nasdaq Market, respectively, and measures the impact of the primary market pricing and the secondary market investor behavior on IPO underpricing through the Two-tier Stochastic Frontier Model. The regression results are given in Tables 4 and 5, respectively.

The OLS regression results of model (15) are given in column 1 of Tables 4 and 5 for comparison. The second column gives the maximum likelihood estimation results of model (15) under additional constraint ($\lambda_\mu = 0$, $\lambda_\omega = 0$). The third column gives the maximum likelihood estimation results of model (15) under the Two-tier Stochastic Frontier Model. Columns 4–5 are the regression results of gradually adding industry dummy variables and year dummy variables based on column 3. It can be found that there is almost no significant change in the coefficient of each column of regression results,

Table 1: Variable symbols and definitions.

Variable type		Variable name	Variable symbol	Variable description
Explained variable		IPO underpricing	UP	IPO underpricing = ln ((first day closing price initial price)/initial price)
Explanatory variable	Enterprise-level metrics	Enterprise age	Age	Logarithm of time from establishment to IPO
		Profitability	ROE	Return on net assets
		Enterprise scale	Size	Logarithm of total assets of the enterprise
		Growth	Growth	Logarithm of enterprise net profit
	Primary market measurement indicators	Total IPO funds raised	TFR	Logarithm of total IPO funds raised
		IPO underwriting and recommendation fee	URF	IPO underwriting and recommendation fee
		Underwriter reputation	UR	Dummy variable, if the underwriter is the top ten underwriters of the year, the value is 1, otherwise it is 0
	Secondary market metrics	Turnover rate on the first day of listing	FT	Turnover rate on the first day of stock listing
		Price to book ratio on the first day of listing	PBR	Price to book ratio on the first day of stock listing
		Relative market rise and fall	RRF	The first day of stock listing rose or fell relative to the market

Table 2: Descriptive statistics of variables of STAR Market.

Variable symbol	Mean	Std	Min	Max
UP	0.938	0.446	0.019	2.620
Age	8.568	0.358	7.432	9.587
ROE	0.127	0.074	0.011	0.686
Size	20.596	0.969	18.643	25.467
Growth	18.362	0.762	16.363	22.036
TFR	11.523	31.036	1.076	532.302
URF	6.247	5.096	1.835	69.199
UR	0.643	0.48	0	1
FT	75.076	5.948	53.075	98.965
PBR	0.283	0.104	0.102	0.874
RRF	−4.257	86.206	−96.11	727.121

Table 3: Descriptive statistics of variables of NASDAQ.

Variable symbol	Mean	Std	Min	Max
UP	0.363	0.282	0.096	2.493
Age	7.607	1.074	2.833	10.567
ROE	−0.887	6.575	−114.996	14.218
Size	18.362	1.928	8.573	23.982
Growth	−0.024	0.099	−0.964	0.612
TFR	1.742	2.689	0.053	34
URF	1.148	1.304	0.042	9.625
UR	0.954	0.209	0	1
FT	19.668	33.101	0.073	521.052
PBR	0.007	0.448	−5.519	2.949
RRF	6.572	9.541	0.01	95.54

indicating that the variables at different levels we choose are reasonable. In addition, in the regression results under the two-tier stochastic Frontier model, all other random errors μ and ω both are significant at the significance level of 1%. Only the random error μ of measuring the impact of the primary market on IPO underpricing in column 3 of Table 4 is not significant. Therefore, it can be considered that the IPO underpricing of the STAR Market and Nasdaq Market are significantly affected by the pricing of the primary market and the behavior of investors in the secondary market.

4.2. Variance Decomposition. The research focuses on the difference in the impact of primary market pricing and secondary market investor behavior on IPO underpricing. Therefore, it is necessary to conduct variance decomposition

Table 4: Estimation of the IPO underpricing model of the STAR Market.

Variable	(1) OLS	(2) MLE	(3) Two-tier SFA	(4) Two-tier SFA	(5) Two-tier SFA
Age	0.040	0.021∗∗∗	0.054	0.030	−0.027
	(0.664)	(3.302)	(0.962)	(0.530)	(−0.499)
ROE	0.860	0.892∗∗∗	0.964∗	0.873	0.592
	(1.305)	(45.570)	(1.708)	(1.530)	(1.081)
Size	0.218∗∗∗	0.240∗∗∗	0.229∗∗∗	0.236∗∗∗	0.209∗∗∗
	(2.699)	(50.533)	(3.292)	(3.363)	(3.109)
Growth	−0.237∗∗∗	−0.285∗∗∗	−0.257∗∗∗	−0.250∗∗∗	−0.211∗∗∗
	(−2.775)	(−65.497)	(−3.390)	(−3.270)	(−2.892)
TFR	0.001	0.002∗∗∗	0.002	0.002	0.002
	(0.967)	(28.882)	(1.642)	(1.490)	(1.417)
URF	−0.006	−0.009∗∗∗	−0.011	−0.012	−0.009
	(−0.661)	(−16.954)	(−1.273)	(−1.324)	(−1.058)
UR	0.030	0.036∗∗∗	0.042	0.019	−0.007
	(0.649)	(6.950)	(0.957)	(0.442)	(−0.163)
FT	0.031∗∗∗	0.032∗∗∗	0.028∗∗∗	0.028∗∗∗	0.031∗∗∗
	(7.286)	(58.973)	(6.955)	(7.007)	(8.158)
PBR	−0.386	−0.330∗∗∗	−0.299	−0.495∗∗	−0.298
	(−1.632)	(−18.198)	(−1.292)	(−2.014)	(−1.283)
RRF	−0.001∗∗∗	−0.001∗∗∗	−0.001∗∗∗	−0.001∗∗∗	−0.001∗∗∗
	(v4.071)	(−27.938)	(−3.741)	(−3.962)	(−3.261)
Cons	−1.859∗∗	−1.422∗∗∗	−1.920∗∗	−1.821∗∗	−1.712∗∗
	(−1.978)	(−20.709)	(−2.255)	(−2.173)	(−2.151)
Industry	—	—	—	Control	Control
Year	—	—	—	—	Control
ω	—	—	−1.262∗∗∗	−1.334∗∗∗	−1.362∗∗∗
μ	—	—	−4.806	−4.798∗∗	−4.861∗∗∗
Adj-R^2	0.267	—	—	—	—
LL	−141.580	−317.207	−132.144	−124.768	−108.659
LR	—	—	370.13	384.88	417.10
*P*value	—	—	0.000	0.000	0.000
N	322	322	322	322	322

Note. The symbols ∗, ∗∗, and ∗∗∗, respectively, mean significant at the level of 10%, 5%, and 1%, respectively, and the values in brackets are *t* statistics.

analysis on the regression results according to (13) and (14). Tables 6 and 7 show the variance decomposition results of IPO underpricing in the STAR Market and Nasdaq Markets, respectively. It can be found in Tables 6 and 7 that σ_μ and σ_ω both are greater than 0, which verifies again that IPO underpricing is affected by both the primary market and the secondary market. However, there are significant differences in IPO underpricing between the STAR Market and Nasdaq Market. Specifically, the impact of the primary market pricing of the STAR Market on IPO underpricing is 0.0077, and the impact of the secondary market investor behavior on IPO underpricing is 0.2562, with a net effect of $NE = \sigma_\omega - \sigma_\mu = 0.2485$. In addition, the total variance of the random term is 0.1246, of which 52.7% is contributed by the influence effect of primary market pricing and secondary market investor behavior. In the total influence of primary market pricing and secondary market investor behavior, the influence degree of secondary market investor behavior accounts for as high as 0.9991%, and the influence degree of primary market pricing accounts for only 0.0009%. This shows that the IPO underpricing phenomenon of the STAR Market is mainly affected by the behavior of investors in the secondary market, and the impact of pricing in the primary market is very weak. This conclusion verifies the previous hypothesis. In the Nasdaq Market, the impact of primary market pricing on IPO underpricing is 0.0729, and the impact of secondary market investor behavior on IPO underpricing is 0.0869, with a net effect of $NE = \sigma_\omega - \sigma_\mu = 0.014$. In addition, it is found that the total variance of the random term is 0.0129, which is completely composed of the influence degree of primary market pricing and secondary market investor behavior, indicating that the influence of primary market pricing and secondary market investor behavior has a strong ability to explain IPO underpricing. In the total impact of primary market pricing and secondary market investor behavior, the impact of secondary market investor behavior accounts for 58.75%, and the impact of primary market pricing accounts for only 41.25%. This shows that IPO underpricing in the Nasdaq Market is not affected by the pricing of the primary market and the behavior of investors in the secondary market.

Further estimate the conditional expectation of the influence degree of pricing in the primary market (FE) and the influence degree of investor behavior in the secondary market (SE) in the phenomenon of IPO underpricing according to formula (13), (14). The results are shown in Tables 8 and 9, where Q1–Q3 represent 25%, 50%, and 75% of the quantiles, respectively. According to the results in

Table 5: Estimation of the IPO underpricing model of the Nasdaq Market.

Variable	(1) OLS	(2) MLE	(3) Two-tier SFA	(4) Two-tier SFA	(5) Two-tier SFA
Age	−0.017∗∗∗	−0.005∗∗∗	−0.004∗∗∗	−0.004∗∗∗	−0.005∗∗∗
	(−2.668)	(−5.749)	(−84.549)	(−31.270)	(−83.440)
ROE	−0.209	0.008	0.022∗∗∗	0.047∗∗∗	0.082∗∗∗
	(−0.648)	(0.164)	(6.280)	(11.972)	(30.353)
Size	−0.010∗∗	−0.005∗∗∗	−0.005∗∗∗	−0.002∗∗∗	−0.004∗∗∗
	(−2.573)	(−9.186)	(−152.128)	(−49.039)	(−302.304)
Growth	0.084	0.063∗∗∗	0.060∗∗∗	0.063∗∗∗	0.060∗∗∗
	(1.136)	(9.594)	(127.438)	(296.781)	(368.263)
TFR	−0.018∗∗∗	−0.001	−0.001∗∗∗	−0.006∗∗∗	−0.005∗∗∗
	(−3.493)	(−1.614)	(−9.220)	(−140.157)	(−223.433)
URF	0.003	−0.008∗∗∗	−0.008∗∗∗	−0.004∗∗∗	−0.005∗∗∗
	(0.294)	(−15.346)	(−184.969)	(−33.996)	(−60.248)
UR	0.016	−0.010	−0.011∗∗∗	−0.001∗	0.009∗∗∗
	(0.498)	(−0.506)	(−60.357)	(−1.813)	(28.826)
FT	−0.813∗∗∗	0.291∗∗∗	0.300∗∗∗	0.091∗∗∗	0.006
	(−3.770)	(10.436)	(159.561)	(9.596)	(0.978)
PBR	0.034∗∗	0.005∗∗∗	0.005∗∗∗	0.003∗∗∗	0.003∗∗∗
	(2.243)	(5.899)	(81.583)	(74.837)	(75.164)
RRF	0.026∗∗∗	0.0321∗∗∗	0.0321∗∗∗	0.0301∗∗∗	0.0301∗∗∗
	(32.898)	(100.647)	(2588.458)	(1935.413)	(3619.262)
Cons	1.110∗∗∗	0.436∗∗∗	0.484∗∗∗	0.541∗∗∗	0.528∗∗∗
	(5.944)	(17.184)	(164.738)	(561.612)	(902.236)
Industry	—	—	—	Control	Control
Year	—	—	—	—	Control
ω	—	—	−2.475∗∗∗	−2.432∗∗∗	−2.443∗∗∗
μ	—	—	−2.508∗∗∗	−2.606∗∗∗	−2.619∗∗∗
Adj-R^2	0.661	—	—	—	—
LL	242.977	−475.642	489.565	503.903	511.132
LR	—	—	1930.41	1959.09	1973.55
P-value	—	—	0.000	0.000	0.000
N	613	613	613	613	613

Note. The symbols ∗, ∗∗, and ∗∗∗, respectively, mean significant at the level of 10%, 5%, and 1%, and the values in brackets are t statistics.

Table 6: Measurement results of IPO underpricing decomposition of the STAR Market.

Symbol	Symbolic meaning	Measure value
σ	Random error term	0.2428
λ_μ	Primary market impact	0.0077
λ_ω	Influence degree of secondary market	0.2562
$\sigma^2+\lambda_\mu^2+\lambda_\omega^2$	Sum of variance of random items	0.1246
$\lambda_\mu^2+\lambda_\omega^2/(\sigma^2+\lambda_\mu^2+\lambda_\omega^2)$	Proportion of primary market and secondary market influence in total variance	52.7%
$\lambda_\mu^2/(\lambda_\mu^2+\lambda_\omega^2)$	Proportion of primary market influence in total variance	0.0009%
$\lambda_\omega^2/(\lambda_\mu^2+\lambda_\omega^2)$	Proportion of secondary market influence in total variance	0.9991%

Table 7: Measurement results of IPO underpricing decomposition of the Nasdaq Market.

Symbol	Symbolic meaning	Measure value
σ	Random error term	0.0000
λ_μ	Primary market impact	0.0729
λ_ω	Influence degree of secondary market	0.0869
$\sigma^2+\lambda_\mu^2+\lambda_\omega^2$	Sum of variance of random items	0.0129
$\lambda_\mu^2+\lambda_\omega^2/(\sigma^2+\lambda_\mu^2+\lambda_\omega^2)$	Proportion of primary market and secondary market influence in total variance	100%
$\lambda_\mu^2/(\lambda_\mu^2+\lambda_\omega^2)$	Proportion of primary market influence in total variance	41.25%
$\lambda_\omega^2/(\lambda_\mu^2+\lambda_\omega^2)$	Proportion of secondary market influence in total variance	58.75%

Table 8, it can be found that the IPO underpricing level of the STAR Market is more affected by the behavior of investors in the secondary market. On average, the influence of the behavior of investors in the secondary market is about 26 times that of the pricing in the primary market, and the influence of the pricing in the primary market basically does

Table 8: Estimated results of FE, SE, and NE of the STAR Market.

Symbol	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
SE:E(1-$e_{-\omega}$|θ)	20.28	11.75	11.51	16.72	25.46
FE:E(1-$e^{-\mu}$|θ)	0.77	0.02	0.75	0.76	0.78
NE:SE-FE	19.51	11.77	10.73	15.95	24.71

Table 9: Estimated results of FE, SE, and NE of the Nasdaq Market.

Symbol	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
SE:E(1-$e^{-\omega}$|θ)	7.76	7.99	3.81	4.16	9.12
FE:E(1-$e^{-\mu}$|θ)	6.41	7.73	3.81	3.81	6.26
NE:SE-FE	1.35	12.00	−2.45	0.35	5.30

not change at different quantiles, but the influence of the behavior of investors in the secondary market changes significantly. This shows that there is heterogeneity in the impact of secondary market investor behavior on IPO underpricing of different stocks in the STAR Market. According to the results in Table 9, it can be seen that the IPO underpricing phenomenon in the Nasdaq Market is not affected by the pricing of the primary market and the behavior of investors in the secondary market, and the net effect (NE) is only 1.35%, which is far less than 19.51% of the STAR Market, indicating that the IPO underpricing degree in the Nasdaq Market is significantly lower than that in the STAR Market. At the same time, by comparing the results of different quantiles, it can be further found that the IPO underpricing of different stocks in the Nasdaq Market is heterogeneous and is affected by the pricing of the primary market and the behavior of investors in the secondary market, which shows that the Nasdaq Market is highly perfect, and the judgment of investors at different levels on the stock price is closer to the real value level of stocks.

Figures 1(a)–1(c) and 2(a)–2(c) show the frequency distribution histograms of FE, SE, and NE in the STAR Market and Nasdaq Market, respectively. Through the graph, we can more intuitively see the difference of the impact of primary market pricing and secondary market investor behavior on IPO underpricing in different stock markets. For the STAR Market, both the influence degree (FE) of primary market pricing on IPO underpricing and the influence degree (SE) of secondary market investor behavior on IPO underpricing show obvious distribution characteristics of tailing to the right, and the influence degree (FE) of primary market pricing is mainly concentrated in the range of 0.74%–0.82%, The influence degree (SE) of investor behavior in the secondary market is widely distributed between 10%–70%, and the net impact (NE) is all distributed on the right side of 0, which shows that the IPO underpricing of STAR Market within the sample range is mainly affected by the behavior of investors in the secondary market. For the Nasdaq Market, Fe and se also show the distribution characteristics of tailing to the right to a certain extent, and both Fe and Se are distributed between about 0% and 20%, with a small range of change. About 30% of the net impact (NE) is located on the right side of 0, indicating that only about 60% of the stocks in the Nasdaq Market within the sample range are affected by the pricing of the primary market and the behavior of investors in the secondary market, thus improving the IPO underpricing level.

5. Robustness Test

To describe the decomposition of IPO underpricing in more detail and avoid the estimation deviation of empirical results caused by accidental factors, the empirical results are grouped according to different standards to test the robustness of the empirical results. There are great differences in financial indicators of listed enterprises in different industries, and investors' preference for stocks in different industries is also inconsistent. Therefore, firstly, the sample listed companies are grouped according to their industries to study whether their IPO underpricing level is affected by different markets. Tables 10 and 11, respectively, show the net effect (NE) of IPO underpricing of sample stocks classified by industry in the STAR Market and Nasdaq Market, which is affected by the pricing of primary market and the behavior field of investors in the secondary market. The industry classification standard refers to the primary industry classification standard of Wind Database. It can be seen from the results in Table 10 that the net effect of IPO underpricing in different industries affected by the pricing of the primary market and the behavior of investors in the secondary market is positive. From the average value, there is little difference in IPO underpricing among industries. It shows that IPO underpricing is common in enterprises listed on the STAR Market, and the behavior of investors in the secondary market is the main reason for IPO underpricing. Through the data of different quantiles, it can be found that there are obvious individual differences in the impact of IPO underpricing level in some industries. For example, in the health care industry, the net effect of IPO underpricing at the first and third quantiles is nearly three times different, which may be related to the investment preference of investors in the market. On the whole, the estimated results of IPO underpricing decomposition of stocks in different industries of the STAR Market are consistent with the IPO underpricing decomposition results of the overall sample, while the estimated results of IPO underpricing decomposition of stocks in different industries of the Nasdaq Market are different from the IPO underpricing decomposition results

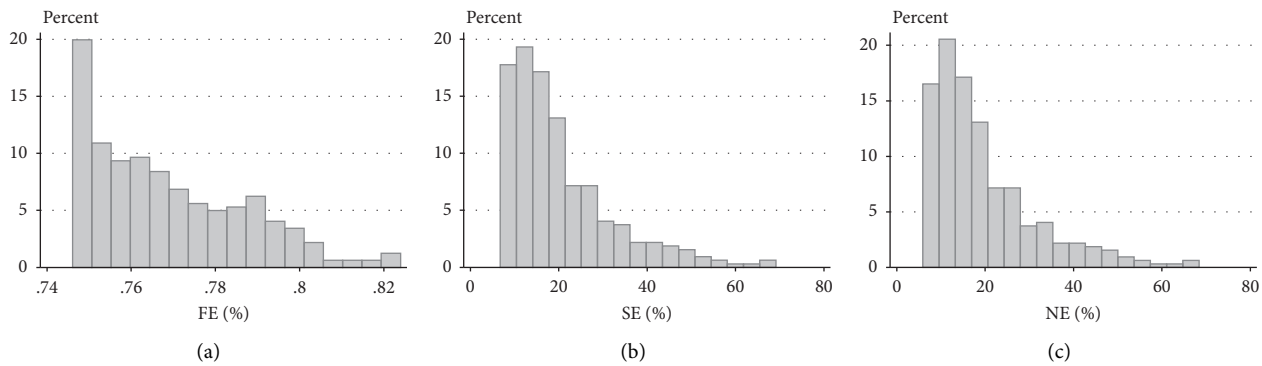


Figure 1: (a) STAR Market FE, (b) STAR Market SE, and (c) STAR Market NE.

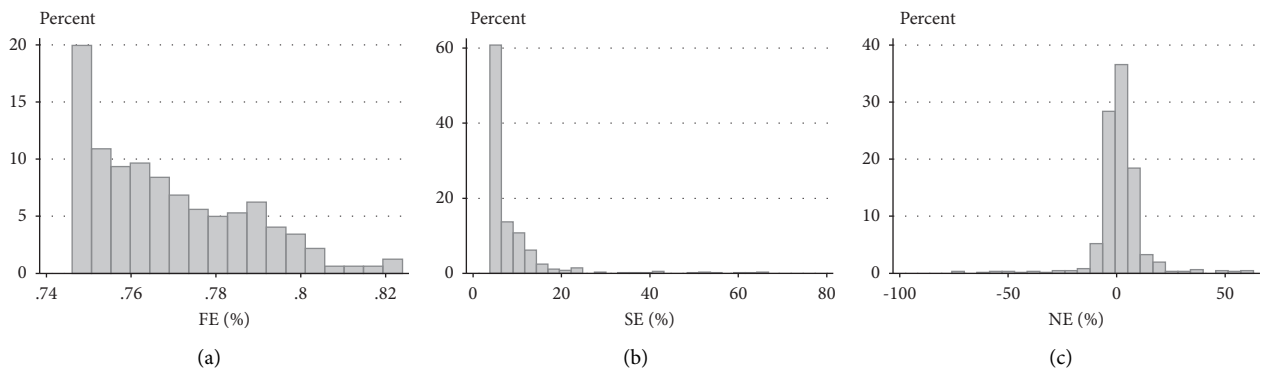


Figure 2: (a) Nasdaq Market FE, (b) Nasdaq Market SE, and (c) Nasdaq Market NE.

Table 10: Net effect of IPO underpricing decomposition in different industries of the STAR Market (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
Information technology	19.57	12.16	11.16	15.66	24.76
Public utility	14.54	—	14.54	14.54	14.54
Medical care	21.01	13.62	9.75	16.63	27.75
Consumer discretionary	15.69	6.47	10.39	14.51	18.32
Industry	18.44	10.48	11.08	15.74	22.56
Daily consumption	20.48	—	20.48	20.48	20.48
Material science	20.06	11.32	10.67	17.62	26.68
Energy	14.54	—	14.54	14.54	14.54

Table 11: Net effect of IPO underpricing decomposition in different industries of the Nasdaq (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
Information technology	−0.75	16.47	−2.91	0.53	5.57
Public utility	6.00	6.52	−1.14	7.50	11.64
Medical care	1.19	6.10	−2.46	0.58	4.77
Consumer discretionary	2.44	17.89	−3.66	0.04	6.38
Industry	5.27	14.38	−1.42	0.49	11.54
Real estate	−15.33	32.35	−5.93	−5.79	0.00
Daily consumption	5.77	20.92	−0.67	1.18	11.23
Material science	12.39	15.81	−2.47	13.02	18.98
Finance	2.69	9.42	−1.39	0.04	3.02
Energy	−6.79	2.16	−8.32	−6.79	−5.27

of the overall sample. In Table 11, the average net effect of IPO underpricing decomposition in information technology, real estate, and energy industries is less than 0. Therefore, for the above three industries, the impact of primary market pricing on IPO underpricing is greater than that of secondary market investor behavior. Further study found that the net effect of IPO underpricing decomposition at the first quantile of all industry classifications was less than

Table 12: Net effect of IPO underpricing decomposition of the STAR Market in different years (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
2019	18.89	10.20	10.39	16.88	23.35
2020	19.36	12.02	10.89	14.87	23.52
2021	19.99	12.32	10.73	16.29	26.34

Table 13: Net effect of IPO underpricing decomposition of the Nasdaq Market in different years (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
2011	−2.77	22.09	−1.66	0.24	7.20
2012	0.12	5.84	−2.25	0.16	4.21
2013	1.23	6.52	−2.28	0.18	4.60
2014	1.24	6.52	−4.22	0.33	4.10
2015	1.79	6.85	−1.93	0.04	4.27
2016	3.44	11.46	−4.16	0.49	5.94
2017	2.00	7.52	−3.66	0.10	5.30
2018	2.62	7.52	−1.88	1.44	6.08
2019	−0.76	8.12	−3.07	0.00	3.64
2020	−1.03	13.49	−2.43	0.86	5.20
2021	2.86	17.51	−1.89	0.91	6.19

Note. The 2011 group includes the samples of stocks listed and issued before 2011. Due to too few data and scattered years, they are combined into one group of data.

Table 14: Net effect of IPO underpricing decomposition of different enterprise sizes on the STAR Market (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
Small and medium-sized enterprises	19.46	11.66	10.68	16.12	24.76
Large enterprises	19.87	12.57	10.97	15.90	21.67

Table 15: Net effect of IPO underpricing decomposition of different enterprise sizes on the Nasdaq Market (NE).

Group	Mean (%)	Std (%)	Q1 (%)	Q2 (%)	Q3 (%)
Small and medium-sized enterprises	1.69	12.47	−2.74	0.59	5.57
Large enterprises	−0.15	9.53	−1.36	0.00	3.31

0. This shows that the IPO underpricing of different industries and different individuals in the same industry in the Nasdaq Market is affected by different markets.

STAR Market was launched late, and the first batch of science and Innovation Board enterprises were officially listed and traded on July 22, 2019. However, since 2019, it has coincided with a great change that has not been seen in a century, profound changes have taken place in economic development, and the capital market has been deeply affected. To explore whether there are differences in IPO underpricing among enterprises listed in different years, it is tested according to the listing year. The results are shown in Tables 12 and 13. It can be seen that the net effect of IPO underpricing of listed companies on the STAR Market affected by different markets gradually expands with the increase of years, and the average net effect increases from 18.89% in 2019 to 19.99% in 2021. In contrast, the net effect of NASDAQ's IPO underpricing in different years changes frequently, and the net effect in 2019 and 2020 is even negative, indicating that there are annual differences in the degree of IPO underpricing affected by different markets. However, the average net effect of NASDAQ's IPO underpricing decomposition in different years is the largest, which was 3.44% in 2016, which is significantly less than the average net effect of 18%–19% in the science and innovation board market, indicating that the IPO underpricing of STAR Market is more vulnerable to the behavior of investors in the secondary market, which once again confirms the previous conclusion.

Different enterprise sizes may also have different effects on IPO underpricing. Therefore, taking the average value of the sample enterprise size as the classification standard, enterprises with total assets below the average value are divided into small and medium-sized enterprises, and enterprises with total assets above the average value are divided into large enterprises. The estimation results are shown in Tables 14 and 15. According to the results in the table, it can be found that the IPO underpricing of small and medium-sized enterprises of Nasdaq-listed enterprises is mainly affected by the behavior of investors in the secondary market, with an average of 1.69%; large enterprises are mainly affected by the pricing of the primary market, with an average of −0.15%. The IPO underpricing of listed enterprises on the STAR Market, whether small and medium-sized enterprises or large enterprises, is mainly affected by the behavior of investors in the secondary market, and the average value is about 19%. This reflects the high degree of pursuit of the newly issued stocks by investors in the secondary market of

the STAR Market, which makes the stock price seriously deviate from the real value of enterprise stocks. In short, through the analysis of Tables 10 to 15, it is found that the average net effect (NE) and the net effect of each quantile of IPO underpricing of sample enterprises on the STAR Market are greater than 0, regardless of different industry categories, different listing years, or different enterprise sizes, indicating that the behavior of secondary market investors is always the main factor affecting the IPO underpricing of science and Innovation Board stocks.

6. Conclusion

STAR Market dominated by scientific and technological innovation enterprises is at the forefront of the pilot implementation of the registration system in China. Studying its IPO underpricing phenomenon can effectively grasp the factors affecting the IPO underpricing of scientific and technological innovation enterprises, and it is also an important way to observe the effectiveness of policies related to the reform of the registration system. This paper takes the enterprise stocks listed on the STAR Market as the main research object by October 2021, compares the Nasdaq Market, and uses the Two-tier Stochastic Frontier Model to decompose the IPO underpricing for empirical analysis. Through the decomposition of IPO underpricing, we find that: (1) the implementation of registration system significantly improves the IPO pricing efficiency of the STAR Market, and the primary market pricing has a weak impact on the IPO underpricing of the STAR Market; (2) blind optimism of secondary market investors and irrational investor structure are the main factors leading to IPO underpricing of science and innovation board; and (3) through the variance decomposition and the robustness test of grouping the industry of the enterprise, the year of listing and issuance and the scale of the enterprise, the results show that the behavior of investors in the secondary market is always the main way to affect the IPO underpricing of the STAR Market.

According to the previous theoretical analysis and empirical test, it can be found that the primary market pricing has little impact on the IPO underpricing of the STAR Market, which shows that the implementation of the registration system has corrected the deviation of the primary market pricing from the real value of stocks to a certain extent, and the price discovery function of the primary market has been restored. This shows that the implementation of the registration system has alleviated the phenomenon of IPO underpricing widely existing in the Main-Board Market to a great extent. In addition, it can be seen from the decomposition results of IPO underpricing of various industry sectors of the STAR Market that there is no significant difference between the net impact of primary market pricing and secondary market investor behavior on IPO underpricing among different industries, indicating that there is no industry-level heterogeneity in the phenomenon of IPO underpricing of the science and innovation board. However, it should be noted that the IPO underpricing of the STAR Market is significantly affected by the behavior of investors in the secondary market than that in the Nasdaq Market, indicating that the behavior of investors in the secondary market is the main influencing factor of IPO underpricing of science and innovation board. Although the fund access mechanism of the STAR Market has optimized the investor structure to a certain extent, there is still a large gap in the overall financial literacy of investors compared with the mature capital market. At the same time, the small scale of institutional investors leads to a heavy speculative atmosphere in the secondary market, which further increases the IPO underpricing degree of STAR Market enterprises. Based on the above analysis, the following policy suggestions are put forward:

First, continue to adhere to the reform of the registration system of the STAR Market and improve the information disclosure system. The reform of the registration system in the Main-Board Market is difficult, and the IPO pricing efficiency is low, which has seriously hindered the healthy development of China's capital market. As the forefront of the pilot reform of the registration system, STAR Market has achieved certain results after more than two years of development. The implementation of the registration system with the information disclosure system as the core has improved the pricing efficiency of the primary market of the STAR Market, reshaped the price discovery function of the primary market, and alleviated the impact of primary market pricing on IPO underpricing. We must adhere to the reform of the registration system of the STAR Market and speed up the construction of a perfect information disclosure system, including the integrity education of stock issuers, the timely transformation of the regulatory functions of regulators, as well as the training of intermediaries' sense of responsibility and professional ethics.

Second, actively guide the correct investment concept and improve the financial literacy of market investors. Different from Nasdaq and other mature stock markets, individual investors are the main participants in China's stock secondary trading market. Moreover, the development of China's stock market started late, the financial literacy of investors is not high, and there is no systematic and reasonable understanding of stock investment. Especially in recent years, with the progress of science and technology, the investment threshold of the stock market has been reduced, and more and more investors without stock investment experience have entered the market. Such investors often refer to institutional investors or all kinds of gossip and blindly follow the trend of the investment, which is easy to form a "herd effect," resulting in sharp fluctuations in stock prices, resulting in serious deviation of IPO secondary market premium from the real value and disturbing the normal order of the market. Therefore, it is necessary to standardize and guide investors' investment ideas, continue to promote the popularization of basic financial knowledge, and improve the financial literacy of investment groups. At the same time, actively publicize the official website of listed enterprises to publish public information, so as to reduce the degree of information asymmetry between investors and stock issuers, so as to enhance investors' rational cognition of listed enterprises.

Third, support the expansion of the scale of institutional investors and improve the composition of investors. At present, blind follow-up investment and speculation in the secondary market are important factors causing IPO underpricing. In order to completely solve the high IPO underpricing phenomenon of the STAR Market, we must start from the root and improve the overall level of investors. Individual investors have natural disadvantages compared with institutional investors in screening the authenticity of public information of listed enterprises. Therefore, while guiding individual investors to the correct investment concept, we should also take policy measures, such as encouraging institutional investors to innovate financial products, so as to expand the proportion of institutional investors in the investment group.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] K. N. Fang, C. He, and Y. Wang, "IPO policy and characteristics of China stock market using Sai-GA-SVR," *Journal of Management Sciences in China*, vol. 18, no. 4, pp. 98–110, 2015.

[2] K. Zhou, B. Zhou, and H. Liu, "IPO underpricing and information quality of prospectuses," *Singapore Economic Review*, vol. 65, no. 6, pp. 1559–1577, 2020.

[3] F. Q. Cao, "Promoting the reformation of stock issuance registration system," *Nankai Journal*, vol. 2, no. 12, pp. 118–126, 2014.

[4] N. Y. Wang, Y. X. Zhu, S. J. H. Chen, and J. L. Chen, "The reference and enlightenment of American securities registration system and securities supervision to China," *Southwest Finance*, vol. 10, no. 6, pp. 46–56, 2019.

[5] E. L. Dennis, "On the pricing of unseasoned equity issues: 1965–1969," *Journal of Financial and Quantitative Analysis*, vol. 8, no. 1, pp. 91–103, 1973.

[6] R. G. Ibbotson, "Price performance of common stock new issues," *Journal of Financial Economics*, vol. 2, no. 3, pp. 235–272, 1975.

[7] D. P. Baron, "A model of the demand for investment banking advising and distribution services for new issues," *The Journal of Finance*, vol. 37, no. 4, pp. 955–976, 1982.

[8] R. P. Beatty and J. R. Ritter, "Investmen banking, reputation, and the underpricing of initial public offerings," *Journal of Financial Economics*, vol. 15, no. 1, pp. 213–232, 1986.

[9] K. Rock, "Why new issues are underpriced," *Journal of Financial Economics*, vol. 15, no. 1-2, pp. 187–212, 1986.

[10] F. Allen and G. R. Faulhaber, "Signalling by underpricing in the IPO market," *Journal of Financial Economics*, vol. 23, no. 2, pp. 303–323, 1989.

[11] J. R. Ritter, "The long-run performance of initial public offerings," *The Journal of Finance*, vol. 46, no. 1, pp. 3–27, 1991.

[12] R. R. Jay and W. Ivo, "A review of IPO activity, pricing, and allocations," *The Journal of Finance*, vol. 57, no. 4, pp. 1795–1828, 2002.

[13] D. François, "IPO pricing in "hot" market conditions: who leaves money on the table?" *The Journal of Finance*, vol. 60, no. 1, pp. 487–521, 2005.

[14] L. Alexander, N. Vikram, and S. Rajdeep, "Hot markets, investor sentiment and IPO pricing," *Journal of Business*, vol. 79, no. 4, pp. 1667–1702, 2006.

[15] G. Baschieri, A. Carosi, and S. Mengoli, "The decision to go public and the IPO underpricing with locally biased investors," *The European Journal of Finance*, vol. 27, no. 15, pp. 1489–1532, 2021.

[16] T. Boulton, B. B. Francis, T. Shohfi, and D. Xin, "Investor awareness or information asymmetry? Wikipedia and IPO underpricing," *Financial Review*, vol. 56, no. 3, pp. 535–561, 2021.

[17] H. N. Duong, A. Goyal, V. Kallinterakis, and M. Veeraraghavan, "Market manipulation rules and IPO Underpricing," *Journal of Corporate Finance*, vol. 67, no. 17, Article ID 101846, 2020.

[18] E. D. Baker, T. J. Boulton, M. V. Braga-Alves, and M. R. Morey, "ESG government risk and international IPO underpricing," *Journal of Corporate Finance*, vol. 67, no. 51, Article ID 101913, 2021.

[19] D. Yang and L. Wang, "IPO underpricing in China—test of a hypothesis," *Fudan Journal (Social Sciences Edition)*, vol. 5, no. 17, pp. 85–90, 2001.

[20] Y. H. Liu and P. Xiong, "Equity separation, government regulations, and Chinese IPO underpricing puzzle," *Economic Research Journal*, vol. 5, no. 9, pp. 85–95, 2005.

[21] L. H. Tian, "Financial regulation, investment risk and excess underpricing of new share issuance," *Journal of Financial Research*, vol. 4, no. 8, pp. 85–100, 2010.

[22] K. J. Chu and H. Y. Zhang, "The effect of the evolution of China's IPO issuance system on the pricing--efficiency of new stocks: a pricing control perspective," *Financial Economics Research*, vol. 34, no. 1, pp. 83–93, 2019.

[23] L. Y. Han and Y. R. Wu, "Investor sentiment and the mystery of IPOs——underpricing or premium," *Management World*, vol. 03, no. 7, pp. 51–61, 2007.

[24] S. L. Song and Y. C. Wang, "How does investor sentiment affect stock pricing? An empirical research based on IPO firms," *Journal of Management Sciences in China*, vol. 19, no. 5, pp. 41–55, 2016.

[25] J. Y. Shi, X. C. Li, and Y. X. Li, "Investor sentiment and IPO first day returns—moderating effect of underwriter's reputation," *Journal of Dalian University of Technolgy*, vol. 39, no. 5, pp. 32–40, 2018.

[26] Y. Zhang and F. Wu, "Co-investment system and IPO pricing: based on the empirical evidence of STAR board," *Business and management journal*, vol. 43, no. 6, pp. 84–99, 2021.

[27] H. L. Lv, W. J. Jia, and W. L. Li, "Individual investment bankers' sponsoring experience and IPO underpricing in STAR market: evidence from China," *Accounting Research*, vol. 5, no. 8, pp. 95–106, 2021.

[28] S. W. Huang, J. Jia, and W. J. Wang, "Research of IPO underpricing decomposition based on two-tiered stochastic frontier model: evidence from Chinese growth enterprises market," *Chinese Journal of Management Science*, vol. 25, no. 2, pp. 21–29, 2017.

[29] H. Janet, C. K. Samuel, and B. F. Bill, "Testing for deliberate underpricing in the IPO premarket: a stochastic frontier

approach," *Review of Financial Studies*, vol. 9, no. 4, pp. 1251–1269, 1996.

[30] W. Meeusen and B. J. Den, "Efficiency estimation from cobb-douglas production functions with composed error," *International Economic Review*, vol. 18, no. 2, pp. 435–444, 1997.

[31] D. Aigner, C. A. K. Lovell, and P. Schmidt, "Formulation and estimation of stochastic Frontier production function models," *Journal of Econometrics*, vol. 6, no. 1, pp. 21–37, 1997.

[32] Z. Q. Hu and M. J. Zhao, "Study of IPO under-pricing decomposition based on stochastic frontier production model and its lag effect," *Journal of Beijing Technology and Business University*, vol. 30, no. 4, pp. 70–77, 2015.

[33] D. Y. Qiu and A. C. Cao, "R&D intensity, willingness of underwriters to follow investment and IPO underpricing—empirical research based on science and technology innovation board listed companies," *Finance and Economics*, vol. 11, no. 10, pp. 73–81, 2020.

[34] X. Y. Zhang, L. Liao, and Y. H. Luo, "Venture capital of underwriters and IPO underpricing—based on information asymmetry theory," *China Industrial Economics*, vol. 11, no. 8, pp. 90–101, 2014.