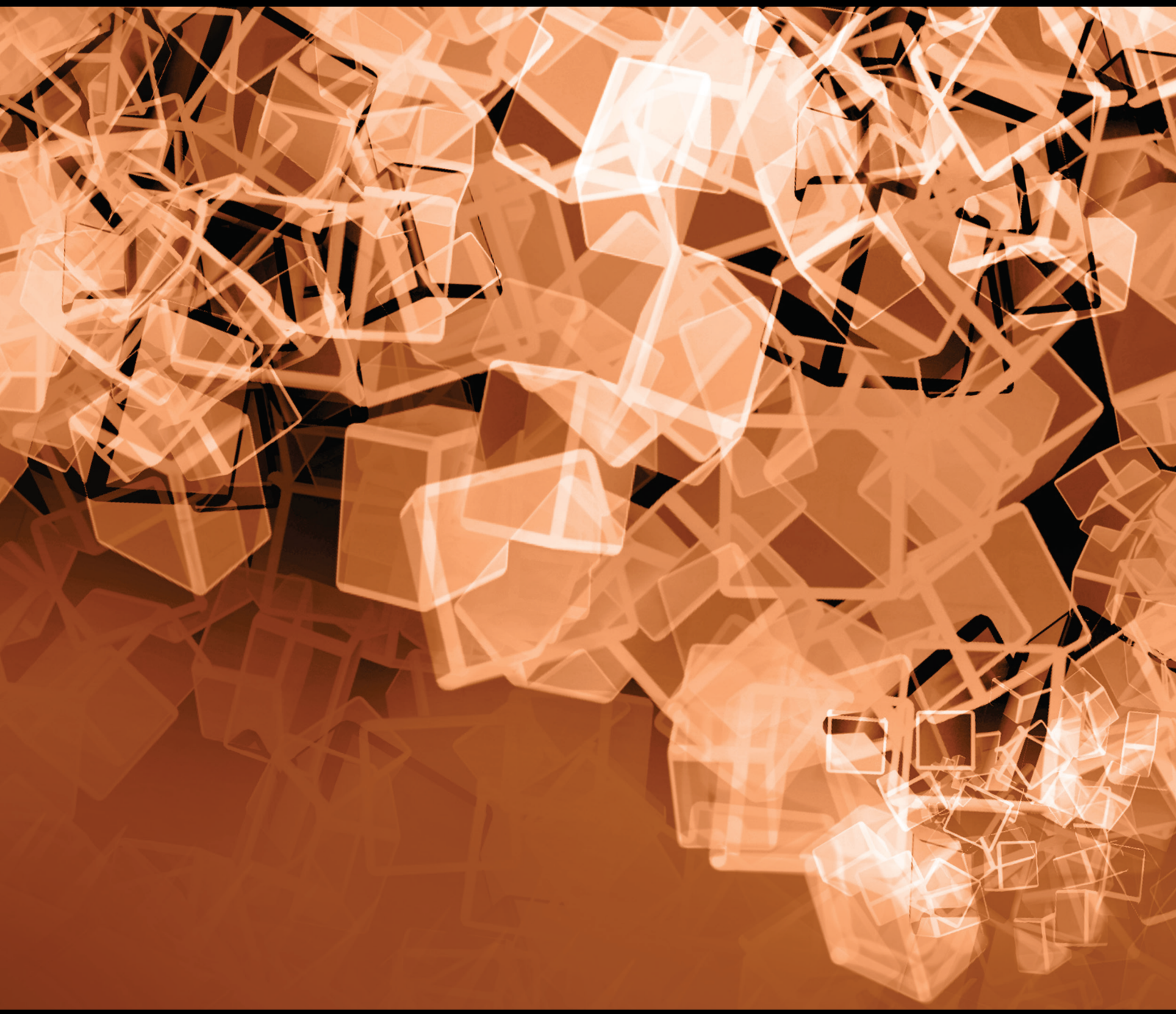
Discrete Dynamics in Nature and Society

Public Health, Safety, and Sustainable Resilient Cities 2021

Lead Guest Editor: Wei Zhang
Guest Editors: Wenyao Zhang and Victor Shi



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Retraction

Retracted: Impacts of the Weighted Deduction Policy for R&D Expenses on Innovation Additionality of Firms: Empirical Evidence from China

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Retraction

Retracted: Research on Spatio-Temporal Complexity Evolution and Influencing Factors of "Nongrain" in Guangxi

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Discrete Dynamics in Nature and Society
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Retraction

Retracted: Land Price Distortion, Financial Development, and Regional Innovation

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Hindawi
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Retraction

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Retraction

Retracted: Empirical Research on the Relationship between Industry Working Capital Shortfall and Company Cash Holding in the Same Industry

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In addition, our investigation has also shown that one or more of the following human-subject reporting requirements has not been met in this article: ethical approval by an Institutional Review Board (IRB) committee or equivalent, patient/participant consent to participate, and/or agreement to publish patient/participant details (where relevant).

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Retraction

Retracted: Robust Two-Stage Location Allocation for Emergency Temporary Blood Supply in Postdisaster

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Retraction

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Retraction

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Discrete Dynamics in Nature and Society

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1].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) Manipulated or compromised peer review

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] W. Bo and C. Mengjia, "Reconstruction Design of Existing Residential Buildings Based on 3D Simulation Method," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 8159213, 11 pages, 2022.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9868314, 1 page
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Retraction

Retracted: Econometric Analysis of the Hot Research of Marxist Theoretical Journals Based on Knowledge Map

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[1] L. Wang and K. Wang, "Econometric Analysis of the Hot Research of Marxist Theoretical Journals Based on Knowledge Map," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 3806576, 10 pages, 2022.

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Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9796231, 1 page
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Retraction

Retracted: Research on the Recommendation Algorithm of Rural Tourism Routes Based on the Fusion Model of Multiple Data Sources

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[1] H. Li, M. Qiao, and S. Peng, "Research on the Recommendation Algorithm of Rural Tourism Routes Based on the Fusion Model of Multiple Data Sources," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2262148, 10 pages, 2022.

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Discrete Dynamics in Nature and Society
Volume 2024, Article ID 9812351, 1 page
https://doi.org/10.1155/2024/9812351

Retraction

Retracted: Knowledge Graph Analysis of Digital Emergency Management Research Based on CiteSpace Visualisation: Comparative Analysis of WOS and CNKI Databases

Discrete Dynamics in Nature and Society

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[1] R. Nan, W. Zhu, and Y. Xiao, "Knowledge Graph Analysis of Digital Emergency Management Research Based on CiteSpace Visualisation: Comparative Analysis of WOS and CNKI Databases," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 4604223, 20 pages, 2022.

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Research Article

Knowledge Graph Analysis of Digital Emergency Management Research Based on CiteSpace Visualisation: Comparative Analysis of WOS and CNKI Databases

Rui Nan, Wenjun Zhu, and Yejing Xiao

School of Law and Humanities, China University of Mining and Technology-Beijing, Beijing 100083, China

Correspondence should be addressed to Rui Nan; nr19841018@163.com

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Facing the dual background of risk society and the fourth scientific and technological revolution, digital emergency management (DEM) research has attracted wide attention worldwide. Based on the comparative analysis of data from Web of Science (WOS) and China National Knowledge Infrastructure (CNKI) databases, the research draws the knowledge map by CiteSpace, in order to analyse the spatiotemporal distribution, hotspots, and trends of DEM research. The following are the results: (1) DEM research shows a spiral growth, with a significant increase in the number of papers. Existing highly cited references are mainly carried out from the perspective of management or technology. (2) The complex countries' cooperation network has been formed from the USA, China, and other countries; the complexity of the institutions' cooperation network must be strengthened, and the density of the authors' cooperation network is low; DEM research has significant interdisciplinary attributes. (3) The hotspots of DEM research can be divided into three categories: means, processes, and objects, but the research emphases between international and China are different. (4) The evolution of DEM research can be divided into three stages between international and China: embryonic, development, and deepening stages, and research contents in each stage show some differences. (5) The trends of DEM research between international and China are different. The former are information technology, artificial intelligence, and machine learning, whereas the latter are emergency decision making, scenario analysis, and public health.

1. Introduction

The rapid development of digital technologies (DTs) represented by the Internet, big data, and blockchain has caused a huge impact on traditional concepts and models of public management. It has triggered a systematic reshaping of structures, relationships, and mechanisms of management. During the process of transforming to digital governance, countries all over the world have planned digital society construction and governance schemes to promote the transformation and development of governance mode. For example, in October 2020, the USA revealed that it would build a technology alliance to realise technology risk management. In March 2021, the European Union proposed to build a people-oriented and sustainable digital society. In March 2021, China issued a document on Outline of the 14th Five-year Plan (2021–2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China, which proposed to build a digital society and emphasised the change in the model of production and lifestyle driven by digital transformation. DTs are gradually becoming the basic elements of economic and social operations and important means of social governance. Digital governance is also gradually becoming the core index of governance capacity competition among countries around the world. At the same time, the world has entered the risk society where unknown and unpredictable consequences have become dominant forces. The sudden increase in unstable factors and the superposition of multiple risks during the process of modernisation have greatly increased the occurrence probability of emergencies. Frequent disasters have become the key features of risk society [1]. Under

the background of global risk society, emergency management for magnitude emergencies has become a new normal. The high complexity of magnitude emergencies puts forward high requirements for DTs. COVID-19 sweeping the world has brought a huge negative impact to the world. The experience in emergency management for magnitude emergencies (e.g., COVID-19) shows that DTs play an irreplaceable role, that is, innovating emergency management concepts with digital mindset and improving emergency management capabilities with DTs. In fact, building a relatively perfect DEM system has become important parts of the transformation and upgrading of an emergency management system around the world.

Under the dual background of digital governance and risk society, the traditional model of emergency management cannot quickly put forward the most suitable scheme for different practical situations. The efficient combination of emergency management and digitalisation also provides a new way for the future development of emergency management [2]. Gruntfest believed that the value of Internet resources in emergency management is growing and has introduced the Internet into the field [3]. DTs, represented by the Internet, are becoming one of the only remaining vectors for economic, educational, and social interactions [4], and are combined with the whole process of emergency management [5, 6], promoting the mode transformation of traditional emergency management to the DEM. However, existing research is too fragmented and lacks a systematic review of the field. As a common tool, CiteSpace is usually performed quantitatively on domain-specific research. It can use its visualisation function to grasp the hotspots and trends of DEM research and display the panorama [7]. It can also extract network relationships to analyse the node structure and characteristics. This is conducive to analysing the DEM research hotspots from an overall perspective, thereby summarising and exploring the research trends, which has important practical significance for accelerating the technological innovation and management optimisation. In order to achieve the purpose of comprehensive analysis, the database used for knowledge graph analysis should contain complete data [8]. In view of the differences in DEM research between international and China, this paper chooses WOS and CNKI databases as the data sources.

The structure of this paper is as follows: (1) Section 1 introduces data and methods. (2) Section 2 analyses the temporal distribution characteristics in terms of annual number and trends of papers and highly cited references and the spatial distribution characteristics in terms of countries, institutions, disciplines, and authors. (3) Section 3 analyses the hotspots and trends of DEM research by co-word and burst words. (4) Section 4 summarises the overall differences in DEM research between international and China and provides suggestions for scholars. This paper uses the knowledge map analysis method to address the following questions: (1) What is the temporal distribution of DEM research? (2) What is the spatial distribution of DEM research? (3) What are the hotspots of DEM research? (4) what are the trends of DEM research?

2. Data and Methods

2.1. Data Collection and Processing. The data sources are the WOS Core Collection, CNKI's Core Journals of China, and Chinese Social Sciences Citation Index (CSSCI) source journals. Among them, WOS, as the world's largest comprehensive and influential academic information resource [9], covers peer-reviewed journals with high impact factors. As the largest full-text database of Chinese journals, CNKI is the largest data source in China, covering most Chinese journals. The retrieval programme is shown in Figure 1.

2.1.1. International Data. First, in order to search more comprehensively, the retrieval mode is set as follows: subject = "blockchain" or "big data" or "artistic intelligence" or "cloud computing" or "information technology" or "Internet" or "digital emergency management" and "emergency management." The language is English, and the time span is 1985–2022. The search was performed on April 25, 2022. Second, conference papers, data papers, online publications, book chapters, and recovered publications are eliminated. Data are also manually screened, excluding emergency medical and other indirectly related papers, and 3385 papers are obtained. Lastly, after the data cleaning by CiteSpace, 2885 valid papers are retained.

2.1.2. Chinese Data. First, referring to some previous studies [10], the retrieval mode is set as follows: subject = "digitisation" or "artificial intelligence" or "big data" or "blockchain" or "cloud computing" or "Internet" or "information technology" or "intelligence" or "intelligence" and subject = "emergency management." The search criteria = "precision," and the publish period is 1985–2022. The search was performed on April 22, 2022, and 462 papers are obtained. Second, manual screening and cleaning are carried out for the first retrieved papers, excluding book reviews, album prefaces, conference abstracts, and other indirectly related papers. Finally, 414 valid papers are retained.

2.2. Methods. CiteSpace is a commonly used tool for knowledge graph analysis, and the analysis results are visualised in the form of knowledge graphs. The valid papers from WOS and CNKI databases are exported in a plain text file and RefWorks format, respectively. In order to ensure language consistency, this paper translates the analysis results of the CNKI database into English. By statistical analysis, the temporal distribution of DEM research is mainly reflected in the annual number and trends of papers and highly cited references. By co-word analysis, the spatial distribution of DEM research is described from countries, institutions, disciplines, and authors. The hotspots and trends of DEM research are visually analysed through co-word clustering map, time zone map, and burst words. By comparative analysis, the differences in DEM research between international and China are analysed.

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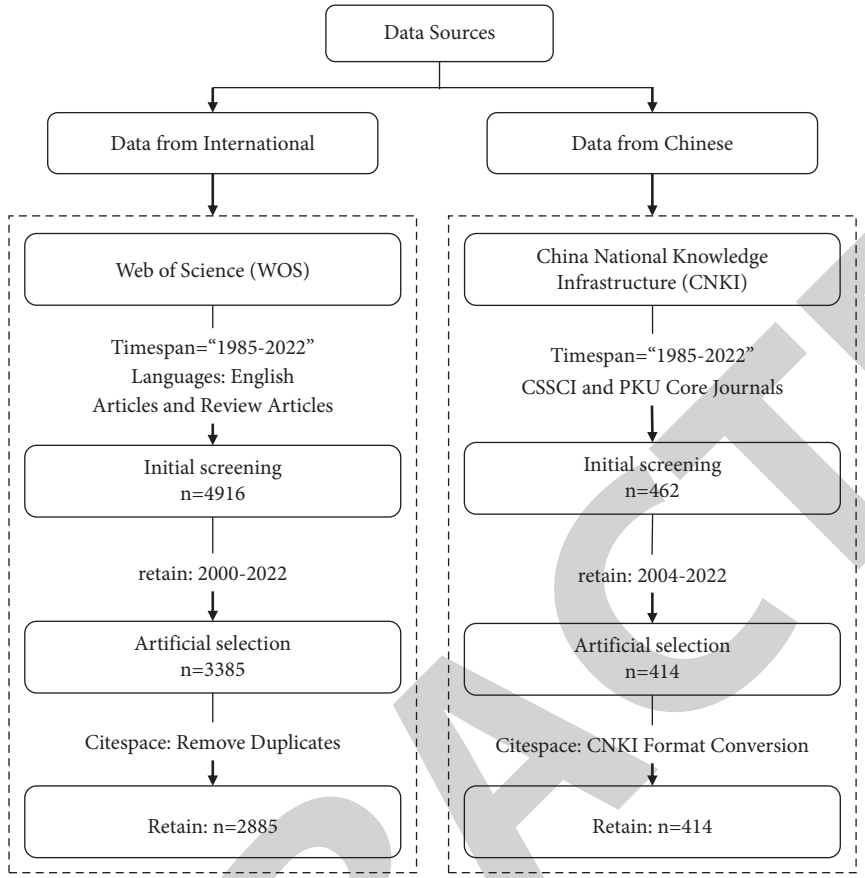

Figure 1: Paper retrieval procedure.

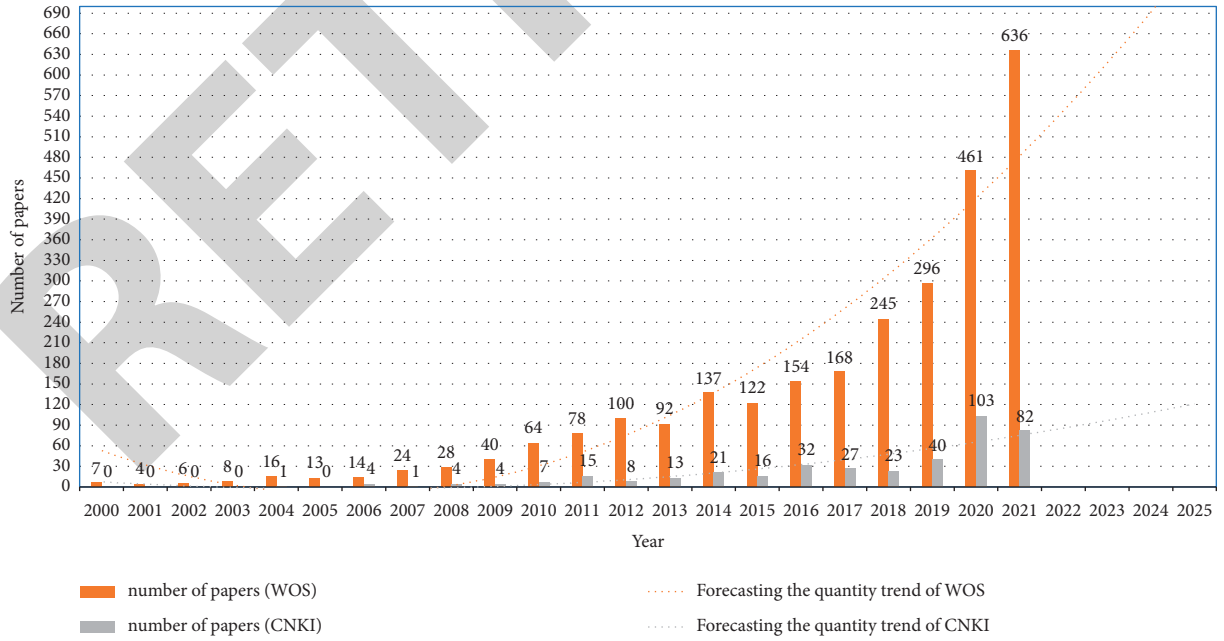

Figure 2: Annual number and trends of papers of DEM research.

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3. Spatiotemporal Distribution

3.1. Temporal Distribution. The analysis of the temporal distribution of DEM research includes two aspects: first, the annual number of papers, which not only helps to visualise and show the development in different periods, but also helps to predict future development trends; and second, the highly cited references, which help to gain insight into the relationship between important research in different periods.

3.1.1. Annual Number and Trends of Papers. Based on WOS and CNKI data, the annual number and trends of papers are drawn (Figure 2).

In Figure 2, international DEM research began in 2000. From 2000 to 2021, related papers showed a spiral growth, with the annual number of papers peaking at 636 in 2021, accounting for 22% of the total. According to the annual number of papers, it can be roughly divided into three stages: in the first stage (2000–2008), the total number of papers is small, with an annual average of 13.3, which is in the initial stage; in the second stage (2009–2014), the number of papers has increased significantly, with an average annual rate of 85.2, which is significantly higher than the previous stage and is in the growth stage; and in the third stage (2015 to present), the number of papers continues to grow, with an average annual rate of more than 100. Specifically, in the period of 2020–2021, the number of papers increased dramatically, with respectively 461 and 636, which is in a period of rapid development. This is also a concrete manifestation of the positive response of the international DEM research to COVID-19. Under the influence of international DEM research, Chinese DEM research started in 2004 and showed a rapid growth trend. From 2004 to 2009, it was in the embryonic stage and the number of papers was small, with an annual average of 2.3. From 2010 to 2021, it exhibited a spiral growth, which is similar to the trend of international DEM research. It also indicates that DEM research is increasingly attracting the attention of Chinese scholars and has gradually emerged as a research hotspot.

According to Figure 2, polynomial prediction analysis is carried out on the data to predict the growth trend of the number of papers in the next four years.

The mathematical expression for predicting the number of papers of international DEM research is as follows:

$$y = 2.0596x^2 - 26.942x + 77.846\left(R^2 = 0.8932\right). \quad (1)$$

The mathematical expression for predicting the number of papers of Chinese DEM research is as follows:

$$y = 0.3298x^2 - 4.3619x + 11.506\left(R^2 = 0.8098\right), \quad (2)$$

where y is the number of papers, x is the year, and R^2 indicates the degree of fit of the trend line. R^2 values in the mathematical expressions are close to 0.9, indicating that the trend lines have a good fit. The trend lines imply that the number of papers will increase from 2022 to 2025. The number of international papers will increase significantly, while the rise in the number of Chinese papers will be relatively flat.

3.1.2. Distribution of Highly Cited References. Based on WOS data, the top 10 cited references of international DEM research are shown in Table 1. Among them, the research contents of highly cited references are mainly studied from the perspective of management or technology. First, from the perspective of management, the research focus is social media, and how to embed social media into the whole process of emergency management is discussed. For example, Yates and Paquette pointed out that social media, as a major knowledge-sharing tool and mechanism, have different impacts on knowledge sharing and emergency decision making [6]. At the same time, social media can work together with other information sources [11]. Subsequently, Kavanaugh et al. pointed out that social media can help improve emergency response, but the huge data flow generated by social media can create data noise and affect decision-making accuracy [12]. The research also found that social media can be used to track contents and pay attention to the changes in public sentiments to decipher the meanings and consequences of emergencies for helping the government form an effective connection from daily management to emergency management using social media. Most existing research focuses on the positive effects of social media on emergencies, but emergencies also magnify the risks of using social media, which may infringe on privacy and other issues. Therefore, the government should pay attention to moral warnings and ensure that social media will not be abused or misused [13]. Second, from the perspective of technology, the optimisation of technology is discussed to enhance the efficiency of emergency management. For example, Li et al. pointed out that networked microgrid can enhance the elasticity of power system, thus improving the flexibility of smart city to deal with extreme events [14]. Goodchild and Glennon emphasised that geographic data and tools are essential in the whole cycle of emergency management. Yet, the information quality of voluntary geographic information provided by amateurs is worrying [5]. In case of emergency, the risks associated with the information are often offset by the benefits of its use [15]. Fotovatikhah et al. revealed that artificial intelligence and computational intelligence technologies can be used to improve flood management systems and improve flood debris prediction accuracy [16].

3.2. Spatial Distribution

3.2.1. Countries' Distribution. Based on WOS data, the functional area is set as "country" to generate the knowledge map of countries' cooperation network (Figure 3) and extract the top 20 countries in the number of papers (Table 2).

In Figure 3, DEM research has formed a countries' cooperation network from China, the USA, England, Australia, Canada, Italy, South Korea, Spain, and India. The interconnection among countries is complex and diverse, indicating a high degree of cooperation. In Table 2, the top

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Table 1: Top 10 highly cited references of international DEM research.

Rank	Citations	Year	Title	Author
1	520	2010	Crowdsourcing geographic information for disaster response: a research frontier	Goodchild M. F. and Glennon J. A.
2	500	2011	Emergency knowledge management and social media technologies: a case study of the 2010 Haitian earthquake	Yates D. and Paquette S.
3	270	2012	Social media use by government: from the routine to the critical	Kavanaugh A. L. et al.
4	265	2017	Networked microgrids for enhancing the power system resilience	Li Z. Y. et al.
5	246	2014	Social media in disaster risk reduction and crisis management	Alexander D. E.
6	245	2020	COVID-19 and digital inequalities: reciprocal impacts and mitigation strategies	Beaunoyer E. et al.
7	220	2018	Survey of computational intelligence as basis to big flood management: challenges, research directions and future work	Fotovatikhah F. et al.
8	202	2011	Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples	Boulos M. N. K et al.
9	198	2015	A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management	de Albuquerque J. P. et al.
10	188	2010	Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: propositions from field exercises	Bharosa N. et al.

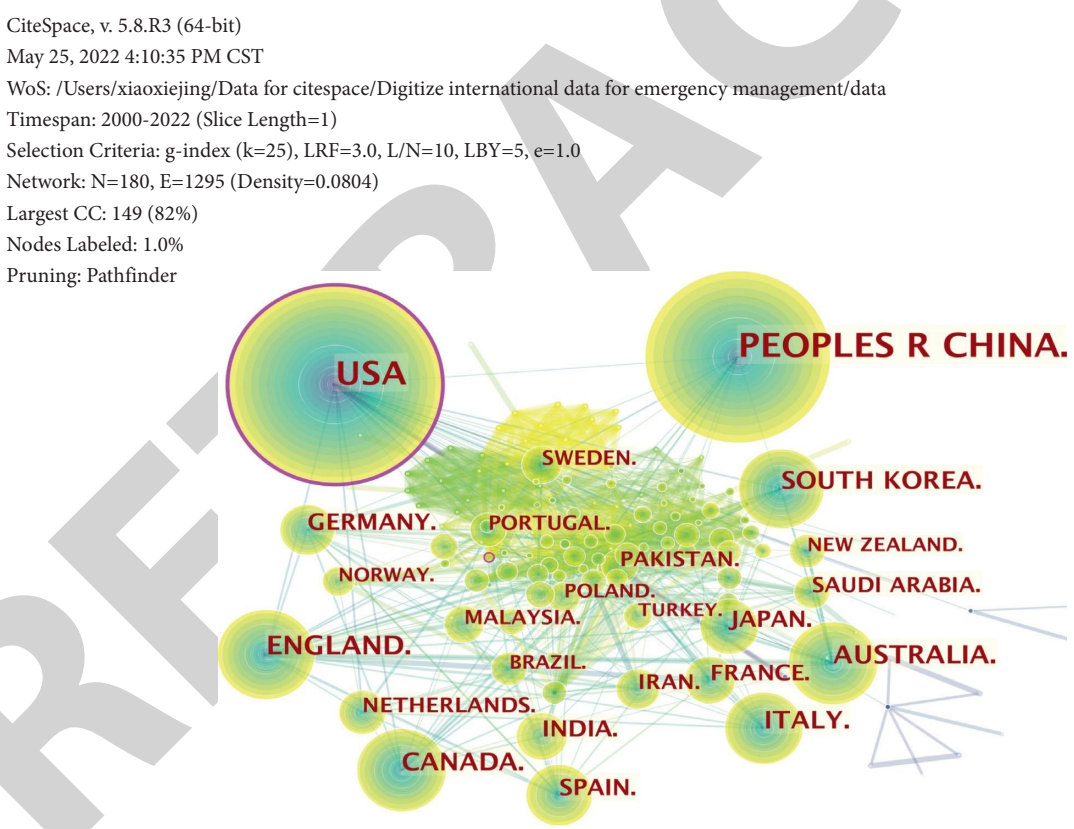

Figure 3: Countries' cooperation network of DEM research.

10 countries are China, the USA, England, Australia, Canada, Italy, South Korea, Spain, India, Japan, and Germany. Research should respond to practical needs, and the relatively large number of papers in these countries is due to the following reasons: first, the USA, Canada, Australia, and India have large areas and experience frequent natural disasters. Second, England, Italy, South Korea, Spain, Japan, and Germany have good economic development and developed science and technology. In conclusion, DEM research comes from the urgent needs of emergency management or the support of strong science and technology. In terms of time, the USA is the first (since 2000), followed by China, England, and Australia (since 2007).

3.2.2. Institutions' Distribution. Based on WOS and CNKI data, the functional area is set to "institution," and the knowledge map of institutions' cooperation network can be

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Table 2: Top 20 countries in the number of papers.

Rank	Countries	Count
1	China	1011
2	USA	860
3	England	205
4	Australia	180
5	Canada	163
6	Italy	152
7	South Korea	138
8	Spain	107
9	India	100
10	Japan	97
11	Germany	93
12	France	78
13	Netherland	73
14	Saudi Arabia	63
15	Pakistan	61
16	Iran	61
17	Malaysia	59
18	Sweden	59
19	Portugal	50
20	Brazil	48

generated (Figures 4 and 5), and the top 20 institutions in the number of papers of international and Chinese DEM research can be extracted, respectively, as shown in Tables 3 and 4. Nodes represent institutions. Node sizes indicate the number of papers by institutions, and the number of links between nodes refers to the strength of cooperation between institutions.

In Figure 4, the density of institutions' cooperation network is 0.0084, and the network presents small-group characteristics. The network structure is relatively compact, and the breadth and depth of node interactions are high. Therefore, there is a high degree of institutions' cooperation and frequent information sharing of international DEM research, which is conducive to integration, deepening, and innovation of knowledge. In Table 3, the top 5 institutions are Chinese Academy of Sciences, Beijing Normal University, Tsinghua University, Beihang University, and University of Washington. For the institutional attributes, these institutions all belong to the university, suggesting that universities are still the main research institutions. In terms of the countries where the institutions are located, 40% of the institutions are from China and 20% are from the USA, both accounting for 60% of the total, indicating that DEM research is still concentrated in China and the USA. Among them, since the Wenchuan earthquake in 2008, the research perspectives of Chinese scholars have gradually diversified, from single computer technology research to multiple-perspective cross-domain technology integration.

In Figure 5, the density of institutions' cooperation network in China is 0.0036. The structure of institutions' cooperation network is relatively loose, mainly manifested as a single-line cooperation network. Sichuan University and Chinese Academy of Social Sciences have published large numbers of papers, and both work independently rather than in cooperation with other institutions. In Table 4, institutions that have published 10 or more papers are Sichuan University, Civil Aviation University of China, Harbin Institute of Technology (Shenzhen), Nanjing University of Science and Technology, Nantong University and Tsinghua University, and Anhui University.

Comparing the institutions' distribution, most are found to have advanced technical advantages or deep management foundation, so they can promote DEM research from the perspective of technology or management. However, due to the strong professional characteristics of technologies, carrying out in-depth cooperation is difficult for institutions with different technical directions, resulting in the inability of institutions to form a close cooperation network.

3.2.3. Disciplines' Distribution. Based on WOS data, with "category" as the network node, the time slice is set to one year, and the knowledge map of disciplines of international DEM research can be derived by CiteSpace (Figure 6). The larger the circle, the more the papers published; the thicker the line, the closer the correlation. The complex linkages established by multiple nodes indicate that DEM research is significantly interdisciplinary.

In Figure 7, the top 6 disciplines of international DEM research in 2000–2022 can be obtained. The closest of the disciplines are engineering, computer science, and healthcare science and services. Before 2017, research in all disciplines was still in the exploratory stage, and the number of papers was basically at the same level. Since then, with the maturity and wide application of DTs, such as blockchain, the number of papers has begun to show a geometric growth trend, and DTs have shifted from simple technical research to complex application research, such as government and governance [17]. At the same time, the world is facing the dual background of risk society and the fourth generation of scientific and technological revolution. The change in the social background provides complex and diverse practical

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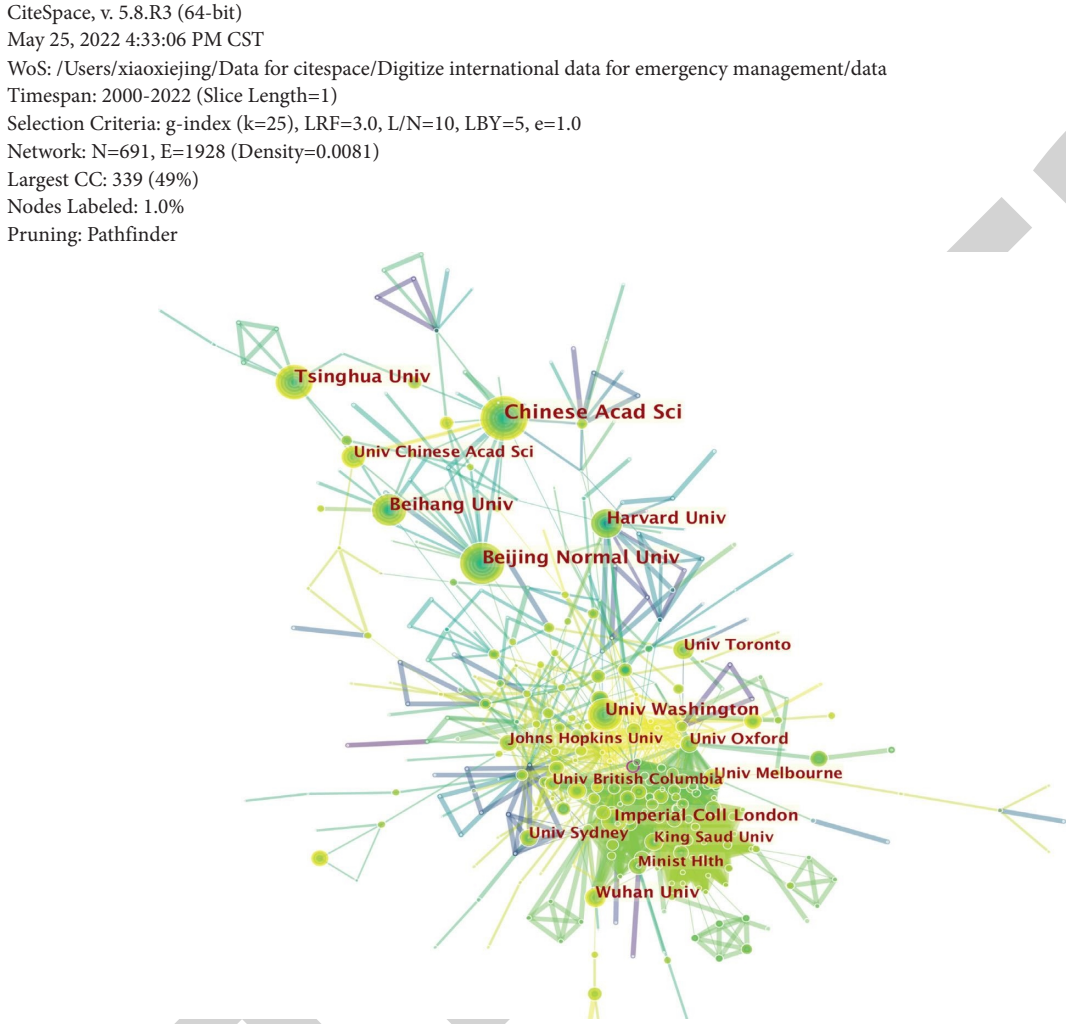

Figure 4: Institutions' cooperation network of international DEM research.

problems for DEM, and the rapid iteration of DTs provides reliable technical support for DEM. Therefore, the number of papers will continue to grow rapidly.

3.2.4. Authors' Distribution. Based on WOS and CNKI data, the functional area is set to "author," and the knowledge map of authors' cooperation network can be exported (Figures 8 and 9). Nodes represent authors. Node sizes indicate the number of papers by authors, and the number of links between nodes refers to the strength of cooperation between authors. The larger the nodes, the denser the connections, indicating that authors play an important role in the network.

In Figure 8, the density of authors' cooperation network of international DEM research is 0.0039, with low network density and loose overall structure, indicating that knowledge dissemination and information penetration in the current research are weak, and the breadth and depth of network node interaction must be further strengthened. In terms of citation, the top 3 authors are Abdallah Samy, Ali Mokdad, and Adnan Kisa.

In Figure 9, the authors' cooperation network of Chinese DEM research shows an obvious small-group characteristic, forming a close-knit small-group network with Yi Liu, Gangyan Xu, Cejun Cao, and Ting Wang as core members. Among them, Liu's research team, whose members are all from Tsinghua University, has been cited the most, and the research results of the team are authoritative in this field.

Comparing the authors' distribution, authors are found to have formed two normal cooperation modes, which are dominated by a certain institution or core member. However, Chinese and international cooperation research is not close enough, and future research should strengthen the broad learning and exchange between Chinese and international authors.

4. Hotspot and Trend Analysis

4.1. Hotspot Analysis. Research hotspots are analysed in CiteSpace by the following two types of maps. The first is the co-word clustering map, which shows the hotspots that scholars pay more attention to. The second is the time zone

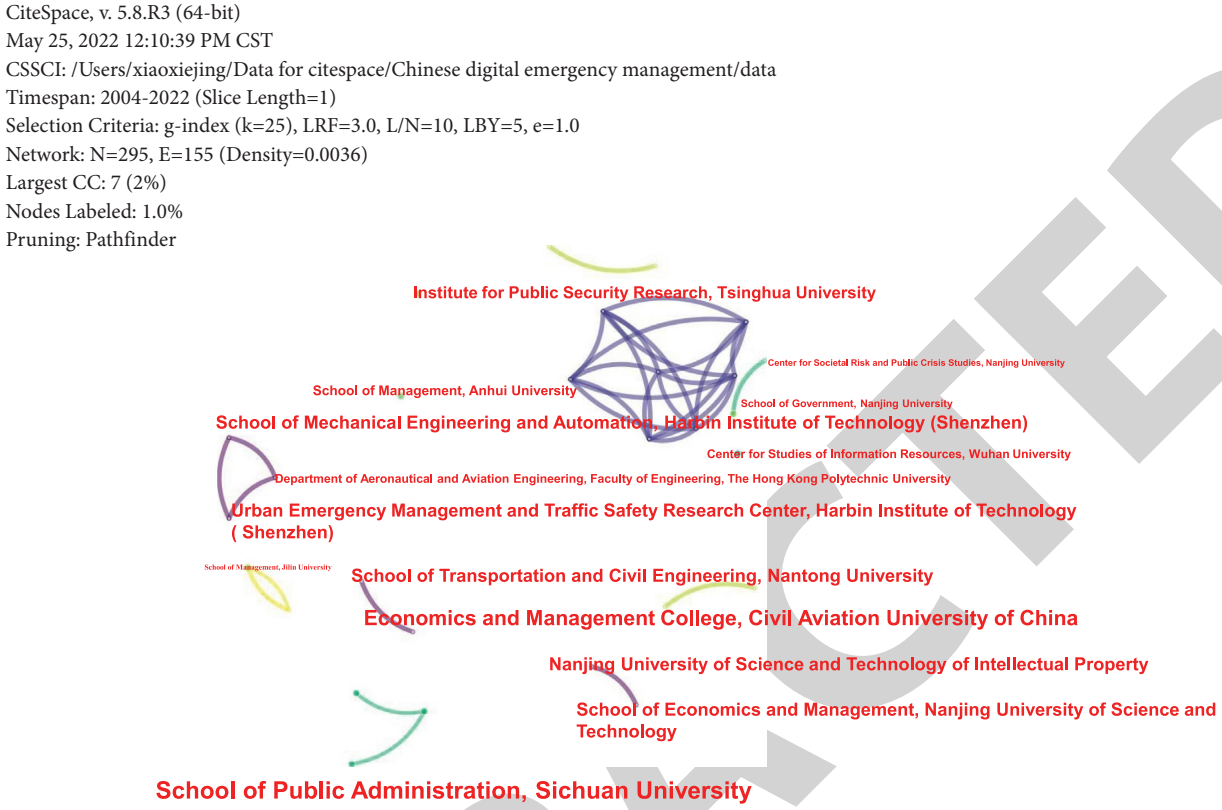

Figure 5: Institutions' cooperation network of Chinese DEM research.

Table 3: Top 20 institutions in the number of papers of international DEM research.

Rank	Institutions	Count
1	Chinese Academy of Sciences	84
2	Beijing Normal University	68
3	Tsinghua University	57
4	Beihang University	53
5	University of Washington	49
6	Harvard University	44
7	Imperial College London	35
8	Wuhan University	34
9	University of Chinese Academy of Sciences	32
10	University of Toronto	31
11	University of Melbourne	31
12	University of Sydney	31
13	University of Oxford	28
14	Johns Hopkins University	27
15	Ministry of Health	26
16	University of British Columbia	26
17	King Saud University	25
18	Huazhong University of Science and Technology	24
19	China University of Mining and Technology	24
20	University of Queensland	24

map of keywords, which shows the distribution and changes of the most popular hotspots in different periods.

4.1.1. Cluster Analysis of Co-Word. Based on WOS and CNKI data, co-word clustering analysis was performed, and co-word clustering maps of international and Chinese DEM research could be obtained, respectively (Figures 10 and 11). In Figures 10 and 11, DEM research is divided into three categories: means, processes, and objects.

(1) DEM Means. The co-word of international DEM research mainly includes #0 Internet of things, #1 mobile phones, #4 simulation, and #11 predictive models. The efficiency improvement of emergency management requires to strengthen the accuracy of information collection and the timeliness of information transmission, and DTs represented by the Internet of things and mobile phones have reshaped the information transmission mechanism. The Internet of things organically combines people and things, enabling "people" to perceive comprehensive information of "things" and even obtain the multidimensional information of "people" through the "things" perception, enhancing the depth, breadth, and fluidity of information [18]. Mobile phones, as important mobile terminals, combine mobile communication with the Internet to realise timely information transmission. The global popularity of mobile phones provides possible solutions for emergency management and establishes perfect systems and mechanisms to deal with disasters [19]. The prediction model and simulation software based on big data conduct scientific analysis

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Table 4: Top 20 institutions in the number of papers of Chinese DEM research.

Rank	Institutions	Count
1	School of Public Administration, Sichuan University	21
2	Economics and Management College, Civil Aviation University of China	18
3	Urban Emergency Management and Traffic Safety Research Center, Harbin Institute of Technology (Shenzhen)	16
4	School of Mechanical Engineering and Automation, Harbin Institute of Technology (Shenzhen)	16
5	School of Economics and Management, Nanjing University of Science and Technology	16
6	Nanjing University of Science and Technology of Intellectual Property	16
7	School of Transportation and Civil Engineering, Nantong University	16
8	Institute for Public Security Research, Tsinghua University	12
9	School of Management, Anhui University	11
10	Department of Aeronautical and Aviation Engineering, Faculty of Engineering, The Hong Kong Polytechnic University	8
11	Center for Studies of Information Resources, Wuhan University	8
12	School of Information Management, Nanjing University	7
13	Institutes of Science and Development, Chinese Academy of Sciences	6
14	School of Government, Nanjing University	6
15	School of Management, Lanzhou University	5
16	Center for Societal Risk and Public Crisis Studies, Nanjing University	5
17	College of Computer Science and Technology, Beihua University	4
18	School of Management, Harbin Institute of Technology	4
19	School of Resources and Safety Engineering, Central South University	4
20	School of Management, Jilin University	4

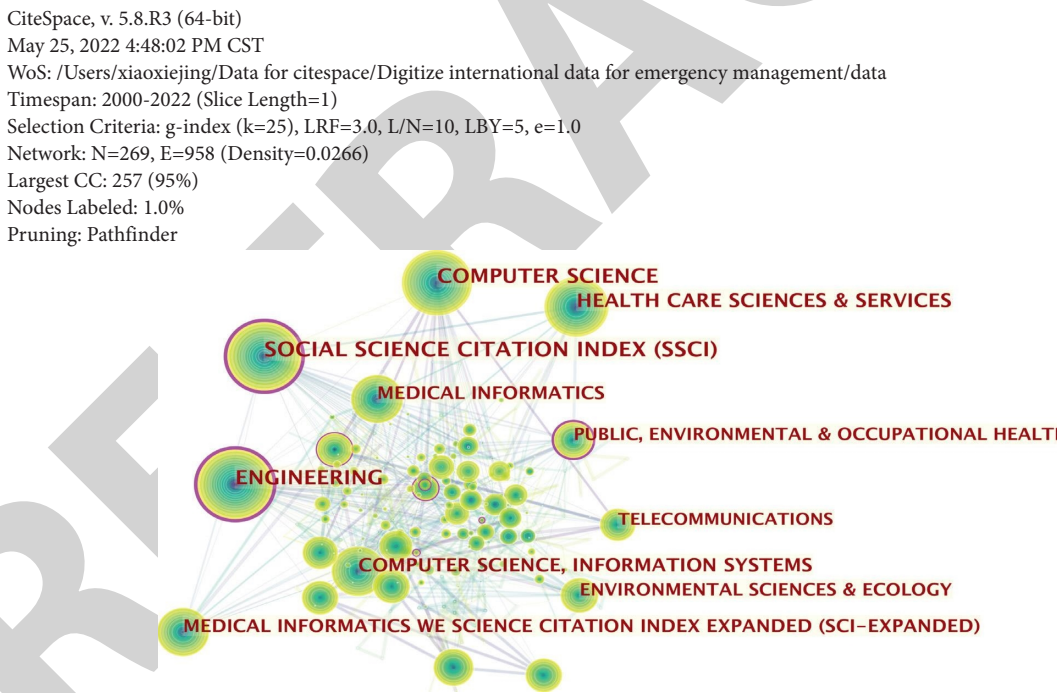

Figure 6: Disciplines' distribution map of international DEM research.

on massive information by integrating digital and intelligent technology to make relatively accurate judgment on reality and prediction, reconstruct the emergency decision making mode, and improve the accuracy and timeliness of emergency decision making. The co-word of Chinese DEM research mainly includes #4 big data, #7 intelligent contract, and #8 cloud computer. Chinese DEM research emphasises DTs as a new growth pole for modernising the emergency management system and capacities. DTs are necessary to achieve the transition from the traditional government-led to a collaborative governance model of emergency management with multiple actors. In fact, DT-driven emergency management has become an important part of the Chinese emergency management system.

(2) DEM Process. International DEM research emphasises the use of DTs throughout the emergency management process, and its co-word includes #3 health information exchange, #7 crisis management, and #9 trends. The creation of digital governments and digital nations is driving the

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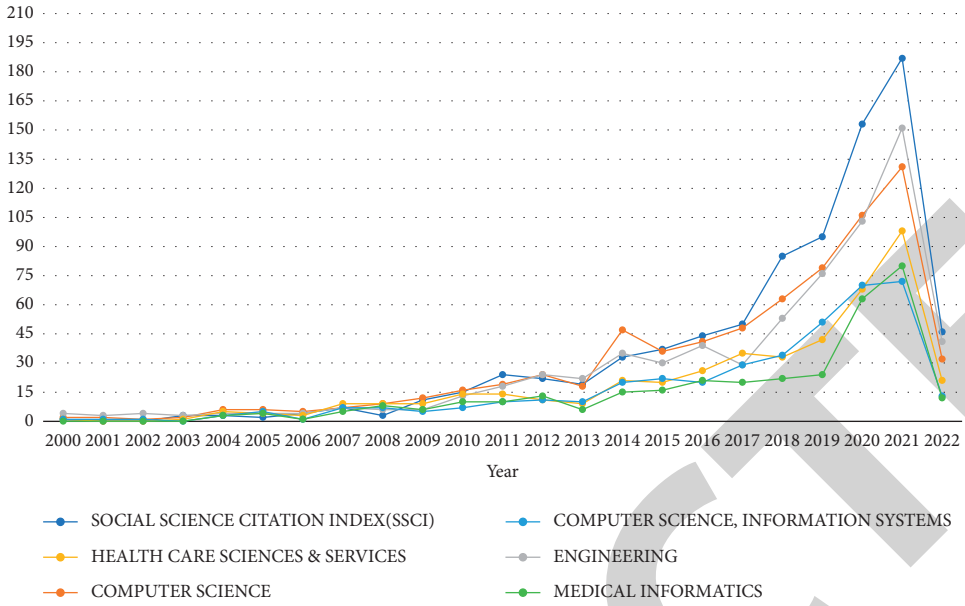

Figure 7: Top 6 disciplines of international DEM research in 2000–2022.

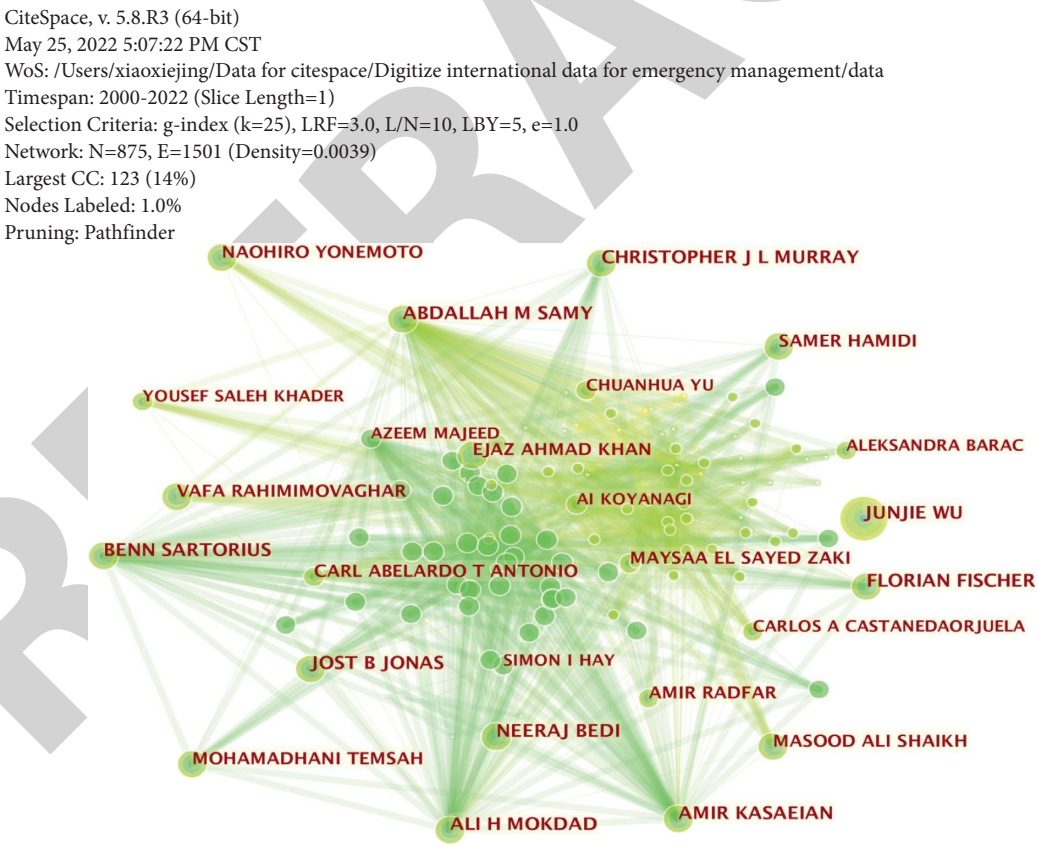

Figure 8: Authors' cooperation network of international DEM research.

creation of a global system of digital information, known as the digital earth [20]. The popularisation of digital information facilities also promotes the comprehensive digital transformation of emergency management. DTs provide increasing convenience to the whole process of emergency management for prevention, preparation, response, and recovery. The co-word of Chinese DEM research mainly includes #2 emergency rescue, #5 information sharing, #6 contingency plan, and #11 emergency response. Chinese scholars began research on emergency management with a

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Figure 9: Authors' cooperation network of Chinese DEM research.

preference for a legal perspective [21], and early research focused on optimising management procedures [22]. Digital contingency plan technology is a new research direction. In practice, it has experienced different stages such as electronics, visualisation, and intellectualisation of contingency plan, which effectively improves the ability to deal with emergency events. For example, the consequences of different policy choices are evaluated by algorithms, and contingency plans are refined based on the results [23]. Emergency rescue and response are dynamic management activities aiming at "efficiency, effectivity, benefit, and equity," and require an enhanced use of DTs to improve the quality and speed of information transmission to reduce the harm degree levels of emergencies.

(3) DEM Objects. The co-word of international DEM research emphasises the diversification of research objects, including #2 social media, #5 humanitarian logistics, #6 geographic information system, and #8 middle east. The DEM not only eliminates the disadvantages of traditional emergency management mode, but also produces a new risk overflow, which has given rise to two major research fields. First, international DEM research continues to pay attention to traditional issues, such as humanitarian logistics, and geographic information systems and regions. Among them, humanitarian logistics research started to focus on digital volunteers, emphasising that volunteers can save many lives by cooperating with one another and using information, communication, and computer technology in a collective and innovative way. In this way, first responders can effectively perform rescue tasks and provide aid resources [24]. Second, it begins to pay attention to emerging digital risk issues, such as social media. Social media expands the existence and path of digital emotional infections and increases the susceptibility of positive and negative emotions [25]. Chinese DEM research includes #0 city safety, #3 epidemic prevention and control, and #9 earthquake disaster. The development of DEM research has profound background of socioeconomic change [26]. With the deepening of the fourth industrial revolution and the social change driven by the information technology revolution, the development of emergency management is objectively required to be carried out under the background of the digital wave, which has derived many new research topics. As the focus of Chinese governance began to sink to the grassroots level, urban safety and grassroots emergency

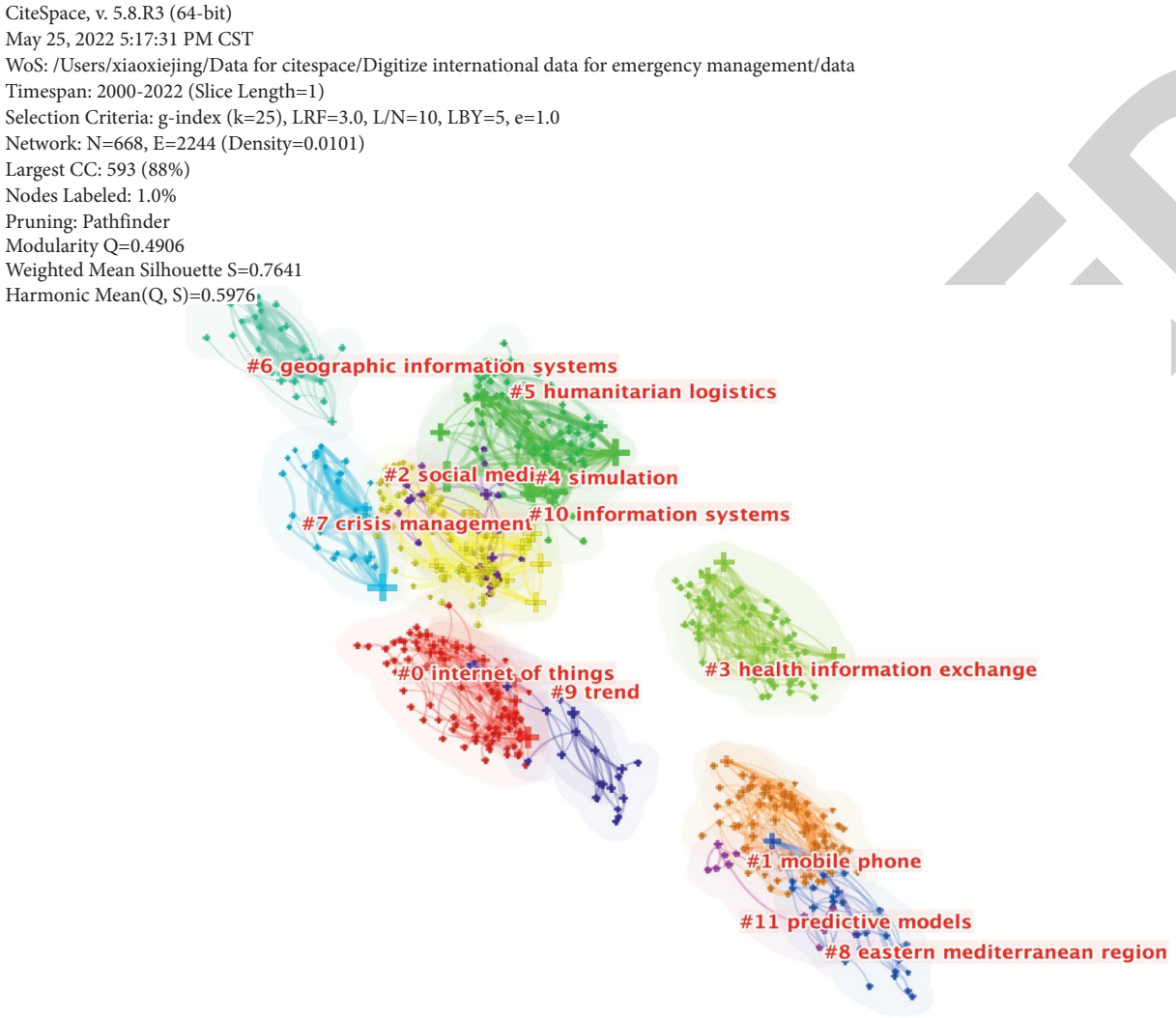

Figure 10: Co-word clustering map of international DEM research.

management became the research focus, and COVID-19 and earthquake disasters often became the social research background.

4.1.2. Evolution Analysis of Research Hotspots. Based on WOS and CNKI data, the time zone maps of international and Chinese DEM research are illustrated in Figures 12 and 13, respectively.

In Figure 12, DEM research shows the evolution characteristics of progressive innovation. International DEM research can be divided into three stages. The first is the embryonic stage (2000–2010), and keywords mainly include system, management, model, and geographic information. In this stage, emergency management and DTs are still studied along two paths, management and technology, and are less integrated with each other. Existing cross-sectional research mainly focuses on improving emergency management efficiency by optimising DTs. For example, Pareschi pointed out that the geographic information remote sensing system should be used to improve the scientific nature of emergency decision making and optimise land planning to reduce the negative impacts of emergencies [27]. The second is the development stage (2011–2016), and keywords mainly include decision making, emergency response, and disaster response. Although DTs, such as information and communication, are highly utilised in the emergency response network [28], core organisations have not made full use of them and have failed to play their due role. Thus, the scholars gradually realise that DEM is not a simple information technology + emergency management. DTs are a "force multiplier" [29], and participating in emergency management produces new risks while playing positive roles [30]. Therefore, digitally reengineering the emergency management process and promoting the construction of the DEM mode are necessary [31, 32]. The third is the deepening stage (2017–2022), and keywords mainly include big data analysis. Based on previous research, the DEM mode is optimised and adjusted with the help of DTs. For example, a risk response and governance cycle system has been established in public health and other fields, which has improved risk response capacity and governance effectiveness [25]. The rapid

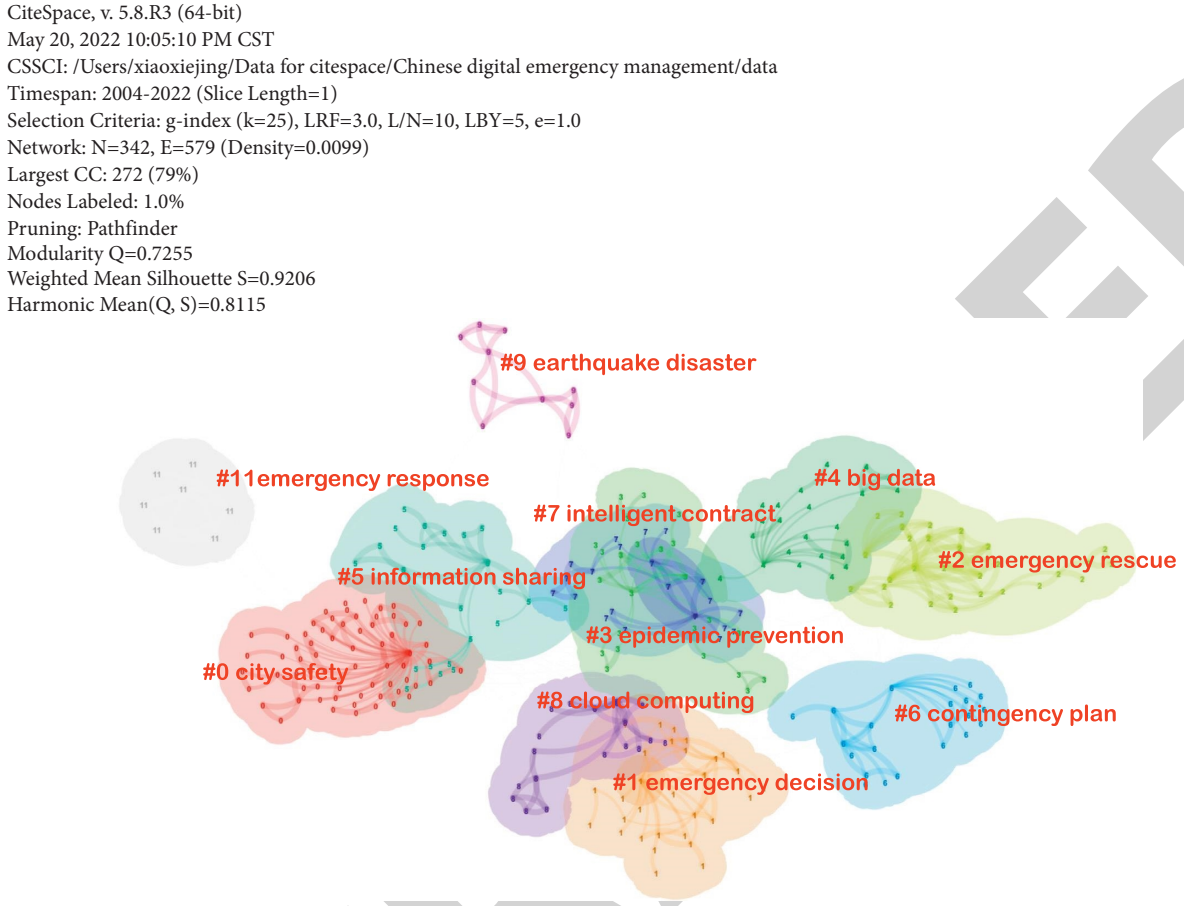

Figure 11: Co-word clustering map of Chinese DEM research.

development of new generation DTs, such as blockchain and artificial intelligence technology, promotes its wide application in emergency management, accompanied by the application risks of technologies, such as digital inequality and information overload pressure [4, 33]. Therefore, the research focus must be shifted from subject digitisation to stakeholder digitisation, which uses virtual reality technology to train people to correctly understand and use crisis information, reduce the deviation between intention and behaviour, and not simply promote technological development [34]. It is gradually forming the digital collaboration of multiple subjects of emergency management to improve the DEM mode.

In Figure 13, Chinese DEM research can be divided into three periods. The first is the embryonic stage (2004–2012), and keywords mainly include emergency rescue, intelligent emergency response, and natural gas. In this stage, there are few papers, most of the keywords are still focused on emergency management, and the research questions are mainly around the basic concepts, characteristics, and applicability of DTs, for example, the optimisation of the emergency management structure of urban power grid by designing the power grid emergency management support platform [35]. The second is the development stage (2013–2017), and keywords include cloud computing, big data, Internet+, information sharing, and crisis management. DEM research has increased significantly in this stage, and most high-frequency keywords have appeared, which plays an important role in guiding and diffusing the follow-up development. Meanwhile, China is stepping into the big data era, which poses application challenges to the Chinese emergency management system in terms of data capacity construction, warning and prediction, information transmission, and related application [36]. China urgently needs to build a personalised DEM model. The third is the deepening stage (2018–2022), and keywords include epidemic prevention. Research in this stage has obvious policy and problem orientations. In October 2019, the Fourth Plenary Session of the 19th Central Committee of the Communist Party of China (CPC) stressed the need to adhere to and improve the socialist system with Chinese characteristics and advance the modernisation of China's system and capacity for governance. Subsequently, research on digital government, digital governance, and smart city has emerged rapidly. DTs can carry out technological supply innovation in three dimensions—organisational structure, technical hardware, and decision basis—and promote the modernisation of risk management system and capacity [37]. The COVID-19 outbreak has also given birth to research on emergency intelligence, big data governance capability evaluation, and intelligent emergency in the public health emergency context [38].

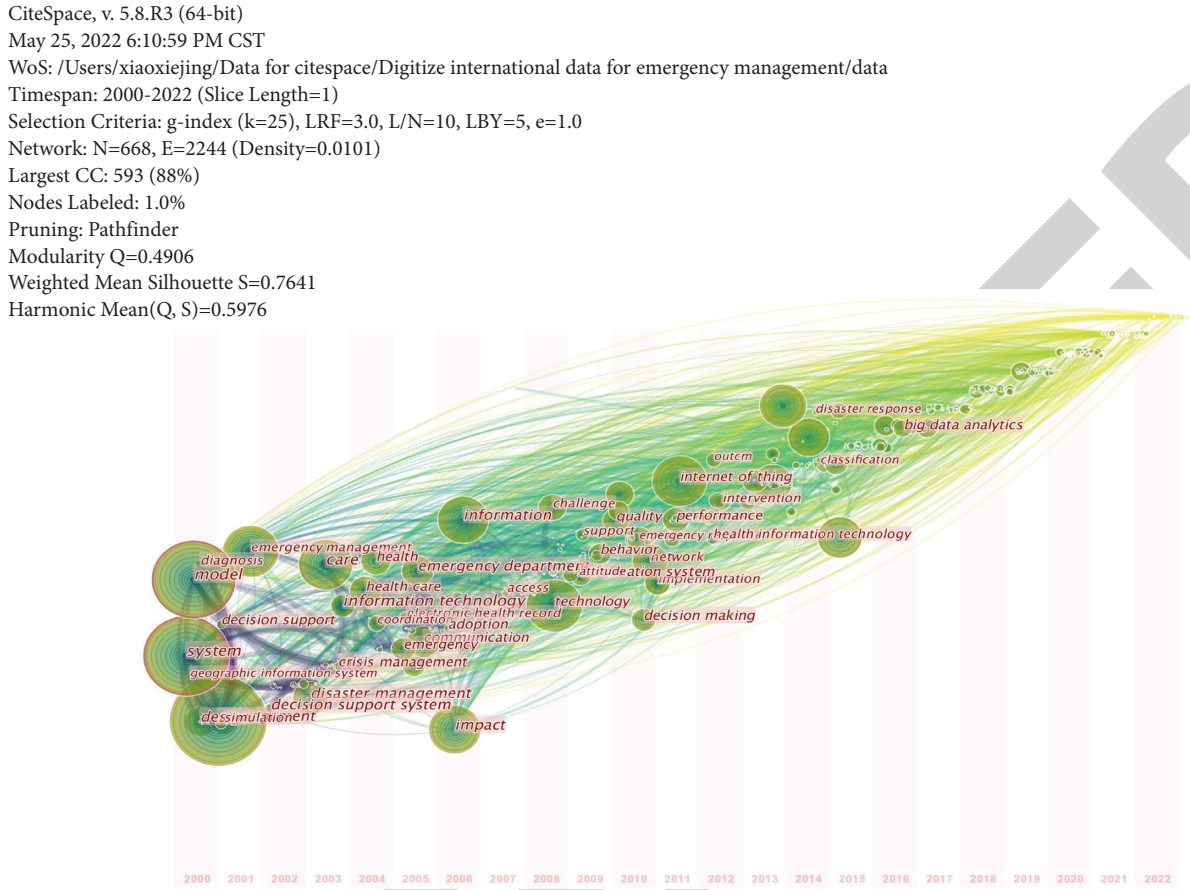

Figure 12: Time zone map of keywords of international DEM research.

Comparing the time zone maps of keywords, international and Chinese DEM research has experienced three stages of embryonic, development, and deepening, but international DEM research follows the technology orientation, gradually recognising the "double-edged sword" characteristics of technologies in the construction of the DEM mode and eliminating the negative effects of technologies through technical iteration. Meanwhile, Chinese DEM research follows the management path. Through the gradual system reform, the practical gap between technology and management is eliminated, and DT effectiveness in solving practical problems is enhanced.

4.2. Trends Analysis. Research trends are analysed with burst words in CiteSpace. By comparing the strength of burst words, it is possible to predict which hotspots will continue the explosive trend in the future. Based on WOS and CNKI data, the keywords with the strongest bursts of international and Chinese DEM research are illustrated in Figures 14 and 15, respectively. Figure 14 shows the 25 strongest burst keywords during 2001–2020, and Figure 15 displays the 20 strongest burst keywords during 2004–2020. The higher the value of burst keywords, the higher the frequency change rate of the keywords in this period. The blue line represents the time interval, and the red line represents the time interval in which the word occurred.

International DEM research trends include decision support system, information management, information technology (IT), access and information system, geographic information, emergency management, implementation, and health information technology. In terms of citation cycle, the decision support system has the longest burst cycle (13 years), and location has the shortest burst cycle (1 year). From the burst intensity, IT is the keyword with the strongest explosive power, followed by artificial intelligence, machine learning, information system, geographic information, and healthy information technology. Through the analysis of burst keywords, the research trends of international DEM research in recent years can be predicted.

4.2.1. Information Technology. DTs commonly used in emergency management include Internet technology, wireless technology, remote sensing technology, emergency management decision system, disaster analysis, simulation technology, and warning system [39]. One or several of them can be integrated into different technology platforms and applied in emergency management. In natural disaster management, IT is used to monitor the representation information of natural disasters, obtain data, and predict natural disaster events through model simulation and deduction [40]. In community crisis management, IT can be used to establish a basic community resource database,

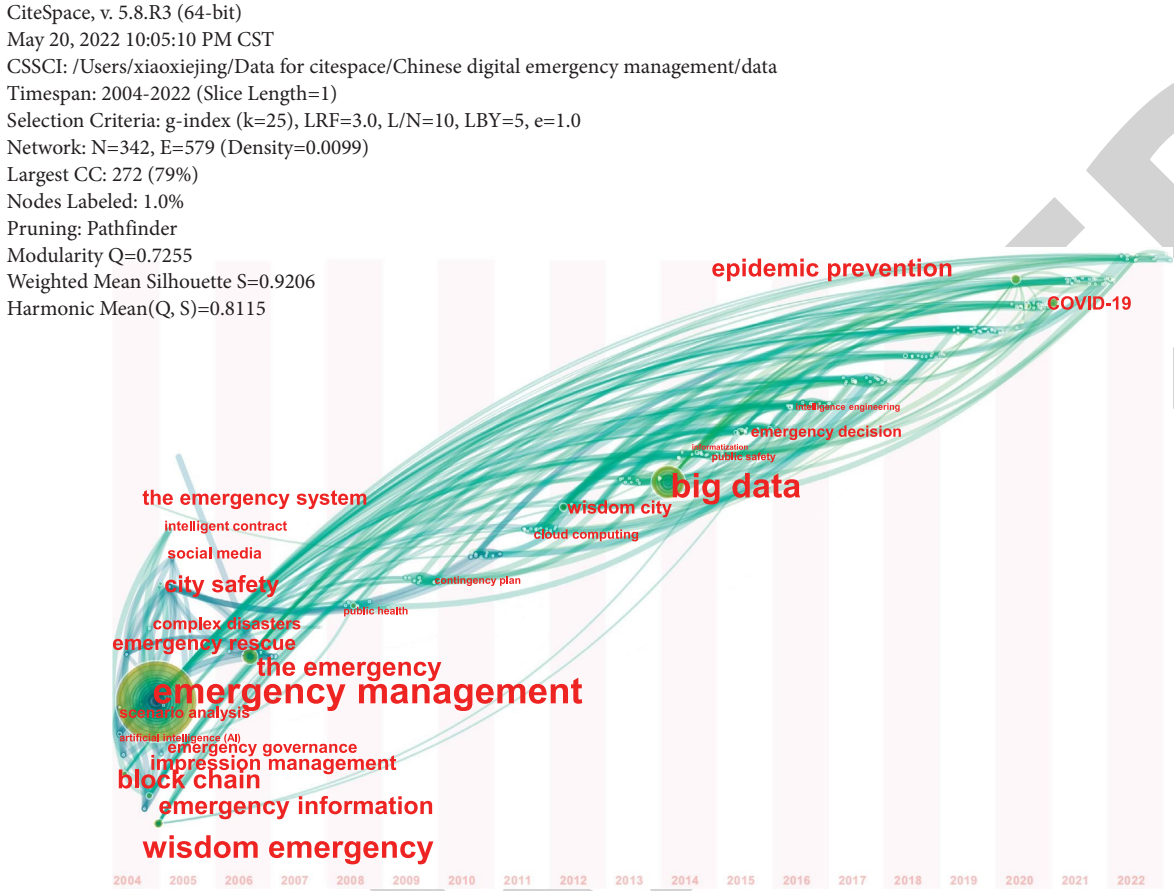

Figure 13: Time zone map of keywords of Chinese DEM research.

supporting crisis communication, crisis response, crisis decision making, and crisis recovery in community crisis management [41]. IT, including computer networks, digital libraries, satellite communications, remote sensing, geographic information systems, and decision support systems, has facilitated the worldwide exchange of disaster information. Moreover, effective data sharing and retrieval methods make the acquisition of crisis information beyond the boundaries of region, country, and discipline [42]. With the wide application of the Internet, online public opinion has been paid increasing attention by crisis managers. IT has been used to monitor the spread of crisis information in online communities and track the development of crisis events. At the same time, the application of IT in crisis management has encountered some obstacles. Information filtering in crisis and other factors affecting this application, such as organisational culture, personnel, structure, and other factors, have attracted varying degrees of attention [43].

4.2.2. Public Health. DTs can effectively enhance the resilience of the public health system and reduce the destructive power of public health emergencies. The vulnerability of the public health system also requires people to reshape the concept of crisis, from emphasising crisis response to a comprehensive cycle of preparation, response, and recovery [44]. Reeder and Turner found that in response to public health emergencies, public health practitioners are allowed to participate in the creation and optimisation of an information design, which is conducive to quickly and accurately assess the availability of labour forces in adverse and changing circumstances to support routine and emergency public health activities [45]. Duan et al. applied artificial intelligence and other technologies to the emergency management of public health emergencies to achieve the optimal allocation of protection and treatment resources [46]. Using COVID-19 in Hong Kong as an example, Chan used computerised random digit dialling and found that there was a lack of awareness of health risks; in addition, there were significant differences in people's attitudes and behaviours [47]. Due to the sudden, serious, and urgent characteristics of public health emergencies, the public encounter psychological problems, such as panic and anxiety. As frontline personnel, community workers know local residents well. Their work easily gains trust and may become the main force to solve residents' psychological problems during public health emergencies [48].

Chinese DEM research trends include smart contract, scenario analysis, social media, emergency rescue, natural gas, emergency linkage, emergency response, emergency disposal, data mining, and smart city. Scenario analysis has

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2000 - 2022
decision support system	2000	5.51	2001	2014	
information management	2000	4.17	2004	2014	
information technology	2000	9.71	2007	2014	
access	2000	3.72	2007	2015	
information system	2000	8.74	2008	2013	
gi	2000	7.46	2009	2014	
emergency management	2000	4.06	2009	2013	
implementation	2000	4.25	2010	2013	
health information technology	2000	6.83	2012	2017	
emergency response	2000	6.59	2012	2014	
cloud computing	2000	5.61	2013	2014	
disaster	2000	3.92	2013	2016	
quality of life	2000	3.67	2013	2016	
sensor network	2000	3.62	2013	2017	
uncertainty	2000	3.86	2014	2015	
electronic health record	2000	5.89	2015	2017	
quality	2000	4.6	2015	2017	
preparedness	2000	4.17	2015	2018	
community resilience	2000	3.76	2018	2020	
resilience	2000	3.67	2018	2020	
location	2000	3.86	2019	2020	
artificial intelligence	2000	9.31	2020	2022	
machine learning	2000	9.04	2020	2022	
digital health	2000	3.71	2020	2022	
public health	2000	3.56	2020	2022	

Figure 14: Top 25 keywords with the strongest citation bursts of international DEM research.

the longest citation period (6 years), whereas emergency linkage has the shortest (1 year) among the 25 keywords. From the burst intensity, the strongest keyword is emergency decision making, followed by intelligence system, emergency response, smart contract, intelligence, social media, and COVID-19. Analysing the burst keywords in Figure 15, the research trends of Chinese DEM research can be predicted.

4.2.3. Emergency Decision Making. In the direction of emergency decision making research, typical topics include emergency resource scheduling and allocation, emergency storage location, and emergency response and warning. Under the background of the gradual establishment of the emergency management system and mechanism, research on emergency decision making can provide scientific and reliable theoretical support for decision makers.

4.2.4. Scenario Analysis. As a research method and forecasting technology, scenario analysis is a potential research hotspot in the future. Scenario construction research is based on the idea of risk management, aiming at the highly destructive events of "small probability and large consequence" that cannot be dealt with by the conventional management mode, to provide guidance and objectives for emergency work. Its working principle can be summarised as follows: based on the analysis of possible emergency scenarios and consequences, study the key nodes that need emergency disposal, consequence mitigation, and prevention preparation; reasonably select the emergency disposal opportunity window and assign work tasks; and make targeted emergency plans, preparation strategies, and development of a set of technical routes and working methods of capacity in advance [49]. In the current situation that huge disasters are difficult to predict and manage, the construction of a corresponding scenario mode can clarify the occurrence process of emergencies to take targeted measures for reducing the probability of accidents and ensuring the safe operation of production. At present, scholars have explored the scenario construction technology in the fields of blowout, flood, earthquake, and pipeline leakage. Future studies on the construction of various disaster scenarios will become research hotspots in the field of emergency management.

4.2.5. Public Health. Public health events are accelerated by population growth, urban development, migration, and other issues brought about by globalisation [50]. The outbreak of public health events, such as COVID-19, has also driven the emergency management process to put public health emergency management in the first place [51]. The digitalisation of public health emergency management is a relatively new field, which utilises specific knowledge, techniques, and organisational principles in emergency management and involves the planning, organisation, leadership, coordination, control, assessment, prevention, preparation, and response of public health emergencies [52, 53]. At present, scholars have studied smart medicine, medical digital resources, health codes, digital empowerment, and other specific issues. Future research on the innovation of governance mode and application of digital governance means in the background of public health emergencies will become research hotspots in this field.

Comparing the burst keywords of international and Chinese DEM research, both have experienced the

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Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2004 - 2022
intelligent contract	2004	4.06	2004	2009	
scenario analysis	2004	3.51	2004	2010	
social media	2004	3.26	2004	2009	
emergency rescue	2004	2.8	2004	2007	
natural gas	2004	2.73	2004	2010	
emergency linkage	2004	2.46	2009	2010	
emergency response	2004	4.07	2010	2012	
emergency disposal	2004	2.42	2010	2014	
data mining	2004	2.36	2010	2011	
the smart grid	2004	2.13	2011	2013	
the simulation	2004	1.79	2011	2014	
artificial society	2004	2.56	2012	2015	
Internet	2004	2.03	2012	2014	
emergency command	2004	2.4	2013	2015	
the information society	2004	2.22	2013	2014	
emergency decision	2004	4.8	2015	2016	
intelligence system	2004	4.69	2015	2016	
intelligence	2004	3.75	2015	2016	
wisdom city	2004	2.9	2015	2016	
intelligence service	2004	1.87	2015	2016	
COVID-19	2004	5.87	2020	2022	
digital governance	2004	4.25	2020	2022	
public health	2004	2.84	2020	2022	
health code	2004	2.64	2020	2022	
research hot spot	2004	2.11	2020	2022	

Figure 15: Top 25 keywords with the strongest citation bursts of Chinese DEM research.

transformation from information technology to emergency management and then to digital management, which shows that the research perspective of DEM research has experienced transformation at micro, macro, and middle levels. Moreover, the research paradigm shows the transformation of technology orientation, management orientation, and technical management orientation. This dual transformation is related not only to the rapid development of social environment and science and technology but also to the development process of DEM research from paying attention to practical application to theoretical construction, and then to both. However, due to the differences between international and Chinese social backgrounds and practical problems, great differences between trends of international and Chinese DEM research remain. The main difference between the two is that international DEM research pays attention to the construction of the emergency management system, whereas Chinese DEM research focuses on the solutions to practical problems.

5. Conclusion

Facing the dual background of risk society and the fourth scientific and technological revolution, DEM research came into being and developed rapidly. To systematically summarise the overall picture of DEM research, first, CiteSpace is used to analyse the spatiotemporal distribution of DEM research. Second, the co-word clustering map reveals the research hotspots. Thirdly, according to the time zone map of keywords, the evolution of research hotspots is summarised. Finally, DEM research trends are predicted on the basis of burst keywords. The specific conclusions are as follows:

(1) *Temporal Ditribution*. Based on descriptive statistics, DEM research shows a spiral growth. In addition, future international papers have a large growth rate, whereas the trend of Chinese papers is relatively flat. From the distribution of highly cited references, existing research is mainly conducted from the perspective of management or technology.

(2) *Spatial Distribution*. From the distribution of countries, a complex countries' cooperation network has been formed from the USA, China, Australia, England, Australia, Canada, Italy, South Korea, Spain, and India. From the distribution of institutions, the complexity of institutions' cooperation networks of international and Chinese DEM research must be strengthened. The former shows small-group characteristics, while the latter shows single-line characteristics. From the distribution of disciplines, DEM research has significant interdisciplinary properties. From the distribution of author, the authors' cooperation networks of international and Chinese DEM research show different characteristics. The former is less dense and loosely

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structured, while the latter shows the characteristics of small groups.

(3) *Research Hotspots*. The hotspots of international and Chinese research can be divided into three categories: DEM means, processes, and objects. Not only that both can be divided into three stages: initial, development, and deepening stages, but also that the research contents of international and Chinese DEM research in each stage show certain differences. In general, the former follows a technical orientation, while the latter follows a managerial route.

(4) *Research Trends*. The focus of future research is still on how to build a relatively complete DEM system. However, due to different social backgrounds and research foundations, the trends of international DEM research focus on information technology, artificial intelligence, and machine learning. Meanwhile, Chinese DEM research pays attention to emergency decision making, scenario analysis, and public health.

Data Availability

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

Disclosure

Rui Nan and Wenjun Zhu are the co-first authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Rui Nan and Wenjun Zhu contributed to the work equally.

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Retraction

Retracted: FH-YOLOv4 with Constrained Aspect Ratio Loss for Video Face Detection and Public Safety

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

In addition, our investigation has also shown that one or more of the following human-subject reporting requirements has not been met in this article: ethical approval by an Institutional Review Board (IRB) committee or equivalent, patient/participant consent to participate, and/or agreement to publish patient/participant details (where relevant).

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.

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[1] Y. Wang, L. Hong, D. Gu, and P. Fu, "FH-YOLOv4 with Constrained Aspect Ratio Loss for Video Face Detection and Public Safety," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 8355174, 10 pages, 2022.

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Research Article

FH-YOLOv4 with Constrained Aspect Ratio Loss for Video Face Detection and Public Safety

Yue Wang, Liang Hong, Dewen Gu, and Pingping Fu

School of Management, Heilongjiang University of Science and Technology, Harbin 150001, China

Correspondence should be addressed to Pingping Fu; 2005801533@usth.edu.cn

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Video face detection is a crucial first step in many facial recognition and face analysis systems. It should serve postprocessing steps as much as possible while satisfying high-accuracy real-time detection. In this paper, we first introduce the constrained aspect ratio loss (CARLoss) for better facial boxes regression and incorporate it into the modified FH-YOLOv4, then the IoU Tracker-based video face image deduplication algorithm is proposed on the detection level. Extensive experiments and comparative tests show the effectiveness of our method.

1. Introduction

Face detection aims at estimating face bounding boxes in a digital image without any scale and position priors, and its landing applications (long-distance automatic body temperature measuring device, digital camera auto-focus function, etc.) have affected all aspects of people's daily life. Importantly, face detection is also a prerequisite for tasks such as facial identify recognition, facial attribute analysis, face editing, and face tracking, and its performance directly affects the effectiveness of these tasks [1, 2]. Therefore, whether it is to satisfy the user's experience or serve the postprocessing steps, higher requirements are placed on the accuracy and real-time video face detection.

Benefiting from the development of generic object detection methods, face detection has also made significant progress. The idea of early face detection methods was to first extract hand-crafted features from sliding windows on the image and then feed them into a classifier to detect possible face regions. One of the most iconic works is Histogram of Oriented Gradients (HOG) followed by SVM [3]. After all, the accuracy of such methods is limited. With the improvement of computing and storage capabilities, deep learning-based face detection methods have surpassed traditional methods in terms of speed, accuracy, and portability.

Existing object detectors can be broadly divided into two categories: two-stage and one-stage methods. For two-stage detectors, R-CNN series [4–7] generate object proposals in the first stage for classification as well as bounding box refinement in the second stage. In particular, the Faster R-CNN [6] architecture uses a regional proposal network (RPN) rather than the selective search method to propose bounding boxes, making object detection much faster. Mask R-CNN [7] can generate high-quality segmentation masks for each instance while efficiently performing object detection. Unlike two-stage proposal-classification detectors, YOLO [8] (you look only once) is a one-step regression method proposed by Redmon et al., whose main contribution is real-time detection of full images and webcams. The YOLO pipeline first divides the input image into $S \times S$ non-overlapping grid cells, then each cell is responsible for detecting those objects whose center points fall within that cell. YOLO network runs at 45 frames per second with no batch processing on a Titan X GPU as compared to Faster R-CNN at 7 fps. However, the experiments showed that YOLO was not good at accurate localization. Soon, several follow-up works [9–14] adopt a series of design decisions from past works with novel concepts to improve YOLOs' speed and precision. For instance, the mature detection framework YOLOv4 [14] uses the architecture of

CSPDarkNet53 with an SPP layer as backbone, PANet as Neck and YOLO detection head. The detection of occluded targets, small targets, etc. has been significantly improved. Another classic one-stage detection framework, SSD [15], introduces a detection method based on pyramidal feature hierarchy to predict objects on feature maps of different receptive fields. Furthermore, CornerNet [16] directly detects an object bounding box as pairs of keypoints, i.e. top-left corner and the bottom-right corner, which triggers the emergence of series of anchor-free detection methods [17, 18].

As well, there are also algorithms [19–24] that are specially tailored for face detection. MTCNN [19] cascades the three networks of P-Net, R-Net, and O-Net, which can simultaneously detect faces and five facial landmarks. Also, Cai at el. [20] still adopt a multitask cascaded CNN-based framework for simultaneous face detection, dense face alignment and fine head pose estimation. The lightweight anchor-free face detector CenterFace [21] can run in real time on a single CPU core and 200 fps using NVIDIA 2080TI for VGA-resolution images but produces more false positives. RetinaFace [22], a generalized face localization method, its architecture consists of three main parts: feature pyramid network, context module, and cascade regression. Also, it utilizes a multi-task learning strategy that combines extra-supervision and self-supervision to achieve stable face detection, accurate 2D face alignment, and robust 3D face reconstruction.

In this paper, we focus on improving a state-of-the-art object detection method to make it suitable for the real-world video face detection task. More and more scenarios in today's society involve video face detection, but there are still some inherent challenges in the development of this technology. On the one hand, not only high precision but also real-time speed is required in video processing. On the other hand, there is a lot of redundant information between adjacent frames in the video data. If all detected faces are output, there will be multiple face images of the same person, resulting in a lot of repetitive work in postprocessing stage. So face deduplication at the detection level is also necessary. In summary, our key contributions are

(i) Due to smaller variations in the facial boxes' aspect ratio, CARLoss (constrained aspect ratio loss) is proposed as a new feedback mechanism.

(ii) Adding a prediction head on the original YOLOv4 for tiny faces, so the modified FH-YOLOv4 is more suitable for large-scale variations.

(iii) A video face image deduplication algorithm based on IoU Tracker is proposed to serve postprocessing tasks.

The remainder of this paper is organized as follows: Section 2 reviews several popular loss functions for bounding box regression. In Section 3, we propose CAR-Losses and four-head architecture FH-YOLOv4 for better face detection. In Section 4, we propose a video face image deduplication algorithm based on IoU Tracker. Extensive experiments are conducted in Section 5. Section 6 presents our conclusions.

2. Analysis of Traditional Bounding Box Regression Loss Functions

Generally, the loss function of the object detection task consists of two components, classification loss and bounding box regression loss. In this section, we focus on the evolution of bounding box regression loss, and analyze several of the most representative loss functions. There are many formats for the labeling of the bounding box, the common ones include Pascal VOC, COCO, and YOLO, which can be converted into each other. We follow the label format of the YOLO dataset and the box is parameterized by the coordinate of its center point, the width and the height. For convenience, we denote the region proposal and ground truth as $B = (x, y, w, h)$ and $B^{gt} = (x^{gt}, y^{gt}, w^{gt}, h^{gt})$, respectively.

2.1. l_n-Norm Loss. The l_n-norm loss functions are widely employed in bounding box regression. l_1 loss function stands for least absolute deviations, and l_2 loss function stands for least square errors. When the gradient descent algorithm is applied, the derivative function of l_1 loss is piecewise constant, so l_1 loss is insensitive to outliers but tends to fluctuate near the stable value in the later training period. l_2 loss is continuously differentiable, but due to its amplification effect on outliers, it is easy to cause gradient explosion in the early training stage. l_1-smooth loss [5] is exactly the integration of the advantages of l_1 loss and l_2 loss. However, the general representation of the location loss based on the l_n-norm is as follows:

$$L_{l_n} = \sum_{i \in x,y,w,h} l_n\left(B_i^{gt} - B_i\right), \tag{1}$$

which ignores the correlation between the four parameters of the bounding box.

2.2. IoU and GIoU Loss. Intersection over union (IoU) of B^{gt} and B,

$$IoU = \frac{\left|B^{gt} \cap B\right|}{\left|B^{gt} \cup B\right|}. \tag{2}$$

The evaluation criterion of positioning accuracy is used to de-redundant region proposals or determine positive and negative samples. In [25], for the first time, it was used as a measure of the distance between the candidate box and the ground truth to construct the loss function.

$$\begin{aligned} L_{IoU} &= -\ln IoU, \\ L_{IoU} &= 1 - IoU. \end{aligned} \tag{3}$$

IoU loss not only treats the bounding box as a unit, but the metric is also scale-invariant.

If the anchor box and the target box have no overlapping area, IoU loss can neither reflect how far apart the two boxes are nor guide the movement of the anchor box. To address this issue, GIoU loss is proposed in [26],

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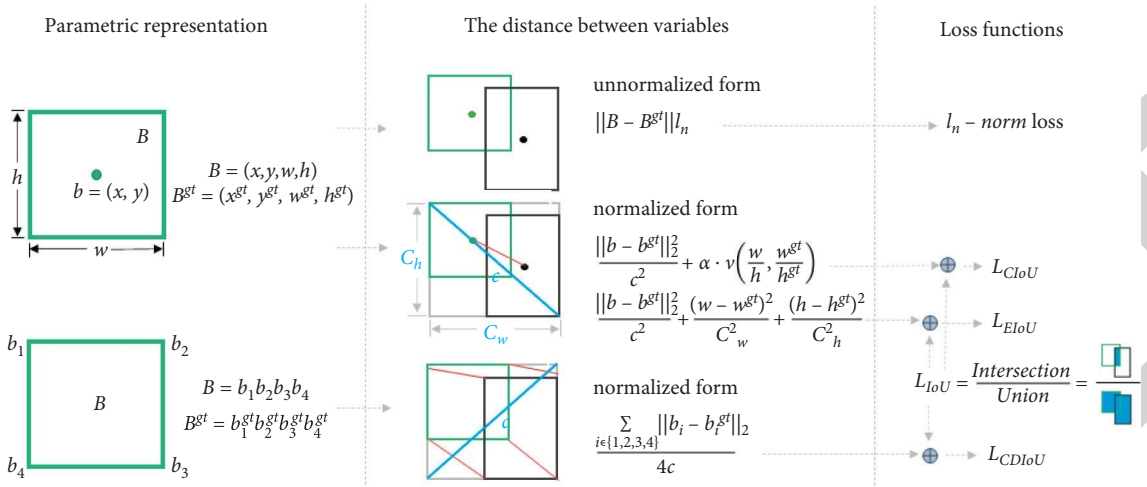

Figure 1: Illustrations of several loss functions that take into account the overlap area of two boxes and the normalized distance between parameters. Green denotes the anchor box. Black denotes the target box. Gray denotes the smallest enclosing box covering the two boxes.

$$GIoU = IoU - \frac{\left|E \setminus \left(B^{gt} \cup B\right)\right|}{|E|},$$
$$L_{GIoU} = 1 - GIoU, \tag{4}$$

where E is the smallest rectangular enclosing both B^{gt} and B. Empirically, this generalization tends to first increase the size of the proposal box to make it overlaps with the target box, and then degenerate into the IoU evaluation-feedback mechanism [27]. There are still problems such as slow convergence speed and inaccurate alignment. Similar to GIoU loss, DIoU loss ([28]) can still provide the direction of movement for the bounding box when it does not overlap with the target box.

2.3. Loss Functions That Consider Both IoU and Parametric Representation. As mentioned above, on the one hand, each box can be uniquely represented by a set of variables. For example, if the coordinates of two nonadjacent vertices are known, or the coordinates of the centroid and the width and height are given, then the rectangle can be positioned and drawn. On the other hand, IoU is an important indicator to judge the similarity of two boxes. Therefore, various positioning losses that take into account the overlap area of the two boxes and the normalized distance between the parameters are emerging one after another as illustrated in Figure 1.

In [27], the Complete-IoU (CIoU) loss is proposed,

$$L_{CIoU} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \alpha \cdot v\left(\frac{w}{h}, \frac{w^{gt}}{h^{gt}}\right), \tag{5}$$

where $\mathbf{b} = (x, y)$ and $\mathbf{b}^{gt} = (x^{gt}, y^{gt})$ are the centroids of B and B^{gt}, respectively, c is the diagonal length of the smallest enclosing rectangle covering the two boxes, $v = 2(\arctan(w/h) - \arctan(w^{gt}/h^{gt}))^2/\pi^2$ measures the difference in the aspect ratio between the two boxes, and $\alpha = v/((1 - IoU) + v)$ is a control parameter. From formula (5), it is obvious that in the process of oriented boxes regression, the deep network first tries to pull the center point of the generating box towards the center point of the target box until the two boxes intersect, and then pay more attention to adjusting the aspect ratio later.

Efficient-IoU (EIoU) loss [29], a revised version of CIoU loss, directly minimizes the gap between the width and height of the two boxes instead of the aspect ratio. Its definition is as follows:

$$L_{EIoU} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \frac{\left(w - w^{gt}\right)^2}{C_w^2} + \frac{\left(h - h^{gt}\right)^2}{C_h^2}, \tag{6}$$

where C_w and C_h are the width and height of the smallest enclosing box covering the two boxes. In addition, Control Distance-IoU (CDIoU) loss [30] considers the regression of the four vertices of the box. Starting from the upper left point of the rectangle, denote the four vertices of B and B^{gt} clockwise as $\mathbf{b}_i$ and $\mathbf{b}_i^{gt}$ $(i = 1, 2, 3, 4)$. The CDIoU loss is defined as follows:

$$L_{C\ DI\ oU} = 1 - IoU - \lambda\left(1 - \frac{\sum_{i\in\{1,2,3,4\}}\left\|\mathbf{b}_i - \mathbf{b}_i^{gt}\right\|_2}{4c}\right). \tag{7}$$

Compared with the previous loss functions, they have greatly improved the convergence speed and detection accuracy. Since the physical description of the distance between boxes is diverse, there is still a lot of room for optimization.

3. FH-YOLOv4 with Constrained Aspect Ratio Loss for Better Face Detection

As a special case of object detection, face detection is also featured by the limited aspect ratio of the facial box (ranging from 1 : 1 to 1 : 1.5) and large-scale variation (occupying several pixels or even thousands of pixels) [22]. These properties open up opportunities for us to adjust the loss

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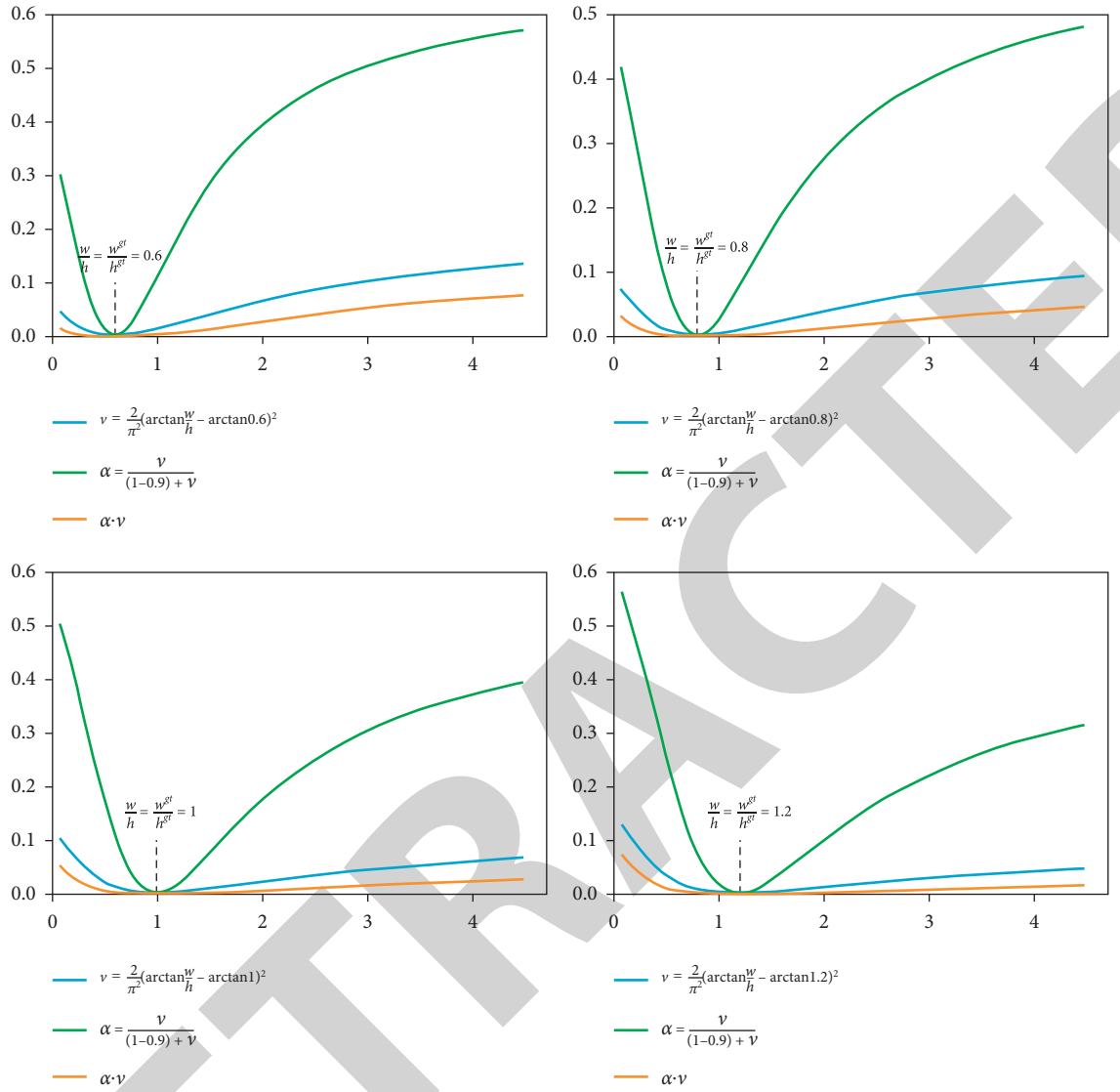

Figure 2: Exploration of the range of I_3 in CIoU loss. The x-axis label is w/h. Set the facial box width-to-height ratio w^{gt}/h^{gt} to 0.6, 0.8, 1.0, 1.2 in sequence, and fix IoU = 0.9. Then, the graphs of functions v, α, and $I_3 = \alpha \cdot v$ are shown.

function and network structure of advanced general object detection methods to yield more promising and faster facial box inference.

3.1. Constrained Aspect Ratio Losses for Better Facial Box Regressing

3.1.1. Limitation of CIoU Loss for Face Detection. Reviewing the definition of CIoU loss in formula (5), we might as well write its three key components as $I_1 = 1 - IoU$, $I_2 = \|\mathbf{b} - \mathbf{b}^{gt}\|_2^2/c^2$, and $I_3 = \alpha \cdot v(w/h, w^{gt}/h^{gt})$, where $I_1 \in [0,1]$, $I_2 \in [0,1)$. And then we analyze the range of I_3. Typically, the width-to-height ratio (of the facial box B^{gt}) $w^{gt}/h^{gt} \in [2/3, 1]$. In Figure 2, the graph of the function v is drawn in blue for the independent variable $w/h \in [0.08, 4.5]$ when w^{gt}/h^{gt} is fixed at 0.6, 0.8, 1.0, and 1.2, respectively. In addition, since the coefficient function α is monotonically increasing with respect to IoU, a larger IoU (fixed IoU = 0.9) is selected here to explore the upper bound of I_3, and the graph of α is plotted in green. So far, we can obtain the graph of $I_3 = \alpha \cdot v$ (orange curve) and find that the range of I_3 is about [0,0.1) in the process of facial box regression. Therefore, compared with I_1 and I_2, the contribution of I_3 to CIoU loss is very small.

3.1.2. Constrained Aspect Ratio Loss. To enhance the contribution of the shape parameter w/h to the facial box regression loss, we revise the CIoU loss and propose a series of more efficient versions, i.e., constrained aspect ratio losses (CARLosses). For the sake of brevity, CARLosses can be unified as expression (10):

$$L_{R_i}\left(B, B^{gt}\right) = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + R_i\left(\frac{w}{h}, \frac{w^{gt}}{h^{gt}}\right). \quad (8)$$

Here, in view of the constraint that the aspect ratio of the facial box is limited, several penalty terms

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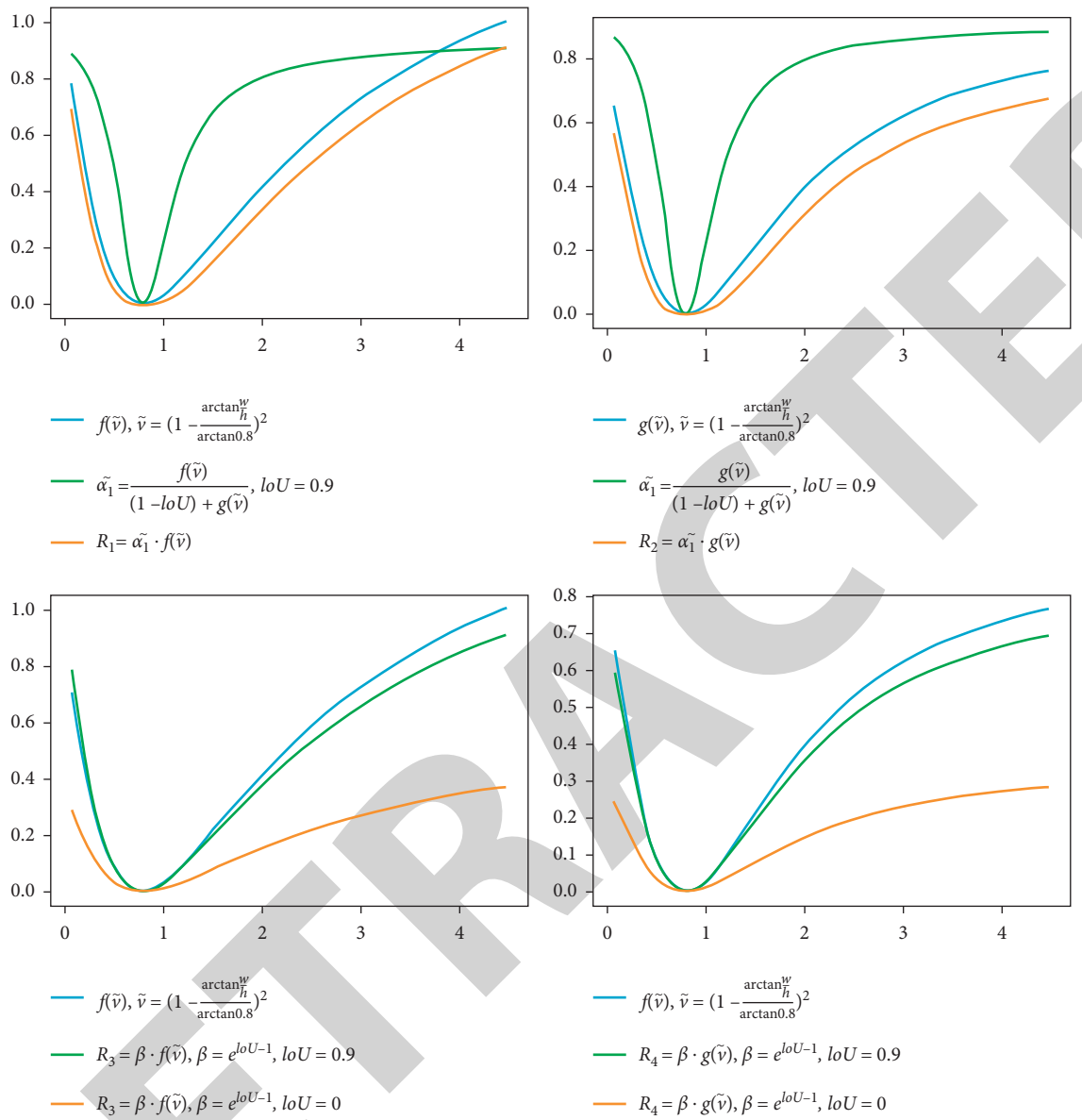

Figure 3: Description of the range of R_i $(i = 1, 2, 3, 4)$ in CARLosses. Set the facial box width-to-height ratio w^{gt}/h^{gt} to 0.8. The x-axis label is w/h.

$R_i(w/h, w^{gt}/h^{gt})$ $(i = 1, 2, 3, 4)$ are designed to improve the convergence speed and positioning accuracy.

Specifically, we define the function $\tilde{v} = (1 - \arctan(w/h)/\arctan(w^{gt}/h^{gt}))^2$, and introduce the piecewise function $f(\cdot)$ and the hyperbolic tangent function $g(\cdot)$:

$$f(x) = \begin{cases} 0, & \text{if } x \le 0 \\ x, & \text{if } 0 < x < 1, g(x) = \dfrac{e^x - e^{-x}}{e^x + e^{-x}}. \\ 1, & \text{if } x \ge 1 \end{cases} \tag{9}$$

Then, the following loss functions L_{R_i} are proposed.

Case 1.

$$L_{R_1} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \tilde{\alpha_1} f(\tilde{v}), \tag{10}$$

where the trade-off parameter $\tilde{\alpha_1} = f(\tilde{v})/((1 - IoU) + f(\tilde{v}))$.

Case 2.

$$L_{R_2} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \tilde{\alpha_2} g(\tilde{v}), \tag{11}$$

where the balance parameter $\tilde{\alpha_2} = g(\tilde{v})/((1 - IoU) + g(\tilde{v}))$.

Case 3.

$$L_{R_3} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \beta f(\tilde{v}), \tag{12}$$

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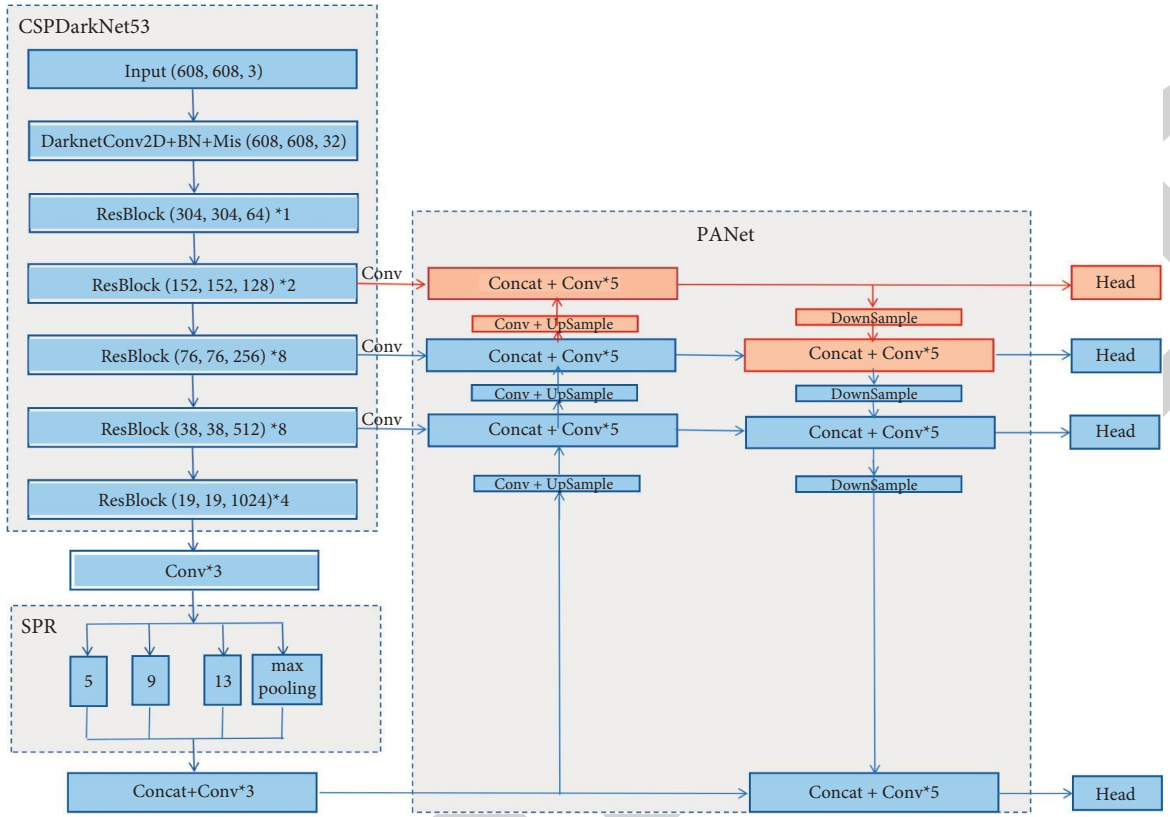

Figure 4: The architecture of the FH-YOLOv4. Compared with the original YOLOv4 structure, one more head (Red) is introduced for tiny face detection.

where the weighting coefficient $\beta = e^{IoU-1}$.

Case 4.

$$L_{R_4} = 1 - IoU + \frac{\left\|\mathbf{b} - \mathbf{b}^{gt}\right\|_2^2}{c^2} + \beta g(\vec{v}), \tag{13}$$

where the coefficient β is the same as the one in expression (12).

First, rough visualization of components R_i in L_{R_i} shows that the contribution of the shape parameter w/h to facial box regression loss is indeed greatly increased, see Figure 3. Furthermore, the performance evaluation of the proposed CARLosses on face detection is presented in Section 5.

3.2. Improved YOLOv4 by Adding a Prediction Head for Tiny Faces

3.2.1. Four-Head Structure (FH-YOLOv4) for Large-Scale Variations. Since the facial boxes in the WIDER FACE dataset vary dramatically in scale (from a few pixels to tens of thousands of pixels), and almost half of them are small instances (occupying less than 200 pixels), we add on the original YOLOv4 framework a prediction head to facilitates correct detection of tiny faces. As shown in Figure 4, the prediction head (the red branch) we add is generated from a low-level feature map with a small receptive field, which is more sensitive to tiny faces. Therefore, FH-YOLOv4 contains a total of 4 detection heads, which are used to detect tiny, small, medium and large faces, respectively.

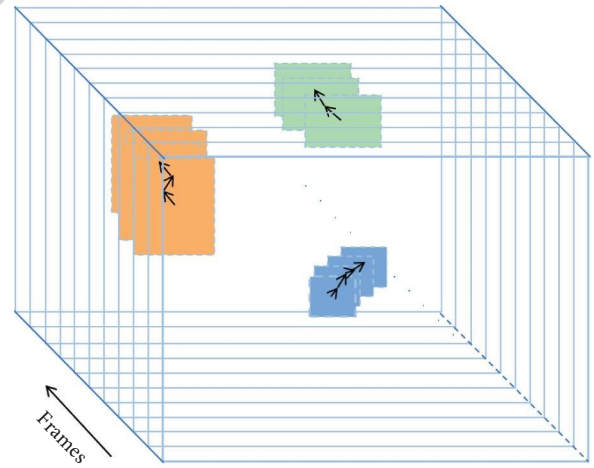

Figure 5: Illustration of the facial boxes in consecutive frames. Blue, Orange, and Green represent the facial boxes of different people, respectively.

3.2.2. Predefined Anchors. We still use k-means clustering to mine the facial bounding box priors. Cluster the width and height in the annotation information of the benchmark dataset WIDER FACE [31] for face detection. In the case

Input: $V = \{v_i\}_{i=1,2,\ldots,F}$, T, p
Initialize: flag = 0, temp = ∅, temp_loc = ∅
For v_i **in** V:
  if flag == T:
    Save the faces stored in the temp;
    flag = 0, temp = ∅, temp_loc = ∅;
  $D_i = \emptyset$, $L_i = \emptyset$;
  Perform face detection on image v_i,
  add the faces $\{d_{ij}\}_{j\in\mathbb{N}}$ to D_i,
  add the corresponding location $\{l_{ij}\}_{j\in\mathbb{N}}$ to L_i;
  if $D_i \neq \emptyset$:
    if temp == ∅:
      Add $\{d_{i,j}\}$ to temp, add $\{l_{i,j}\}$ to temp_loc;
      flag+ = 1, continue;
    for l_{ij} in L_i:
      [max_loc, max_IoU] = max IoU (l_{ij}, temp_loc);
      if max_$IoU < p$:
        Add $d_{i,j}$ to temp, add $l_{i,j}$ to temp_loc.
      else:
        Replace max_loc with $l_{i,j}$;
  flag+ = 1;
Output: The faces saved after deduplication operation.

Algorithm 1: The IoU tracker-based video face deduplication algorithm.

Table 1: Quantitative comparison of traditional YOLOv4 trained using L_{CIoU} (baseline) and proposed L_{R_i}.

	L_{CIoU}	L_{R_1}	L_{R_2}	L_{R_3}	L_{R_4}
Epoch 50th	66.14%	65.39%	66.46%	66.79%	66.58%
Epoch 100th	72.91%	72.07%	72.95%	73.30%	73.63%
Epoch 150th	74.08%	74.01%	74.55%	73.96%	74.26%
Max AP	74.55%	74.28%	**74.63%**	74.10%	**74.57%**

where the size of the input image is 608 × 608, we employ 12-mean clustering to get predefined anchors' size. The 12 clusters centroids are (2.36,3.96), (3.56,6.33), (4.75,8.75), (5.34,12.67), (6.53,10.68), (8.31,15.11), (10.69,20.77), (15.44,28.49), (22.56,40.95), (34.44,59.09), (59.38,97.92), and (139.53,208.18). Also, the prior settings in YOLOv4 are adjusted accordingly to make it more suitable for face detection tasks.

4. The Application of FH-YOLOv4 for Video Face Detection: IoU Tracker-Based Face Image Deduplication

Because the detected faces may be within the range of video surveillance for a long time, a large number of repeated detection faces are filled between consecutive frames. It is obviously unreasonable to do a follow-up 1: N face recognition for all repeating faces. So, in this subsection, we study the face deduplication algorithm, which deduplicates the detected faces to reduce the number of recognitions of the same person.

Inspired by the idea of IoU Tracker [32] in target tracking, we simplify and apply it to video face deduplication tasks. Different from multiobjective tracking [33], the deduplication algorithm proposed in this paper does not need to store a large amount of historical information, which reduces the storage cost.

When the time interval between frames is short and the person moves slowly, analyzing the position of all facial boxes in the current frame and the previous frame will find that the facial boxes of the same person will partially overlap (please see Figure 5). Thus, we can use the IoU as a measurement indicator for face deduplication. A detailed description of the IoU Tracker-based video face deduplication algorithm is shown in Algorithm 1, where V represents the test video, a continuous image sequence containing F frames in total. Period T and IoU threshold p need to be set empirically, flag is a counter, temp, and temp_loc are used to store faces and their corresponding locations, respectively. The detections at frame i are recorded in D_i and L_i, d_{ij} is the j^{th} face at frame i, l_{ij} is the location of d_{ij}. IoU (l_{ij}, temp_loc) means calculating the IoU between l_{ij} and all the facial boxes in the temp_loc, and the element in the temp_loc that makes the max_IoU valid is assigned to max_loc.

Because no visual information about the frames is used, the overall complexity of the method is very low. So, it can be thought of as a simple filtering process at the detection level.

5. Experiments

5.1. Effect of CARLosses. To evaluate the performance of the proposed CARLosses on face detection, we train the traditional YOLOv4 using L_{CIoU} (baseline) and proposed L_{R_i} ($i = 1, 2, 3, 4$) on the WIDER FACE training set. The input image size is set to be 608 × 608. Also, the AP at epochs 50th, 100th, 150th and maximum AP on the WIDER FACE validation set are recorded in Table 1. The results show that

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Table 2: The performance when incorporating the CIoU loss and CARLosses with FH-YOLOv4.

Methods	YOLOv4+ L_{CIoU}	FH-YOLOv4+ L_{CIoU}	FH-YOLOv4+ L_{R_1}	FH-YOLOv4+ L_{R_2}	FH-YOLOv4+ L_{R_3}	FPS+ L_{R_4}
AP	74.55%	78.89%	78.91%	78.38%	79.06%	79.20%

Table 3: The performance of FH-YOLOv4 on test videos.

Test videos	Frames	Video length	Detection time	Total run time	FPS
video1.mp4	7783	00:05:18	00:05:55	00:07:27	21.9
video2.mp4	6283	00:04:18	00:04:40	00:05:56	22.4
video3.mp4	7783	00:05:18	00:06:21	00:07:55	20.4
video4.mp4	7783	00:05:18	00:06:06	00:07:38	21.3
video5.mp4	7783	00:05:18	00:05:58	00:07:33	21.7
video6.mp4	7783	00:05:18	00:05:57	00:07:34	21.8
video7.mp4	7783	00:05:18	00:03:59	00:04:19	32.6

Table 4: Effectiveness of the IoU tracker-based face deduplication algorithm.

Test videos	Detected faces	Time for detection	Reserved faces	Detection + deduplication	Deduplication ratio (%)
video1.mp4	2660	00:00:51	59	00:00:54	97.782
video2.mp4	4276	00:00:49	86	00:00:52	97.989
video3.mp4	672	00:00:50	48	00:00:52	92.857
video4.mp4	1750	00:00:51	65	00:00:53	96.286
video5.mp4	1573	00:00:51	56	00:00:54	96.440

training YOLOv4 using our L_{R_2} and L_{R_4} can not only promote the fast convergence of the model but also improve its performance compared to CIoU loss.

5.2. Ablation Studies. Aims to verify the effectiveness of FH-YOLOv4 and CARLoss in face detection, some experiments are carried out, and the results are recorded in Table 2.

First, cooperating the CIoU loss (L_{CIoU}) with traditional YOLOv4 and FH-YOLOv4, respectively, one can find that the added prediction head for tiny faces brings an astonishing performance gain of 4.34%. Second, when FH-YOLOv4 is trained with our proposed CARLosses, L_{R_1}, L_{R_3}, and L_{R_4} can all improve its performance compared to CIoU loss. It is worth noting that, the results in Tables 1 and 2 show consistent improvements in the performance of YOLOv4 and FH-YOLOv4 when they are trained using L_{R_4}. Thus, in the following text, we will abbreviate the proposed method FH-YOLOv4+ L_{R_4} as FH-YOLOv4.

5.3. Video Face Detection Speed. We apply FH-YOLOv4 to perform face detection on 7 test videos. The basic information of the videos (number of frames, duration), the time spent in the detection process, and the total running time are shown in Table 3. Among them, the total running time refers to the time consumption of all links including the reading of video frames, face detection, and result saving. Also, FPS refers to the number of video frames detected per second.

With the exception of video7.mp4, the FSP of other videos is around 21, which does not show a considerable speed advantage. On the one hand, the newly added prediction head for tiny faces in FH-YOLOv4 increases the number of network layers, which inevitably leads to an increase in the amount of computation. However, it is worth sacrificing a small computational cost in exchange for a big boost to the AP. On the other hand, the above experiment is a frame-by-frame detection of video. In practical application scenarios, the restricted random sampling (RRS) method [34] is usually used to randomly sample the video frames first, and then only the sampled video frames are processed. This not only improves the efficiency of the program but also allows more time for subsequent face recognition tasks.

5.4. Face Deduplication. In the following experiments, the FH-YOLOv4 and IoU Tracker-based deduplication algorithms are combined to detect and deduplicate the faces in the video clips. Under the setting of the IoU threshold $p = 0.8$, the statistical results of the number of faces before and after deduplication are shown in Table 4. It can be seen that the IoU Tracker-based deduplication algorithm can effectively remove repeated faces without increasing a lot of computing time, which helps to relieve the pressure of subsequent face recognition.

6. Conclusion

In this paper, we first propose CARLosses for better facial boxes regression according to the fact that the width-to-height ratio of faces is roughly ranging from 1 : 1 and 1 : 1.5. Second, by clustering the width and height in the annotation information of the benchmark dataset WIDER FACE, we add a prediction head on the original YOLOv4 for tiny faces and obtain a modified network structure FH-YOLOv4. The

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FH-YOLOv4 guided by CARLoss can achieve a significant improvement in AP compared to traditional YOLOv4. Third, we propose the IoU Tracker-based face image deduplication algorithm, and the deduplication rate is over 95 for all test videos. Experiments demonstrate that our method can achieve real-time speed and high accuracy, making it an ideal alternative for most face detection and recognition applications.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: Dynamic Combined Optimal Scheduling of Electric Energy and Natural Gas Energy Consumption in Data Center

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] X. Liu, G. Hou, and L. Yang, "Dynamic Combined Optimal Scheduling of Electric Energy and Natural Gas Energy Consumption in Data Center," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 3917170, 8 pages, 2022.

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Research Article

Dynamic Combined Optimal Scheduling of Electric Energy and Natural Gas Energy Consumption in Data Center

Xuehui Liu, Guisheng Hou, and Lei Yang

College of Economics and Management, Shandong University of Science and Technology, Qingdao 266590, China

Correspondence should be addressed to Lei Yang; yanglei@sdust.edu.cn

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Energy consumption is the key factor leading to high operating costs in data center. In this paper, considering the data center service level under the premise of using electricity and gas as energy supply of energy supply and energy consumption from two angles, the data center energy scheduling model is built. The lower model is calculation scheduling model for the data center, and the upper model is data center energy supply scheduling model. Then the particle swarm algorithm is used to simulate the schedule. The results show that using natural gas as supplementary energy supply can effectively reduce the overall energy consumption of data center in considering the service delay level of data center.

1. Introduction

The data center is the core foundation of applications such as cloud computing, blockchain, and Internet of Things (IoT). Due to its special nature of running 24 hours a day, its energy consumption is much higher than that of general commercial buildings. The problem of energy consumption has become an important factor hindering the development of data centers. The energy consumption of the data center includes the cooling system energy consumption, the servers and storage equipment energy consumption, the network equipment energy consumption, the power supply system energy consumption, and the lighting energy consumption mainly, the energy consumption of the cooling system accounts for about 50% of all the energy consumption. The energy sources of the cooling system of the data center mainly include electricity, natural gas, and solar energy. How to combine the service requirements of the data center to optimize the cooling system energy consumption dynamically can reduce the data centre's energy consumption effectively.

The cooling method of the data center is divided into two methods: air cooling and liquid cooling. The air cooling system of the data center uses air circulation and air conditioning technology to remove the heat generated by the data center. Zhang et al. expanded and developed the distributed airflow control model of the data center energy consumption model and applied to the distributed airflow control of the raised floor ventilation system and the vertical placed server, and it could reduce the cooling energy consumption of the traditional ventilation system significantly [1]. Yang et al. applied the free cooling mode to the data center air conditioning system to reduce the energy consumption [2], Ham et al. proposed a server model that could simulate the cooling energy consumption of the data center to determine the temperature difference between the server heat production, and it was proposed that when the supply air temperature of the computer room air handler is higher than 19°C, and the cooling energy consumption increases due to the increase of fan energy consumption [3].

Combining cooling system energy consumption with data center services, configuration is the focus of current research. Zhou et al. considered the energy consumption of processing unit, memory, disks, and the network interface cards in the data center comprehensively, as well as the characteristics of the application, and the prediction accuracy of the model is over 95% [4]. Nehra and Nagaraju built models of different resources or hardware used in data centers to analyze their energy consumption to develop sustainable data centers [5]. Pop et al. mapped particle

locations onto data center configurations and used a fitness function that took the server hardware resources and the data center cooling system energy consumption as the evaluation criteria [6]. Mursleen and Kothyari proposed a new energy-saving algorithm to build data center asset allocation technology effectively, obtained the balance between the energy consumption and performance of the data center, and reduced energy consumption without affecting the performance of the data center [7]. Xu et al. utilized finite Markov decision processes (MDP) to optimize the use of renewable energy in data centers by dynamically shutting down nonenforced microservices and executed on workloads according to user preferences and brown energy consumption [8]. Cho and Jinkyun proposed a data center energy flow and baseline method based on IT loading, systematically proposed the formulation of the data center energy structure, and found that equipment energy efficiency was the key to energy saving [9, 10]. Conterato et al. defined the flow path according to the traffic bandwidth requirements and adjusted the operation status of the data center network equipment according to the flow path to reduce the network equipment consumption [11]. Considering both physical machines (PM) and virtual machines (VM), Chou et al. proposed a dynamic energy resource allocation mechanism for data centers based on the particle swarm algorithm to solve the problem of the air conditioner energy efficiency ratio [12]. Based on the multiresource energy-saving allocation model and the particle swarm optimization method, Xiong and Xu proposed the fitness function of the particle swarm algorithm as the total European Distance to determine the optimal point between data center resource manipulation and energy consumption [13]. Luo et al. proposed a multiobjective particle swarm optimization algorithm, which took the physical resource manipulation and link loss rate as the optimization goal, and took the tenant's business reliability and the quality of service as constraint condition to reduce the waste of physical resources and link resources, thereby reduced the data center energy consumption [14]. In order to solve the problem that traditional data center energy consumption modeling methods were limited to dealing with the randomness, burstiness and interdependence of energy systems, Wang et al. proposed and implemented an agent-based approach of power consumption in data centers, it shown that operate the cooling load according to the practical load of the servers dynamically could save 13% of the total energy consumption [15].

In data center energy scheduling research, Fernández-Cerero et al. evaluated the natural DEA and constant return to scale (CRS) of data center energy consumption and performance metrics to determine optimal energy sources policies and scheduling strategies for high and low data center demand as well as medium and large data centers [16]. Santiago and Sergio constructed a multitarget data center energy consumption scheduling method for traditional energy and green energy data sources by scheduling the status of servers, cooling equipment, and data center workload simultaneously [17]. Renewable energy sources such as solar energy and wind energy have been considered for data center, and two improvements to small and medium-sized data center based on opportunistic scheduling and reliance on energy storage devices had been considered [18]. It was believed that the low server utilization rate caused by the resource scheduling mechanism with the completion time as the priority and the excessive cooling supply caused by the data center cooling system based on the peak strategy were the main reasons for the increase in the data center energy consumption, and artificial intelligence could be used to construct an energy consumption control scheduling framework aiming at reducing energy consumption [19]. Kumar proposed to use the dynamic voltage frequency scheduling (DVFS) scheme to assign task to virtual machines and extended data center energy efficient network aware scheduling through point-to-point load balancers to reduce network energy consumption [20].

Through literature review, it can be found that the combination of energy consumption level and service capability is the entry point of current research, and particle swarm optimization is an effective method for energy consumption scheduling in data centers. Considering that the data center's service level is guaranteed, the data center energy consumption is analyzed from the two levels of system operation cost and data load power consumption hierarchically. Therefore, this paper proposes a dual-objective scheduling model of data center energy consumption considering the supply of natural gas and electricity. The particle swarm optimization algorithm is used to solve the model and the simulation is carried out. The results show that use of electricity as main energy which is supplemented by natural gas energy that can reduce the data center overall energy consumption effectively on the premise of ensuring the service level of the data center.

2. Data Center Energy Hub Equipment Model

2.1. Gas Turbine. The relationship between the input gas power and the output electric power of the gas turbine is shown in formula (1)

$$P_{GT} = \lambda G_{GT}. \tag{1}$$

In the formula, G_{GT} and P_{GT} are the input gas power and output electric power of the gas turbine, and λ is the energy conversion efficiency [21].

2.2. Absorption Refrigeration Unit. The lithium bromide absorption refrigeration unit is driven by the waste heat generated by the gas turbine, and the mathematical model is

$$C_{GC} = \eta \cdot Q_{GT} \cdot \xi. \tag{2}$$

C_{GC} is the refrigerating capacity of lithium bromide absorption refrigerator; η is the waste heat recovery rate, which is related to room temperature, and its value is 0.55 at room temperature; ξ is the cooling coefficient of the unit; Q_{GT} is the waste heat generated by the gas turbine, and its value can be expressed as

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$$Q_{GT} = \frac{P_{GT}(1-\lambda-\lambda_1)}{\lambda} \tag{3}$$

λ_1 is the heat dissipation loss coefficient of the gas turbine, and a fixed value of $\lambda_1 = 0.03$ is often taken [22]. The electric refrigerator drives the compressor to work and cools by consuming electric energy, and its mathematical model is

$$C_{EC} = \gamma P_{EC}. \tag{4}$$

C_{EC} is the electric refrigerator output cooling power; P_{EC} is the electric refrigerator input electric power; and γ is the energy conversion efficiency [22].

3. Data Center Power Consumption Model

The power consumption of a data center is linearly related to the number of active servers in it, as shown in formula (5)

$$e_{i,t} = km_{i,t} + \beta \forall i \in I, \quad t \in T. \tag{5}$$

In this formula, T is the set of time nodes; I is the set of data centers; $e_{i,t}$ is the power consumption of data center i at time t; k and β are parameters representing the relationship between data center power consumption and active servers, respectively; $m_{i,t}$ is the number of active servers in data center i at time t [23], and it satisfies the following formula

$$m_{i,t} = 0, \quad 1, \ldots, M_i. \tag{6}$$

M_i is the total number of servers in the data center.

The server is a device that processes data load. The time delay of data processing is related to the average service rate and number of servers. The model can be expressed as

$$0 < \frac{1}{\mu - L_{i,t}/m_{i,t}} \le D. \tag{7}$$

μ is the average service rate of active servers; $L_{i,t}$ is the total data load allocated to data center i at time t; and D is the settable upper limit of the time delay of data center processing data load.

After sorting out the above formula, the power consumption model of the data center is

$$\begin{cases} e_{i,t} = km_{i,t} + \beta, \\ m_{i,t} \ge \dfrac{L_{i,t}}{\mu - 1/D}, \\ 0 \le m_{i,t} \le M_i, m_{i,t} \in N^*. \end{cases} \tag{8}$$

Although the number of active servers $m_{i,t}$ is a positive integer that varies in units, compared with the total number of servers with a very large value, $m_{i,t}$ can be regarded as a continuous variable in the simulation analysis. Combining terms 1 and 2 of formula (8), we can get

$$\frac{\mu - 1/D}{k}\left(e_{i,t} - \beta\right) \ge L_{i,t}. \tag{9}$$

Combining items 1 and 3 of formula (8), we can get

$$\beta \le e_{i,t} \le kM_{i,t} + \beta. \tag{10}$$

So the formula (9) and (10) are the power consumption model of the data center.

4. Dual-Objective Economic Dispatch Model for Data Center

4.1. Upper-Layer Scheduling Model

4.1.1. Objective Function. The objective function of the upper model in the data center energy hub optimization scheduling model is to minimize the system operation cost including the energy purchase cost and the unit operation and maintenance cost. The objective function is

$$\begin{aligned} \min C = \Big[& \left(c_t^e \cdot P_t^L + c_t^g \cdot G_t^L\right) \\ & + \left(\varepsilon_t^{GT} \cdot P_t^{GT} + \varepsilon_t^{GC} \cdot C_t^{GC} + \varepsilon_t^{EC} \cdot C_t^{EC}\right) \Big]. \end{aligned} \tag{11}$$

P_t^L and G_t^L are the electric power and natural gas power purchased, respectively; c_t^e and c_t^g are the unit power price of purchased electricity and natural gas; P_t^{GT}, C_t^{GC}, and C_t^{EC} are the electric power output by the gas turbine, the cooling power output by the absorption chiller, and the cooling power output by the electric chiller; ε_t^{GT}, ε_t^{GC}, and ε_t^{EC} are the gas turbine, operation, and maintenance costs of absorption chillers and electric chillers.

4.1.2. Constraints

(1) System operating power balance constraints

$$\begin{aligned} P_t^L + P_t^{GT} + P_t^W + P_t^{PV} + P_t^{ES} &= Q_t^E + P_t^{EC}, \\ C_t^{GC} + C_t^{EC} + C_t^{CS} &= Q_t^C. \end{aligned} \tag{12}$$

In the formula, Q_t^E and Q_t^C are the electrical load and cooling load demand, and the electrical load includes the basic electrical load and data load.

(2) Unit output constraints

$$\begin{aligned} P_{t,\min}^{GT} \le P_t^{GT} \le P_{t,\max}^{GT}, \\ C_{t,\min}^{GC} \le C_t^{GC} \le C_{t,\max}^{GC}, \\ C_{t,\min}^{EC} \le C_t^{EC} \le C_{t,\max}^{EC}, \\ P_{i,t,\min} \le P_{i,t} \le P_{i,t,\max}. \end{aligned} \tag{13}$$

In the formula, $P_{t,\max}^{GT}$ and $P_{t,\min}^{GT}$ are the upper and lower output limits of the gas turbine; $C_{t,\max}^{GC}$ and $C_{t,\min}^{GC}$ are the upper and lower output limits of the absorption chiller; $C_{t,\max}^{EC}$ and $C_{t,\min}^{EC}$ are the upper and lower output limits of the electric chiller; and $P_{i,t,\max}$ and $P_{i,t,\min}$ are the upper and lower limits of the generator output of subdata center i.

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4.2. Lower-Level Scheduling Model

4.2.1. Objective Function. The objective function of the lower model is that the data center allocates the data load with the smallest total power consumption and the smallest total delay time of data processing

$$\min D = \omega_1 \cdot \sum_{i \in I} e_{i,t} + \omega_2 \cdot \sum_{i \in I} \frac{L_{i,t}}{\mu - L_{i,t}/m_{i,t}}. \quad (14)$$

In the formula, ω_1 and ω_2 are the weight coefficients of the two targets.

4.2.2. Constraints. The constraints of the lower model include the number of servers in the data center and the delay constraints. For specific formulas, it can refer to formula (8)–(10).

4.3. Solution Method. According to the characteristics of the model, the particle swarm optimization algorithm is used to solve the dual-objective scheduling model. Like most swarm intelligence optimization algorithms, this algorithm usually initializes a set of solutions (particles) in a random way and then updates these solutions through iterations continuously. The entire population is adjusted to a better fitness value as a whole, and finally, it is expected that the optimal solution to the problem can be found within a limited number of iteration steps.

4.3.1. Data Center Energy Scheduling Process. In this paper, the algorithm is run on the MATLAB-YALMIP platform to solve the dual-objective model. Combined with the previous model construction, the data center energy scheduling process is described as following.

Step 1. The user puts forward data service requirements to the data center, including data processing volume, response time, data transmission speed, and maximum delay time.

Step 2. According to user requirements, the data center calculates a demand configuration scheme according to the data center virtual machine occupation, virtual machine distribution, data center energy consumption cost, and data center maintenance cost.

Step 3. Based on the user's type and service demand preference, data center provides the user with a corresponding service plan, including response time, transmission speed, delay time, and service fee.

Step 4. Calculate the schedulable virtual machine resources and cooling energy consumption resources in this period according to the service demand parameters of each user, and input the energy scheduling model of the data center.

Step 5. The upper model aims to minimize the operating cost of the data center system and formulate a load scheduling plan for the lower model.

Step 6. The lower-layer model aims to minimize the total power consumption of the data load and minimize the total delay time of data processing. Considering the user's data service requirements and the load distribution of the virtual machine in the data center, formulate the performance of this layer's consumption requirements and upload to the upper model.

Step 7. After the upper-layer model receives the virtual machine scheduling strategy formulated by the lower-layer model, it ensures that the energy consumption strategy required by the lower-layer service and the upper-layer energy consumption scheduling plan have the smallest deviation. After several iterations, the data center energy supply scheduling plan is output when the result meets the requirements.

4.3.2. Scheduling Model Pseudo Code

(1) Algorithm input: number of particles M_1, M_2, N_1, N_2, maximum number of iterations T, inertia weight ω_1, acceleration factor C_1, C_2
(2) Algorithm output: global optimal position G_t, H_t, $D(G_t)$, $C(H_t)$
(3) $X_i = (e_i, L_i, m_i)$, randomly generate initialization position $X_i(0)$, speed $V_i(0)$, $Y_i = (P_t^L, G_t^L, P_t^{GT}, C_t^{GT}, C_t^{ET})$, randomly generate initialization position $Y_i(0)$, speed $U_i(0)$, set the particle best position $P_i^{\text{best}} = X_i(0)$, $O_i^{\text{best}} = Y_i(0)$
(4) $n = 0$
(5) while $n < T$
(6) for $i = 1$ to M_1 do
(7) for $j = 1$ to M_2 do
(8) Calculate $V_{i,n+1}^j$ according to $V_{i,n+1}^j = wV_{i,n}^j + c_1 r_{i,n}^j (P_{i,n}^j - X_{i,n}^j) + c_2 R_{i,n}^j (G_n^j - X_{i,n}^j)$
(9) if $-V_{\max}^j < V_{i,n+1}^j < V_{\max}^j$
(10) Calculate $X_{i,n+1}^j = X_{i,n}^j + V_{i,n+1}^j$
(11) end for
(12) Calculate $D(X_i)$
(13) if $D(P_{i,n}) < D(X_{i,n+1})$
(14) $P_{i,n+1} = P_{i,n}$
(15) else
(16) $P_{i,n+1} = X_{i,n+1}$
(17) Calculate the data center energy consumption by e_i
(18) for $k = 1$ to N_1 do
(19) for $l = 1$ to N_2 do
Calculate $U_{i,n+1}^j$ according to $U_{i,n+1}^j = wU_{i,n}^j + c_1 r_{i,n}^j (Q_{i,n}^j - Y_{i,n}^j) + c_2 R_{i,n}^j (H_n^j - \mathrm{Y}_{i,n}^j)$
(20) if $-U_{\max}^j < U_{i,n+1}^j < U_{\max}^j$
(21) Calculate $Y_{i,n+1}^j = Y_{i,n}^j + U_{i,n+1}^j$
(22) end for

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Table 1: Basic electrical load and cooling load.

Time	Basic electric load (kW)	Cooling load (kW)
0	341.25	1200
1	325.78	1192
2	451.69	1177
3	341.96	1165
4	349.68	1176
5	485.44	1189
6	509.38	1250
7	418.06	1310
8	293.36	1409
9	471.67	1567
10	402.64	1652
11	506.57	1679
12	356.64	1677
13	495.21	1679
14	423.12	1665
15	373.89	1652
16	319.42	1574
17	300.15	1521
18	415.21	1379
19	527.52	1300
20	524.12	1297
21	493.13	1296
22	326.46	1263
23	489.5	1260

(23) Calculate $C(Y_i)$
(24) if $C(Q_{i,n}) < C(Y_{i,n+1})$
(25) $Q_{i,n+1} = Q_{i,n}$
(26) else
(27) $Q_{i,n+1} = Y_{i,n+1}$
(28) end for
(29) end for
(30) Find the best from $Q_{i,n+1}$ as H_{n+1}, calculate $C(H_t)$
(31) $n = n + 1$
(32) end while

5. Example Simulation

5.1. Example Parameters. In order to verify the validity of the model proposed, an energy hub of a data center is selected as a simulation example. The scheduling period is 24 hours a day, and the components included in the example are those described in the model. The basic electrical load (the electrical load consumed by the servers in the three service centers is not included) and the cooling load are shown in Table 1.

Among them, the data load of the data center is a random value between 60000 and 100000, and the power load consumed by the server varies according to the data load allocated by the service center. The data load lower-limit value of 60000 and the data load upper-limit value of 100000 are adjustable values, and the upper-limit value and lower-limit value of each moment can be different. The operating parameters of the equipment are shown in Table 2.

The energy purchase price is shown in Table 3.

Table 2: Equipment operating parameters.

Equipment	Efficiency	Cost (RMB/kW)	Output range (kW)
Gas turbine	0.4	0.041	[0, 1700]
Lithium bromide absorption chiller	0.95	0.035	[0, 1300]
Electric refrigerator	3	0.050	[0, 500]

Table 3: Energy purchase prices.

Category	Period		Price (Yuan/kWh)
Electricity	Peak hours	09 : 00–20 : 00	1.112
	Normal period	05 : 00–09 : 00	0.667
	Valley period	00 : 00–05 : 00	0.322
Natural gas	Peak hours	08 : 00–24 : 00	0.428
	Valley period	00 : 00–08 : 00	0.162

Table 4: Data center s' parameters.

Parameter	Data center one	Data center two	Data center three
Data load capacity (unit)	[0, 45000]	[0, 45000]	[0, 45000]
B (kW)	100	150	200
M_i (unit)	1500	1500	1500
K (kW/unit)	0.3	0.3	0.3
μ (unit/s)	30	30	30
Db (ms)	200	150	100

Table 5: Simulated data load.

Time	Data load (unit)
0	78075
1	78222
2	65831
3	75304
4	75032
5	63556
6	64462
7	77394
8	91664
9	74933
10	82036
11	71943
12	87136
13	72379
14	79288
15	86311
16	92058
17	94185
18	81379
19	68948
20	69188
21	72187
22	88154
23	71250

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Table 6: Data center load and server allocation.

Time (h)	Data center one	Data center two	Data center three
0	27380/1095	27733/1189	22962/1148
1	33516/1341	26747/1146	17959/898
2	28347/1134	26843/1151	10641/533
3	27788/1112	26065/1120	21451/1076
4	26750/1070	27713/1188	20569/1028
5	27562/1102	26134/1120	9860/493
6	27809/1113	28094/1205	8559/513
7	32410/1296	26653/1142	18331/917
8	31870/1275	33218/1425	26576/1330
9	27891/1116	25986/1114	21056/1053
10	33195/1356	26359/1135	22482/1124
11	27348/1094	28961/1241	15634/1009
12	31200/1248	30628/1313	25307/1265
13	28830/1153	27198/1166	16352/818
14	26699/1068	27324/1171	25265/1263
15	35298/1412	28185/1208	22829/1141
16	34315/1373	31979/1371	25764/1288
17	34073/1443	34792/1491	25320/1302
18	29011/1160	26270/1126	26098/1305
19	27992/1120	27396/1174	13560/1098
20	30765/1231	27493/1178	10930/547
21	25997/1040	26649/1142	19542/977
22	34234/1370	30647/1313	23273/1164
23	26615/1065	26292/1127	18343/917

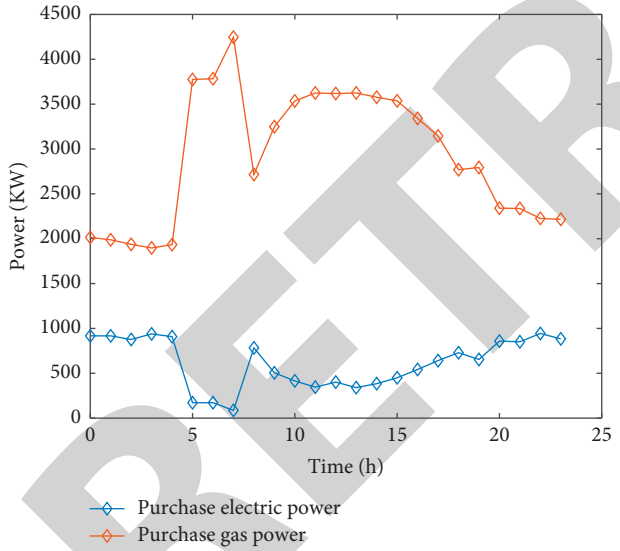

Figure 1: Situation of purchase electric power and gas power.

The relevant parameters of the data center are shown in Table 4:

In the example analysis, the 24-hour simulated data load values randomly generated are shown in Table 5.

5.2. Example Simulation. (1) After the example simulation, the data load distribution of each data center and the number of servers used are shown in Table 6.

The data before and after "/" in the table are the data load amount allocated by each data center and the number of servers used.

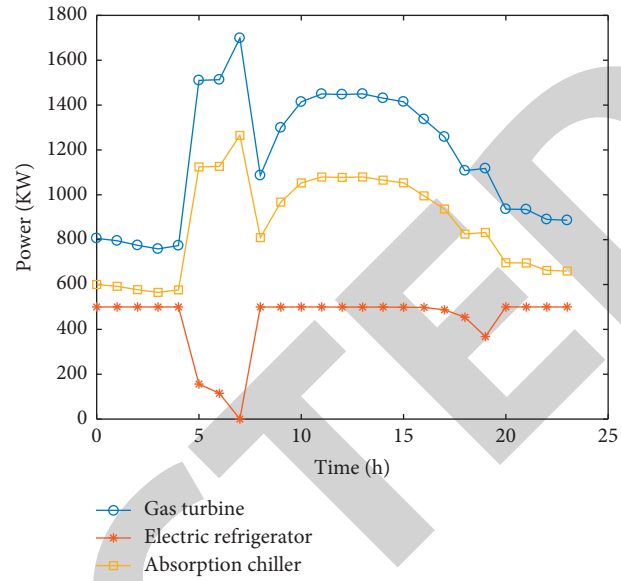

Figure 2: Output of each energy conversion equipment.

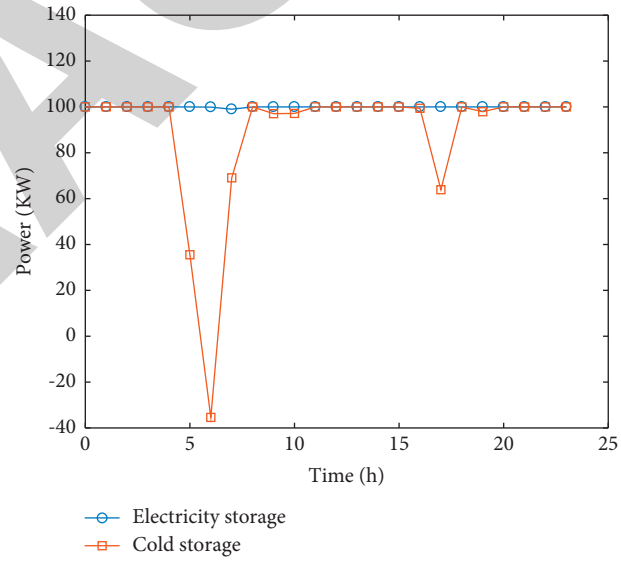

Figure 3: Output of electricity storage and cooling storage equipment.

Figures 1–3 show values of purchased electricity, gas power, output of various energy conversion equipment, and energy storage devices.

After calculation, the total cost of the data center energy hub system operation is 37,618.22 yuan, compared with using electricity alone, the overall energy consumption decreased by 10.2%.

6. Conclusion

As the scale and complexity of data center increases, their resource consumption is also increasing, and energy consumption optimization of data centers is an important and challenging research topic. In the process of data center operation, it is first necessary to ensure that the service delay

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speed of the data center is within an acceptable range to ensure the response speed and service level, and at the same time, it is necessary to minimize its operating cost and environmental impact. Existing researches are mostly analyzed from the perspective of energy consumption, and less consideration is given to the perspective of energy supply under the condition of ensuring the service level of the data center. A dual-objective data center energy consumption scheduling method considering electric energy and natural gas energy is proposed. Under the constraints of system operating power balance, unit output, server number, and delay, a dual-objective model is constructed. The objective function of the upper model is to minimize the system operating cost, and the objective function of the lower model is to allocate the total data load to each data center. Minimal power consumption and minimal overall latency for data processing. The particle swarm optimization algorithm is used to solve the dual-objective scheduling model, the corresponding flow chart and pseudocode are given, and simulation is carried out with MATLAB. The results show that under a certain service level, using electricity as the main component and natural gas as a supplement can reduce the overall energy consumption of the data center compared to simply using electricity.

The research on energy management of data center focuses more on the utilization and scheduling of the same kind of energy, but less on the energy efficiency under the consideration of task allocation, energy price, and efficiency output. The main contribution of this paper is to build a data center energy scheduling model, and considered usage of variety of different types of energy and mechanical efficiency of data center energy consumption problems at the same time, and it can provide a tentative exploration for follow-up study. The future research can focus on the energy consumption of data center under the condition of heterogeneous task, service requirements such as level of response and energy price fluctuation.

Data Availability

The data needed for this study are collected and sorted by the author and are available via email: yanglei@sdust.edu.cn.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Retraction

Retracted: Local Null-Controllability for Some Quasi-Linear Phase-Field Systems with Neumann Boundary Conditions by one Control Force

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] S. Shi and D. Zhang, "Local Null-Controllability for Some Quasi-Linear Phase-Field Systems with Neumann Boundary Conditions by one Control Force," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7645304, 16 pages, 2022.

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Research Article

Local Null-Controllability for Some Quasi-Linear Phase-Field Systems with Neumann Boundary Conditions by one Control Force

Shengzhu Shi and Dazhi Zhang

School of Mathematics, Harbin Institute of Technology, Harbin 150001, China

Correspondence should be addressed to Shengzhu Shi; 15b912007@hit.edu.cn

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In this article, we study the local null-controllability for some quasi-linear phase-field systems with homogeneous Neumann boundary conditions and an arbitrary located internal controller in the frame of classical solutions. In order to minimize the number of control forces, we prove the Carleman inequality for the associated linear system. By constructing a sequence of optimal control problems and an iteration method based on the parabolic regularity, we find a qualified control in Hölder space for the linear system. Based on the theory of Kakutani's fixed point theorem, we prove that the quasi-linear system is local null-controllable when the initial datum is small and smooth enough.

1. Introduction

In this paper, we are concerned with the local null-controllability for some quasi-linear phase-field systems with Neumann boundary conditions by a control force acting on an arbitrary small open set $\omega \subset\subset \Omega$. Here $\Omega \subset \mathbb{R}^N$ $(N \geq 1)$ is a connected bounded domain with $C^{2,\theta}$ boundary $\partial\Omega$ for some $\theta \in (0,1)$. For a given $T > 0$, we consider the cylindrical domain $Q_T = \Omega \times (0,T)$ with lateral boundary $\Sigma_T = \partial\Omega \times (0,T)$, and by $n = n(x)$, we denote the outward unit normal vector to Ω at a point $x \in \partial\Omega$. Consider the following quasi-linear phase-field system:

$$\begin{aligned}
&w_t + l\psi_t - \sum_{i,j=1}^{N} \frac{\partial}{\partial x_j}\left(a_{ij}(w)\frac{\partial w}{\partial x_i}\right) + f(w,\psi) = g, \quad \text{in } Q_T,\\
&\psi_t - \Delta\psi + h(\psi) + rw = 0, \quad \text{in } Q_T,\\
&\frac{\partial w}{\partial n_A} = \sum_{i,j=1}^{N} a_{ij}(w) n_j \frac{\partial w}{\partial x_i} = 0, \frac{\partial \psi}{\partial n} = 0, \quad \text{on } \Sigma_T,\\
&w(x,0) = w_0(x), \psi(x,0) = \psi_0(x), \quad \text{in } \Omega,
\end{aligned} \tag{1}$$

where $l \in \mathbb{R}$, $l \neq 0$ is a constant, $r \in C^{\theta,\theta/2}(\overline{Q_T})$ and there exists a constant r_0 such that $|r| \geq r_0 > 0$ in $\omega \times (0,T)$, w is the temperature function while ψ is the phase-field function, the initial datum (w_0, ψ_0) is given in $(C^{2+\theta}(\overline{\Omega}))^2$. And $g(x,t)$ is a control function in the space

$$\mathcal{U}(\omega) = \left\{g(x,t) \in C^{\theta,\theta/2}(\overline{Q_T}) \colon \operatorname{supp} g \subset \overline{\omega} \times [0,T]\right\}. \tag{2}$$

Besides, we assume that $f(\cdot,\cdot)\colon \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ is a C^2 function with $f(0,0) = 0$, $h(\cdot)\colon \mathbb{R} \longrightarrow \mathbb{R}$ is a C^2 function with $h(0) = 0$, $a_{ij}(\cdot)\colon \mathbb{R} \longrightarrow \mathbb{R}$ are C^2 functions satisfying $a_{ij} = a_{ji}$ and the uniform parabolic condition, i.e., there exist constants $0 < \tilde{\Lambda} < \Lambda$ such that

$$\tilde{\Lambda}|\xi|^2 \leq \sum_{i,j=1}^{N} a_{ij}(\zeta)\xi_i\xi_j \leq \Lambda|\xi|^2, \ \forall \zeta \in \mathbb{R}, \ \xi \in \mathbb{R}^N. \tag{3}$$

In addition, we put

$$A = \sum_{i,j=1}^{N} \sup_{|\zeta|\le 1} \left(\left|a_{ij}(\zeta)\right|^2 + \left|\left(a_{ij}\right)'(\zeta)\right|^2 \right) + \sup_{|\eta|\le 1} \left|h'(\eta)\right|^2 + \sup_{||\zeta|\le 1, |\eta|\le 1} \left(\left|\frac{\partial}{\partial \zeta} f(\zeta,\eta)\right|^2 + \left|\frac{\partial}{\partial \eta} f(\zeta,\eta)\right|^2 \right) + 1. \tag{4}$$

Phase-field systems model a large amount of physical phase transition phenomena. Usually, the phase-field function ψ describes the level of liquid solidification $(l > 0)$ or solid crystallization $(l < 0)$. In particular, the quasi-linear system (1) describes a kind of phenomenon where heat conduction coefficients a_{ij} depend on the temperature w in a manner as $a_{ij} = a_{ij}(w)$ in the phase transition process. Different from Dirichlet boundary conditions which mean the phase on the boundary should be maintained, Neumann boundary conditions in system (1) describe that there is no flux of phases at the boundary. We refer to [1, 2] and the references therein for more detailed descriptions about the model.

In recent years, lots of researchers have focused on addressing the controllability problems of linear and semilinear equations. For example, Barbu [3] investigated the local controllability of the phase-field system with two control forces and gave the observability estimate for the adjoint system with the global Carleman inequality established in [4]. The work of [3] illuminates us to expand the results of partial differential equations (a variety of results have been established, see for instance [5–10]) to coupled systems [11, 12] which model real physical or biological phenomena. In addition, controlling a system with a minimum number of forces is a common problem in the control theory [13, 14]. From this point of view, Ammar Khodja etc. gave the Carleman inequality for the adjoint system by constructing a suitable functional Λ with suitable weights (see Lemma 3.4 in [13]). It is worth noticing that their results are based on the Carleman inequality given in [15] which makes it possible to improve the regularity of the control function. This method has also been applied to solve the null-controllability for some general reaction-diffusion systems which arise in mathematical biology in [16]. Observing that [13] considered the system on a sub-domain of $\mathbb{R}^N$ with $1 \le N < 6$, González-Burgos and Pérez-García [17] considered a more general case with an arbitrary $N \ge 1$ and the nonlinearity $f = f(u, \nabla u, \phi, \nabla\phi)$. They used a method called strategy of fictitious control functions to construct a control function $g \in L^r(Q_T)$, $\forall r \ge 2$. Furthermore, [18] studied the case of unbounded domains. In addition, [11] studied a phase-field system with Neumann boundary conditions and showed the relationship between the optimal control and the controllability.

However, few work has been done to address the controllability of the quasi-linear form such as (1). The main problem is that the generalized solution of the quasi-linear system is not good enough, which makes the fixed point theorem not applicable. To overcome this difficulty, we would like to recall some work on the quasi-linear parabolic equation. To our knowledge, [19] proved the local null-controllability of a quasi-linear diffusion equation in one spacial dimension with the Sobolev embedding relation $L^\infty(0,T; H_0^1(\Omega)) \subseteq L^\infty(\Omega \times (0,T))$ which is only valid for one spacial dimension. And for the multidimensional case, [20] analyzed the controllability in the frame of classical solutions and gave a control in the Hölder space with given initial datum of high regularity and small enough. Enlightened by [19, 20], we also investigate the problem in the frame of classical solutions, while the coupled systems make the case more complex.

As for boundary conditions, it is necessary to notice that different boundary conditions describe different physical phenomena, however, there is little difference on mathematic controllability discussion. Thanks to the study in [21], we can find that the Carlemen inequality with Neumann boundary conditions has an additional weight function compared to the one with Dirichlet boundary conditions. Since there are abundant discussions on the case with homogeneous Dirichlet boundary conditions, we pay attention to the system with homogeneous Neumann boundary conditions. Moreover, all of our results established in this paper are valid for homogeneous Dirichlt boundary conditions.

As introduced in [22], in the general case, the observability for the adjoint system implies the controllability for the original system. To prove this, we pay attention to the variational method introduced in [4, 21]. We extend the method in [4] from the case of the parabolic equation to the case of coupled systems. Moreover, our adjoint system is different from the usual one because of the different optimal control problem.

The paper is organized as follows. Section 2 introduces a list of notations and presents preliminaries. In Section 3, we establish a Carleman inequality for the phase-field system which plays a key role in minimizing the number of control forces. In Section 4, we give an observability estimate for the adjoint system. In Section 5, we obtain a qualified control in $L^2(Q_T)$ by constructing a sequence of optimal control problems. Then we prove the control function belongs to $C^{\theta,\theta/2}(\overline{Q_T})$ by an iteration method based on the parabolic regularity and the embedding theorem. Finally, by utilizing the Kakutani's fixed point theorem, we prove that the quasi-linear system is local null-controllable when the initial datum is small and smooth enough in Section 6.

2. Preliminaries

In this section, we present some preliminaries. We first introduce some results on the existence, uniqueness and regularity of the solution for the associated linear phase-field system

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$$
\begin{aligned}
&L_1(w,\psi) = w_t + l\psi_t - \sum_{i,j=1}^{N} \frac{\partial}{\partial x_j}\left(b_{ij}(x,t)\frac{\partial w}{\partial x_i}\right) + qw + d\psi = g, \quad \text{in } Q_T,\\
&L_2(w,\psi) = \psi_t - \Delta\psi + e\psi + rw = 0, \quad \text{in } Q_T,\\
&\frac{\partial w}{\partial n_B} = \sum_{i,j=1}^{N} b_{ij}(x,t) n_j \frac{\partial w}{\partial x_i} = 0, \frac{\partial \psi}{\partial n} = 0, \quad \text{on } \Sigma_T,\\
&w(x,0) = w_0(x), \psi(x,0) = \psi_0(x), \quad \text{in } \Omega,
\end{aligned}
\tag{5}
$$

where $g \in \mathcal{U}(\omega)$ is a control function to be determined, $|r| \geq r_0 > 0$ in $\omega \times (0,T)$, $b_{ij}(\cdot,\cdot) \in C^{1+\theta,\theta/2}(\overline{Q_T})$ satisfy $b_{ij} = b_{ji}$ and the uniform parabolic condition, i.e., there exist constants $0 < \widetilde{\Lambda} \leq \Lambda$ such that

$$
\widetilde{\Lambda}|\xi|^2 \leq \sum_{i,j=1}^{N} b_{ij}(x,t)\xi_i\xi_j \leq \Lambda|\xi|^2, \ \forall (x,t) \in Q_T, \ \xi \in \mathbb{R}^N, \tag{6}
$$

and $q, d, e, r \in C^{\theta,\theta/2}(\overline{Q_T})$. In what follows, we denote

$$
\begin{aligned}
B = 1 + \sum_{i,j=1}^{N} \left\|b_{ij}\right\|_{C^{1+\theta,\theta/2}(\overline{Q_T})} + \|q\|_{C^{\theta,\theta/2}(\overline{Q_T})} + \|d\|_{C^{\theta,\theta/2}(\overline{Q_T})}\\
+ \|e\|_{C^{\theta,\theta/2}(\overline{Q_T})} + \|r\|_{C^{\theta,\theta/2}(\overline{Q_T})}.
\end{aligned}
\tag{7}
$$

Since l is a constant, without loss of generality, we assume $l > 0$ in the following demonstration.

We use standard notations $L^p(Q_T)$, $W^{k,p}(Q_T)$, $W_r^{2,1}(Q_T)$, $H^1(Q_T)$ in Sobolev space for the L^p estimate and $C^{\theta,\theta/2}(\overline{Q_T})$ in Hölder space for the Schauder estimate (for more information, one can see [23]). Moreover, we also need the following Hilbert spaces in [11].

$$
\begin{aligned}
V &= \left\{ f \in H^2(\Omega) : \frac{\partial f}{\partial n} = 0 \text{ on } \partial\Omega \right\},\\
V_B &= \left\{ f \in H^2(\Omega) : \frac{\partial f}{\partial n_B} = 0 \text{ on } \partial\Omega \right\},
\end{aligned}
\tag{8}
$$

and the compatibility condition in [24, 25].

$$
\begin{aligned}
&\frac{\partial w}{\partial n_B}(x,0) = \frac{\partial w_0}{\partial n_B}(x) = 0,\\
&\frac{\partial \psi}{\partial n}(x,0) = \frac{\partial \psi_0}{\partial n}(x) = 0, \text{ on } \partial\Omega\ .
\end{aligned}
\tag{9}
$$

In the sequel, the symbols c, C stand for various positive constants depending on different parameters and the values may change.

By analogy with the proof of Theorem 3.1.2 and Theorem 3.4.2 in [23], we have the following lemma.

Lemma 1. *If $g \in L^2(Q_T)$, $(w_0, \psi_0) \in (H^1(\Omega))^2$, $b_{i,j} \in C^{1+\theta,\theta/2}(\overline{Q_T})$ satisfy $b_{i,j} = b_{j,i}$ and the uniform parabolic condition (6), $q, d, e, r \in C^{\theta,\theta/2}(\overline{Q_T})$, there exists a unique weak solution $(w,\psi) \in (W_2^{2,1}(Q_T))^2$ of the system (5) satisfying the estimate*

$$
\begin{aligned}
\|w\|_{W_2^{2,1}(Q_T)} + \|\psi\|_{W_2^{2,1}(Q_T)} \leq \exp(CB)\\
\left(\|w_0\|_{H^1(\Omega)} + \|\psi_0\|_{H^1(\Omega)} + \|g\|_{L^2(Q_T)}\right),
\end{aligned}
\tag{10}
$$

where $C = C(\Omega, N, l, T, \Lambda, \widetilde{\Lambda})$ and B is given in (7).

By recalling the L^p theory of linear parabolic equations of second order (see, for instance, Theorem 6.4 in [26], Theorem 9.2.2 and Theorem 9.2.4 in [23]), we give the result on the L^p estimate.

Lemma 2. *For any $p \geq 2$, $g \in L^p(Q_T)$, $w_0 \in W^{2-2/p,p}(\Omega) \cap V_B$, $\psi_0 \in W^{2-2/p,p}(\Omega) \cap V$, $b_{i,j} \in C^{1+\theta,\theta/2}(\overline{Q_T})$ satisfy $b_{i,j} = b_{j,i}$ and the uniform parabolic condition (6), $q, d, e, r \in C^{\theta,\theta/2}(\overline{Q_T})$, there exists a unique strong solution $(w,\psi) \in (W_p^{2,1}(Q_T))^2$ of the system (5) satisfying the estimate*

$$
\begin{aligned}
\|w\|_{W_p^{2,1}(Q_T)} + \|\psi\|_{W_p^{2,1}(Q_T)} \leq \exp(CB)\\
\left(\|w_0\|_{W^{2-2/p,p}(\Omega)} + \|\psi_0\|_{W^{2-2/p,p}(\Omega)} + \|g\|_{L^p(Q_T)}\right),
\end{aligned}
\tag{11}
$$

where $C = C(\Omega, N, l, p, T, \Lambda, \widetilde{\Lambda})$ and B is given in (7).

If we improve the regularity of g and the initial datum (w_0, ψ_0) in Lemma 2, we can obtain the following Schauder estimate.

Lemma 3. *Let $\theta \in (0,1)$ be an arbitrary fixed constant, $b_{i,j} \in C^{1+\theta,\theta/2}(\overline{Q_T})$ satisfy $b_{i,j} = b_{j,i}$ and the uniform parabolic condition (6), $q, d, e, r \in C^{\theta,\theta/2}(\overline{Q_T})$. If $g \in C^{\theta,\theta/2}(\overline{Q_T})$, $(w_0, \psi_0) \in (C^{2+\theta}(\overline{\Omega}))^2$ satisfy the compatibility condition (9), there exists a unique classical solution $(w,\psi) \in (C^{2+\theta,1+\theta/2}(\overline{Q_T}))^2$ of the system (5) satisfying the estimate*

$$
\begin{aligned}
\|w\|_{C^{2+\theta,1+\theta/2}(\overline{Q_T})} + \|\psi\|_{C^{2+\theta,1+\theta/2}(\overline{Q_T})} \leq \exp(CB)\\
\left(\|w_0\|_{C^{2+\theta}(\overline{\Omega})} + \|\psi_0\|_{C^{2+\theta}(\overline{\Omega})} + \|g\|_{C^{\theta,\theta/2}(\overline{Q_T})}\right),
\end{aligned}
\tag{12}
$$

where $C = C(\Omega, N, l, \theta, T, \Lambda, \widetilde{\Lambda})$ and B is given in (7).

The proof of this Lemma is a standard consequence of the classical Schauder estimate theory. For more information, one can see Theorem 4.2, Theorem 5.1 in [26], Theorem 7.2.24 in [23] and Theorem 3.4 in [24]. In addition, the usual Schauder estimate always includes a maximum norm of the solution on

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the right-hand side. We use the Moser iteration ([23]) and the result in Lemma 1 to estimate the maximum norm.

Finally, we introduce the embedding theorem of the space $W_r^{2,1}(Q_T)(r>1)$ introduced in [20, 27].

Lemma 4. *Let N be a positive integer and $r>1$, then the following continuous embedding holds:*

(1) If $N+2>2r$, then $W_r^{2,1}(Q_T) \longrightarrow L^{r^*}(Q_T)$, where $r^* = (N+2)r/(N+2-2r)$.

(2) If $N+2=2r$, then $W_r^{2,1}(Q_T) \longrightarrow L^s(Q_T)$ for any $s>1$.

(3) If $\theta = 2-((N+2)/r)$ is not an integer, then $W_r^{2,1}(Q_T) \longrightarrow C^{\theta,\theta/2}(\overline{Q_T})$.

3. Carleman Inequality

In this section, we give a Carleman inequality for the adjoint system associated to the linear phase-filed system (5) based on the strategy developed in [21]. We need to notice that, unlike the usual form, the adjoint system we construct is not homogeneous, which is necessary because of the different optimal control problem we give in Section 5.

Let us consider the following adjoint system associated to (5)

$$\begin{aligned} L_1^*(v,\varphi) &= -v_t - \sum_{i,j=1}^{N}\frac{\partial}{\partial x_i}\left(b_{ij}(x,t)\frac{\partial v}{\partial x_j}\right) + qv + r\varphi = g_1, \quad \text{in } Q_T,\\ L_2^*(v,\varphi) &= -\varphi_t - lv_t - \Delta\varphi + dv + e\varphi = g_2, \quad \text{in } Q_T,\\ \frac{\partial v}{\partial n_B} &= \sum_{i,j=1}^{N} b_{ij}(x,t)n_i\frac{\partial v}{\partial x_j} = 0, \frac{\partial \varphi}{\partial n} = 0, \quad \text{on } \Sigma_T,\\ v(x,T) &= v_T(x), \varphi(x,T) = \varphi_T(x), \quad \text{in } \Omega. \end{aligned} \tag{13}$$

Following [21], let us introduce some weight functions with parameter $\lambda>0$ as follows:

$$\begin{aligned} \rho(x,t) &= \frac{e^{\lambda\beta(x)}}{t(T-t)},\\ \widetilde{\rho}(x,t) &= \frac{e^{-\lambda\beta(x)}}{t(T-t)},\\ \alpha(x,t) &= \frac{m(x)}{t(T-t)},\\ \widetilde{\alpha}(x,t) &= \frac{\widetilde{m}(x)}{t(T-t)}, \end{aligned} \tag{14}$$

where $m(x) = e^{\lambda\beta(x)} - e^{2\lambda\|\beta\|}$ and $\widetilde{m}(x) = e^{-\lambda\beta(x)} - e^{2\lambda\|\beta\|}$, the function $\beta(\cdot)\in C^2(\overline{\Omega})$ satisfies

$$\beta(\cdot)>0 \text{ in } \Omega, \beta(\cdot)=0 \text{ on } \partial\Omega \text{ and } \min\{|\nabla\beta(\cdot)|,\ x\in\Omega/\omega_0\}>0, \tag{15}$$

with $\omega_0 \subset\subset \omega$ and $\|\beta\| = \|\beta(\cdot)\|_{C(\overline{\Omega})}$.

For simplicity, we define a family of weight functions $u_k = s^k\rho^k(e^{2s\alpha} + e^{2s\widetilde{\alpha}})$ $(k=0,1,2\cdots)$ with parameter $s>0$ and $\alpha, \widetilde{\alpha}, \rho, \widetilde{\rho}$ defined in (14). With above weight functions, we have a modified Carleman inequality for Neumann boundary value problems such as

$$\begin{aligned} \frac{\partial z}{\partial t} - \sum_{i,j=1}^{N}\frac{\partial}{\partial x_j}\left(b_{ij}(x,t)\frac{\partial z}{\partial x_i}\right) &= \widetilde{g}(x,t), \quad \text{in } Q_T,\\ \frac{\partial z}{\partial n_B} = \sum_{i,j=1}^{N} b_{ij}(x,t)n_j\frac{\partial z}{\partial x_i} &= 0, \quad \text{on } \Sigma_T,\\ z(x,0) &= z_0(x), \quad \text{in } \Omega, \end{aligned} \tag{16}$$

where $\widetilde{g}\in L^2(Q_T)$, $z_0\in H^1(\Omega)$ and the coefficients fulfill conditions (6) and (7).

Lemma 5. *There exists a constant $\lambda_0 = \lambda_0(B)\geq 1$ such that for any $\lambda\geq\lambda_0$ there exists a constant $s_0 = s_0(\lambda)\geq 1$ such that for every $s\geq s_0$, the solution of (16) satisfies the inequality*

$$\begin{aligned} \delta(k,z) &= \iint_{Q_T}\left(u_{k-1}\left(|z_t|^2 + |\Delta z|^2\right) + u_{k+1}|\nabla z|^2 + u_{k+3}z^2\right)\mathrm{d}x\mathrm{d}t\\ &\leq Ce^{C\lambda}B^2\left(\iint_{Q_T} u_k\widetilde{g}^2\mathrm{d}x\mathrm{d}t + \iint_{\omega_0\times(0,T)} u_{k+3}z^2\mathrm{d}x\mathrm{d}t\right), \end{aligned} \tag{17}$$

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where $k = 0, 1, 2\cdots$, $u_{-1} = s^{-1}\rho^{-1}(e^{2s\alpha} + e^{2s\widetilde{\alpha}})$, *the constant* λ_0 *depends continuously on* B, *the constant* s_0 *depends continuously on* λ *and the positive constant* C *is independent of* s.

Remark 1. In [21], Lemma 1.2 gives a detailed proof of the Carleman inequality (17) with $k = 0$. However, it can not be applied to our case directly because of the term lv_t (see the proof of Lemma 6). Replacing the auxiliary functions

$$\begin{aligned} w(x,t) &= e^{s\alpha}z(x,t), \\ \widetilde{w}(x,t) &= e^{s\widetilde{\alpha}}z(x,t) \end{aligned} \tag{18}$$

introduced in [21] with

$$\begin{aligned} w(x,t) &= \rho^{k/2}e^{s\alpha}z(x,t), \\ \widetilde{w}(x,t) &= \widetilde{\rho}^{k/2}e^{s\widetilde{\alpha}}z(x,t), \end{aligned} \tag{19}$$

and following the proof procedure of Lemma 1.2 in [21], one can prove Lemma 5. The method of constructing an auxiliary function is a usual technique in proving Carleman inequality (see, for instance, [15, Theorem 7.1, p.288]).

Applying Lemma 5 to the adjoint system (13), we get the following lemma.

Lemma 6. *Let* λ_0, s_0 *be the constants given in Lemma 5. Then, for every* $\lambda \geq \lambda_0$ *and*

$$s \geq s_1 = Ce^{C\lambda}\left(s_0 + \|q\|_{C(\overline{Q_T})}^{2/3} + \|d\|_{C(\overline{Q_T})}^{1/2} + \|e\|_{C(\overline{Q_T})}^{2/3} + \|r\|_{C(\overline{Q_T})}\right)B^2T^2, \tag{20}$$

the solution (v, φ) *of the adjoint system (13) satisfies the estimate*

$$\delta(1,v) + \delta(0,\varphi) \leq Ce^{C\lambda}B^4\left(\iint_{Q_T}\left(u_1g_1^2 + u_0g_2^2\right)\mathrm{d}x\mathrm{d}t + \iint_{\omega_0\times(0,T)}\left(u_4v^2 + u_3\varphi^2\right)\mathrm{d}x\mathrm{d}t\right). \tag{21}$$

Proof. We apply Lemma 5 to the first equation of the system (13) with $k = 1$, $\widetilde{g} = g_1 - r\varphi - qv$. This implies that there exists

$$s \geq s_{11} = \max\left\{s_0, Ce^{C\lambda}B^{2/3}\|q\|_{C(\overline{Q_T})}^{2/3}\frac{T^2}{4}\right\}, \tag{22}$$

such that

$$Ce^{C\lambda}B^2\|q\|_{C(\overline{Q_T})}^2u_1 \leq \frac{1}{2}u_4. \tag{23}$$

And as a consequence, we have

$$\delta(1,v) \leq Ce^{C\lambda}B^2\left(\iint_{Q_T}u_1g_1^2\mathrm{d}x\mathrm{d}t + \|r\|_{C(\overline{Q_T})}^2\iint_{Q_T}u_1\varphi^2\mathrm{d}x\mathrm{d}t + \iint_{\omega_0\times(0,T)}u_4v^2\mathrm{d}x\mathrm{d}t\right). \tag{24}$$

Similarly, we apply Lemma 5 to the second equation of the system (13) with $k = 0$, $\widetilde{g} = g_2 + lv_t - dv - e\varphi$. Taking

$$s \geq s_{12} = \max\left\{s_0, Ce^{C\lambda}B^{2/3}\|e\|_{C(\overline{Q_T})}^{2/3}\frac{T^2}{4}\right\}, \tag{25}$$

we get

$$\begin{aligned} \delta(0,\varphi) &\leq Ce^{C\lambda}B^2\left(l^2\iint_{Q_T}u_0|v_t|^2\mathrm{d}x\mathrm{d}t + \iint_{Q_T}\left(u_0g_2^2 + u_0|dv\ |^2\right)\mathrm{d}x\mathrm{d}t + \iint_{\omega_0\times(0,T)}u_3\varphi^2\mathrm{d}x\mathrm{d}t\right) \\ &\leq Ce^{C\lambda}B^2\left(l^2\delta(1,v) + \iint_{Q_T}u_0g_2^2\mathrm{d}x\mathrm{d}t + \|d\|_{C(\overline{Q_T})}^2\iint_{Q_T}u_0v^2\mathrm{d}x\mathrm{d}t + \iint_{\omega_0\times(0,T)}u_3\varphi^2\mathrm{d}x\mathrm{d}t\right). \end{aligned} \tag{26}$$

Therefore, we deduce the result by choosing $s \geq s_1$. □

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To prove the main result of this section, we need the following estimates of u_k $(k = 0, 1, 2, \ldots)$, which will play a crucial role in our following demonstrations. □

Lemma 7. *For any $s \geq 1$, $\lambda \geq 1$, by the definition of ρ, we have $\rho \geq 4/T^2$, therefore we have $u_k \leq (T^2/4)u_{k+1}$ and*

$$\begin{aligned} \left|(u_k)_t\right| &\leq Ce^{C\lambda}\left(1+T^3\right)u_{k+2}, \\ \left|\nabla u_k\right| &\leq C\lambda\left(1+T^2\right)u_{k+1}, \\ \left|D^2 u_k\right| &\leq C\lambda^2\left(1+T^4\right)u_{k+2}, \end{aligned} \tag{27}$$

where $C = C(k, N, \|\beta\|)$, $D^2u = \sum_{i,j=1}^{N} \partial^2 u/\partial x_i \partial x_j$.

Proof. For $s \geq 1$, $\lambda \geq 1$ and $\beta(\cdot)$ given in (15), we have

$$\begin{aligned} \left|\rho_t\right| &= \left|\rho \frac{(2t-T)}{t(T-t)}\right| \leq T\rho^2, \\ |\nabla\rho| &= |\lambda\rho\nabla\beta(x)| \leq C\lambda\rho, \\ \left|D^2\rho\right| &= \left|\lambda\rho\left(\lambda\left(\sum_{i=1}^{N}\frac{\partial\beta}{\partial x_i}\right)^2 + D^2\beta\right)\right| \leq C\lambda^2\rho, \end{aligned} \tag{28}$$

provided by

$$\begin{aligned} |2t-T| &\leq T, \\ e^{\lambda\beta(x)} &\geq 1, \\ \frac{1}{t(T-t)} &\leq \frac{e^{\lambda\beta(x)}}{t(T-t)} = \rho. \end{aligned} \tag{29}$$

Again, in the same way, we get

$$\begin{aligned} \left|(\alpha+\tilde{\alpha})_t\right| &\leq Ce^{C\lambda}T\rho^2, \\ |\nabla(\alpha+\tilde{\alpha})| &\leq C\lambda\rho, \\ \left|D^2(\alpha+\tilde{\alpha})\right| &\leq C\lambda^2\rho, \end{aligned} \tag{30}$$

by observing $\rho(x,t) > \tilde{\rho}(x,t)$, $\alpha(x,t) > \tilde{\alpha}(x,t)$ and

$$|\alpha+\tilde{\alpha}| \leq \frac{2\left(e^{2\lambda\|\beta\|}-1\right)}{t(T-t)} \leq Ce^{2\lambda\|\beta\|}\rho = Ce^{C\lambda}\rho. \tag{31}$$

Thus, combined with (28) and (30), we get

$$\begin{aligned} (u_k)_t &\leq Ce^{C\lambda}T\left(u_{k+1}+u_{k+2}\right), \\ \left|\nabla u_k\right| &\leq C\lambda\left(u_k+u_{k+1}\right), \\ \left|D^2u_k\right| &\leq C\lambda^2\left(u_k+2u_{k+1}+\left(1+\frac{T^2}{4}\right)u_{k+2}\right), \end{aligned} \tag{32}$$

by virtue of

$$\begin{aligned} \left|D^2(f\cdot g)\right| &= \left|fD^2g + gD^2f + 2\sum_{i,j=1}^{N}\frac{\partial f}{\partial x_i}\frac{\partial g}{\partial x_j}\right| \\ &\leq \left|fD^2g + gD^2f\right| + 2N^2|\nabla f||\nabla g|. \end{aligned} \tag{33}$$

Finally, noting that $u_k \leq (T^2/4)u_{k+1}$, $\forall \quad k = 0, 1, 2\cdots$, we finish the proof of Lemma 7. □

There are plenty of methods to get the null-controllability by one control force. The method developed in [13] is to estimate the term $\iint_{\omega_0\times(0,T)} e^{-2\alpha}\varphi^2 \mathrm{d}x\mathrm{d}t$ by the term $\iint_{\omega\times(0,T)} e^{-r\alpha}v^2 \mathrm{d}x\mathrm{d}t$ for any $r \in [0, 2)$, which is deduced by constructing a weight function $\Lambda(t)$. And in [17], the authors used a different weight $e^{-2s\alpha}t^{-7}(T-t)^7$. Whichever the method is, the computation is complex but necessary. Enlightened by above two methods and the properties of weight functions in Lemma 7, we prove the Carleman inequality for the adjoint system (13) as the following proposition. □

Proposition 1. *Let λ_0, s_0 be the constants given in Lemma 5. Then, for every $\lambda \geq \lambda_0$, $s \geq s_1$ given in Lemma 6, the solution (v, φ) of the adjoint system (13) satisfies the estimate*

$$\begin{aligned} \delta(0,\varphi) + \delta(1,v) \leq Ce^{C(B+\lambda)} \\ \left(\iint_{Q_T} u_3\left(g_1^2+g_2^2\right)\mathrm{d}x\mathrm{d}t + \iint_{\omega\times(0,T)} u_7 v^2 \mathrm{d}x\mathrm{d}t\right). \end{aligned} \tag{34}$$

Proof. Let us begin with introducing a truncation function $\xi \in C_0^\infty(\Omega)$ satisfying

$$\begin{aligned} &0 \leq \xi \leq 1, \quad \text{in } \Omega, \\ &\xi = 1, \quad \text{in } \omega_0, \\ &\xi = 0, \quad \text{in } \frac{\Omega}{\omega}, \\ &|\nabla\xi| \leq C, \quad \text{in } \Omega, \\ &\frac{\nabla\xi}{\xi^{2/3}} = 6\hat{\xi}\nabla\hat{\xi} \in L^\infty(\Omega)^N, \\ &\text{and } \frac{D^2\xi}{\xi^{2/3}} = 30|\nabla\hat{\xi}|^2 + 6\hat{\xi}D^2\hat{\xi} \in L^\infty(\Omega), \end{aligned} \tag{35}$$

where $\xi = \hat{\xi}^6$ with $\hat{\xi} \in C_0^\infty(\Omega)$ satisfying (35), $\omega_0 \subset\subset \omega$ and C is a constant depending on ω_0 and ω.

Observe that $(u_3\xi v(\varphi+lv))(x,0) = (u_3\xi v(\varphi+lv))(x,T) = 0$ and integrate $(u_3\xi v(\varphi+lv))_t$ in Q_T. Integrating by parts, recalling the boundary conditions in (13) and replacing v_t, $(\varphi+lv)_t$ by their expressions given in (13), we see that

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$$\begin{aligned}\iint_{Q_T} ru_3\xi\varphi^2 \mathrm{d}x\mathrm{d}t &= -\iint_{Q_T} u_3\xi \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial \varphi}{\partial x_i}\mathrm{d}x\mathrm{d}t - l\iint_{Q_T} u_3\xi \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial v}{\partial x_i}\mathrm{d}x\mathrm{d}t \\ &\quad - \iint_{Q_T} \varphi \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial (u_3\xi)}{\partial x_i}\mathrm{d}x\mathrm{d}t - l\iint_{Q_T} v \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial (u_3\xi)}{\partial x_i}\mathrm{d}x\mathrm{d}t \\ &\quad - \iint_{Q_T} u_3\xi\big((q+lr+e)\varphi v + (d+lq)v^2\big)\mathrm{d}x\mathrm{d}t - \iint_{Q_T} \nabla(u_3\xi v)\cdot\nabla\varphi \mathrm{d}x\mathrm{d}t \\ &\quad - \iint_{Q_T} (u_3)_t\xi v(\varphi + lv)\mathrm{d}x\mathrm{d}t + \iint_{Q_T} u_3\xi(\varphi+lv)g_1\mathrm{d}x\mathrm{d}t + \iint_{Q_T} u_3\xi v g_2 \mathrm{d}x\mathrm{d}t \\ &= I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9.\end{aligned} \tag{36}$$

In order to estimate the first term on the right-estimate the first term on the right-hand side, we need the Young inequality with $\gamma > 0$, i.e.,

$$ab \le \gamma a^2 + \frac{1}{4\gamma}b^2,\ \forall\gamma > 0, \quad a > 0, \quad b > 0. \tag{37}$$

We will use the Young inequality with different coefficients $\gamma_i > 0$ for many times in the following estimates, and for simplicity, we do not point it out each time. Since the coefficients b_{ij} satisfy the condition (7), we have

$$\begin{aligned}|I_1| &\le BN^2\iint_{Q_T} u_3\xi|\nabla v||\nabla\varphi|\mathrm{d}x\mathrm{d}t \\ &\le \gamma_1\iint_{Q_T} u_1|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t + \frac{CB^2}{\gamma_1}\iint_{Q_T} u_5\xi|\nabla v|^2\mathrm{d}x\mathrm{d}t,\end{aligned} \tag{38}$$

by virtue of $|\partial v/\partial x_i| \le |\nabla v|$ and $|\partial\varphi/\partial x_j| \le |\nabla\varphi|$, $i, j = 1, 2, \ldots, N$. We deduce from the uniform parabolic condition (6) that

$$\begin{aligned}I_2 &= -l\iint_{Q_T} u_3\xi \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial v}{\partial x_i}\mathrm{d}x\mathrm{d}t \\ &\le -\tilde{\Lambda}l\iint_{Q_T} u_3\xi|\nabla v|^2\mathrm{d}x\mathrm{d}t \le 0.\end{aligned} \tag{39}$$

Since $u_3\xi = 0$ in Ω/ω, it appears that

$$\frac{\partial(u_3\xi)}{\partial x_i} = 0,\ i = 1, 2, \ldots, N \text{ on } \partial\Omega\ . \tag{40}$$

Integrating by parts again, we rewrite I_3 as

$$\begin{aligned}I_3 &= -\iint_{Q_T} \varphi \sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_j}\cdot\frac{\partial(u_3\xi)}{\partial x_i}\mathrm{d}x\mathrm{d}t \\ &= \iint_{Q_T} v \sum_{i,j=1}^{N} b_{ij}\frac{\partial\varphi}{\partial x_j}\cdot\frac{\partial(u_3\xi)}{\partial x_i}\mathrm{d}x\mathrm{d}t + \iint_{Q_T} v\varphi \sum_{i,j=1}^{N}\frac{\partial b_{ij}}{\partial x_j}\cdot\frac{\partial(u_3\xi)}{\partial x_i}\mathrm{d}x\mathrm{d}t \\ &\quad + \iint_{Q_T} v\varphi \sum_{i,j=1}^{N} b_{ij}\frac{\partial}{\partial x_j}\left(\frac{\partial(u_3\xi)}{\partial x_i}\right)\mathrm{d}x\mathrm{d}t \\ &= I_{31} + I_{32} + I_{33}.\end{aligned} \tag{41}$$

It follows from the estimates in Lemma 7 and (35) that

$$\left|\nabla(u_k\xi)\right| = \left|\xi\nabla u_k + u_k\nabla\xi\right| \le C\left(u_k\xi^{2/3} + \lambda\left(1+T^2\right)u_{k+1}\xi\right). \tag{42}$$

Thus the above inequality with $k = 3$ yields

$$|I_{31}| \le BN^2\iint_{Q_T} |v||\nabla\varphi|\left|\nabla(u_3\xi)\right|\mathrm{d}x\mathrm{d}t$$

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$$\begin{aligned}
&\le CB\iint_{Q_T}|v||\nabla\varphi|\left(\lambda\left(1+T^2\right)u_4\xi+u_3\xi^{2/3}\right)\mathrm{d}x\mathrm{d}t\\
&\le \gamma_1\iint_{Q_T}u_1\xi|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t+\frac{C\lambda^2B^2}{4\gamma_1}\left(1+T^4\right)\iint_{Q_T}u_7\xi v^2\mathrm{d}x\mathrm{d}t\\
&\quad+\gamma_1\iint_{Q_T}u_1\xi|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t+\frac{CB^2}{4\gamma_1}\iint_{Q_T}u_5\xi^{1/3}v^2\mathrm{d}x\mathrm{d}t\\
&\le 2\gamma_1\iint_{Q_T}u_1|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t+\frac{C\lambda^2B^2}{\gamma_1}\left(1+T^4\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{43}$$

Using similar arguments, we can obtain

$$\begin{aligned}
\left|I_{32}\right|&\le 2\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t+\frac{C\lambda^2B^2}{\gamma_2}\\
&\quad\left(1+T^8\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{44}$$

By analogy with (42), we get

$$\begin{aligned}
\left|D^2\left(u_k\xi\right)\right|&=\left|2\sum_{i,j=1}^{N}\frac{\partial u_k}{\partial x_i}\cdot\frac{\partial\xi}{\partial x_j}+\xi D^2u_k+u_kD^2\xi\right|\\
&\le 2N^2|\nabla\xi||\nabla u_k|+\xi|D^2u_k|+u_k|D^2\xi|\\
&\le C\left(u_k\xi^{2/3}+2\lambda\left(1+T^2\right)u_{k+1}\xi^{2/3}+\lambda^2\left(1+T^4\right)u_{k+2}\xi\right).
\end{aligned}\tag{45}$$

We deduce from (45) that

$$\begin{aligned}
\left|I_{33}\right|&\le CB\iint_{Q_T}|v||\varphi|\Bigg(u_3\xi^{\frac{2}{3}}+2\lambda\left(1+T^2\right)u_4\xi^{\frac{2}{3}}\\
&\quad+\lambda^2\left(1+T^4\right)u_5\xi\Bigg)\mathrm{d}x\mathrm{d}t\\
&\le 3\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t+\frac{C\lambda^4B^2}{\gamma_2}\\
&\quad\left(1+T^8\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{46}$$

Hence, by virtue of above estimates, we conclude that

$$\begin{aligned}
\left|I_3\right|\le\ & 2\gamma_1\iint_{Q_T}u_1|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t+5\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t\\
&+C\lambda^4B^2\left(1+T^8\right)\left(\frac{1}{\gamma_1}+\frac{1}{\gamma_2}\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{47}$$

Similar to the estimate of I_{31}, we can prove the estimate

$$\begin{aligned}
\left|I_4\right|&\le 2\gamma_3\iint_{Q_T}u_2|\nabla v|^2\mathrm{d}x\mathrm{d}t+\frac{C\lambda^2B^2}{\gamma_3}\\
&\quad\left(1+T^6\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{48}$$

It is easy to check that

$$\left|I_5\right|\le\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t+\frac{CB^2}{\gamma_2}\left(1+T^8\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.\tag{49}$$

Proceeding as previously, we have

$$\begin{aligned}
\left|I_6\right|&=\left|\iint_{Q_T}v\nabla\left(u_3\xi\right)\cdot\nabla\varphi\mathrm{d}x\mathrm{d}t\right|+\left|\iint_{Q_T}u_3\xi\nabla v\cdot\nabla\varphi\mathrm{d}x\mathrm{d}t\right|\\
&\le 3\gamma_1\iint_{Q_T}u_1|\nabla\varphi|^2\mathrm{d}x\mathrm{d}t+\frac{1}{4\gamma_1}\iint_{Q_T}u_5\xi|\nabla v|^2\mathrm{d}x\mathrm{d}t\\
&\quad+\frac{C\lambda^2}{\gamma_1}\left(1+T^4\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{50}$$

We bound I_7 with the above estimate for $(u_3)_t$ in Lemma 7 as follows

$$\begin{aligned}
\left|I_7\right|&\le C\left(1+T^3\right)\iint_{Q_T}u_5|\xi v\cdot(\varphi+lv)|\mathrm{d}x\mathrm{d}t\\
&\le\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t+\frac{Ce^{C\lambda}}{\gamma_2}\left(1+T^8\right)\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t.
\end{aligned}\tag{51}$$

It appears that

$$\begin{aligned}
\left|I_8\right|&\le\gamma_2\iint_{Q_T}u_3\varphi^2\mathrm{d}x\mathrm{d}t+CT^8\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t\\
&\quad+\left(\frac{1}{4}+\frac{1}{4\gamma_2}\right)\iint_{Q_T}u_3g_1^2\mathrm{d}x\mathrm{d}t,
\end{aligned}\tag{52}$$

and

$$\left|I_9\right|\le CT^8\iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t+\frac{1}{4}\iint_{Q_T}u_3g_2^2\mathrm{d}x\mathrm{d}t.\tag{53}$$

By virtue of above estimates for $I_1\sim I_9$ and the condition $|r(x,t)|\ge r_0>0$ in $\omega\times(0,T)$, we have the estimate for (36) as follows

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$$\iint_{\omega_0\times(0,T)} u_3\varphi^2\,dxdt \le \frac{6\gamma_1}{r_0}\iint_{Q_T} u_1|\nabla\varphi|^2\,dxdt + \frac{8\gamma_2}{r_0}\iint_{Q_T} u_3\varphi^2\,dxdt + \frac{2\gamma_3}{r_0}\iint_{Q_T} u_2|\nabla v|^2\,dxdt + \frac{CB^2}{\gamma_1 r_0}\iint_{Q_T} u_5\xi|\nabla v|^2\,dxdt + \frac{Ce^{C\lambda}B^2}{r_0}\left(\frac{1}{\gamma_1}+\frac{1}{\gamma_2}+\frac{1}{\gamma_3}\right)\iint_{\omega\times(0,T)} u_7v^2\,dxdt + \frac{1}{4r_0}\left(1+\frac{1}{\gamma_2}\right)\iint_{Q_T} u_3\left(g_1^2+g_2^2\right)dxdt. \tag{54}$$

Our following goal is to get rid of $\iint_{Q_T} u_5\xi|\nabla v|^2\,dxdt$ on the right-hand side of (54). By analogy with above discussions, we integrate $(u_5\xi v^2)_t$ in Q_T and integrate by parts, then it appears that

$$\begin{aligned}\tilde{\Lambda}\iint_{Q_T} u_5\xi|\nabla v|^2\,dxdt &\le \iint_{Q_T} u_5\xi\sum_{i,j=1}^{N} b_{ij}\frac{\partial v}{\partial x_i}\cdot\frac{\partial v}{\partial x_j}dxdt\\ &= -\iint_{Q_T} v\sum_{i,j=1}^{N} b_{ij}\frac{\partial(u_5\xi)}{\partial x_i}\cdot\frac{\partial v}{\partial x_j}\,dxdt - \iint_{Q_T} qu_5\xi v^2\,dxdt\\ &\quad - \iint_{Q_T} ru_5\xi\varphi v\,dxdt - \frac{1}{2}\iint_{Q_T}(u_5\xi)_t v^2\,dxdt + \iint_{Q_T} u_5\xi v g_1\,dxdt\\ &= J_1+J_2+J_3+J_4+J_5.\end{aligned} \tag{55}$$

Taking into account the estimate on I_{31} and observing the estimate for $|\nabla(u_k\xi)|$ in (42) with $k=5$, we obtain

$$|J_1| \le 2\gamma_4\iint_{Q_T} u_5\xi|\nabla v|^2\,dxdt + \frac{C\lambda^2B^2}{\gamma_4}\left(1+T^4\right)\iint_{\omega\times(0,T)} u_7v^2\,dxdt. \tag{56}$$

It is obvious that

$$|J_2| = \left|-\iint_{Q_T} qu_5\xi v^2\,dxdt\right| \le C\|q\|_{C(\overline{Q_T})}T^4\iint_{\omega\times(0,T)} u_7v^2\,dxdt. \tag{57}$$

And it follows that

$$|J_3| = \left|-\iint_{Q_T} ru_5\xi\varphi v\,dxdt\right| \le \gamma_5\iint_{\omega\times(0,T)} u_3\varphi^2\,dxdt + \frac{\|r\|^2_{C(\overline{Q_T})}}{4\gamma_5}\iint_{Q_T} u_7v^2\,dxdt \tag{58}$$

Furthermore, by virtue of the estimate for I_7 and Lemma 7, the following result holds

$$|J_4| = \left|-\frac{1}{2}\iint_{Q_T}(u_5\xi)_t v^2\,dxdt\right| \le Ce^{C\lambda}\left(1+T^8\right)\iint_{\omega\times(0,T)} u_7v^2\,dxdt. \tag{59}$$

Utilizing Young inequality again with $\gamma = 1/2$, we get

$$|J_5| = \left|\iint_{Q_T} u_5\xi v g_1\,dxdt\right| \le \frac{1}{2}\iint_{Q_T} u_3g_1^2\,dxdt + \frac{1}{2}\iint_{\omega\times(0,T)} u_7v^2\,dxdt. \tag{60}$$

Thus, from the estimates for $J_1 \sim J_5$, we can rewrite (55) as

$$\iint_{Q_T} u_5\xi|\nabla v|^2\,dxdt \le \frac{1}{\tilde{\Lambda}}\iint_{Q_T} u_3g_1^2\,dxdt + \frac{2\gamma_5}{\tilde{\Lambda}}\iint_{Q_T} u_3\xi\varphi^2\,dxdt + \frac{Ce^{C\lambda}B^2}{\tilde{\Lambda}}\left(\frac{4}{\tilde{\Lambda}}+\frac{1}{\gamma_5}\right)\left(1+T^4\right)\iint_{\omega\times(0,T)} u_7v^2\,dxdt, \tag{61}$$

by choosing $\gamma_4 = \tilde{\Lambda}/4$.

Combining (54) and (61) and Lemma 6, we finish the proof of this part by choosing $\gamma_1 = r_0/12Ce^{C\lambda}B^4$, $\gamma_2 = r_0/16Ce^{C\lambda}B^4$, $\gamma_3 = r_0/4Ce^{C\lambda}B^4$ and $\gamma_5 = (r_0\tilde{\Lambda}/4Ce^{C\lambda}B^4)\gamma_1$. □ □

4. Observability Estimate

This section addresses the study of the observability estimate for (13). Notice that, unlike the general case, the adjoint system (13) is not homogeneous and the observability estimate with u_k can not deduce the null controllability for the linear system (5). To obtain the qualified observability estimate, we need to construct a new sequence of weight functions

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$$\mu_k = s^k \rho_1^k \left(e^{2s\alpha_1} + e^{2s\widetilde{\alpha}_1} \right),\ k = 0, 1, 2, \ldots, \tag{62}$$

where

$$\rho_1 = \frac{e^{\lambda\beta(x)}}{T(T-t)},$$
$$\alpha_1 = \frac{m(x)}{T(T-t)}, \tag{63}$$
$$\widetilde{\alpha}_1 = \frac{\widetilde{m}(x)}{T(T-t)},$$

with the parameters given in Section 3.

Then, we have the following lemma.

Lemma 8. *For any $s \geq kT^2/2(e^{2\lambda\|\beta\|} - e^{\lambda\|\beta\|})$, we have*

$$Cs^k e^{-c_1 s} \leq u_k,\ \forall (x,t) \in \overline{\Omega} \times \left[\frac{T}{4}, \frac{3T}{4}\right],$$
$$Cs^k e^{-c_1 s} \leq \mu_k, \quad \forall (x,t) \in \overline{\Omega} \times \left[0, \frac{3T}{4}\right], \tag{64}$$
$$u_k \leq \mu_k \leq Ce^{C\lambda} s^k,\ \forall (x,t) \in \overline{Q_T},$$

where $C = C(k, T, \|\beta\|)$ and $c_1 = CT^{-2}(e^{2\lambda\|\beta\|} - e^{-\lambda\|\beta\|} - 1)$.

Proof. By analogy with the proof of Lemmas 1 and 2 in [6], we denote the auxiliary function with the variable $\tau \geqslant 0$ as follows

$$f_x^k(\tau) = As^k \frac{\left(e^{sB/\tau} + e^{sB_1/\tau}\right)}{\tau^k}, \quad \tau \in [0, \tau_{\max}], \tag{65}$$

where $A(x) > 0$, $B_1(x) < B(x) < 0$. Then, it can be verified that $\lim_{\tau \longrightarrow 0} f_x^k(\tau) = f_x^k(0) = 0$ and $f_x^k(\tau)$ is monotone increasing on $[0, -sB/k]$. Therefore by choosing $s \geqslant \max_{x \in \overline{\Omega}} \{k\tau_{\max}/-B(x)\}$, we can obtained that

$$f_x^k(\tau) \leq f_x^k(\tau_{\max}) \leq Cs^k. \tag{66}$$

In addition, we notice that $t(T-t) \leq T(T-t) \leq T^2 = \tau_{\max}$ for all $t \in [0, T]$, thus for $s \geq kT^2/2(e^{2\lambda\|\beta\|} - e^{\lambda\|\beta\|})$, we have

$$\begin{aligned} u_k &= f_x^k(t(T-t)) \leq \mu_k \\ &= f_x^k(T(T-t)) \leq f_x^k\left(T^2\right),\ \forall (x,t) \in \overline{Q_T}, \end{aligned} \tag{67}$$

and the other results can be obtained in the same way. □

Thus, with above estimates, the following result holds.

Proposition 2. *Let λ_0 be the constant given in Lemma 5 and s_1 be the constant given in Lemma 6. Then, for every $\lambda \geq \lambda_0$, $s \geq \max\{s_1, 3T^2/2(e^{2\lambda\|\beta\|} - e^{\lambda\|\beta\|})\}$, the solution (v, φ) of the adjoint system (6) satisfies the observability estimate*

$$\begin{aligned} &\int_\Omega |\varphi(x,0)|^2 dx + \int_\Omega |v(x,0)|^2 dx \leq Ce^{C(B+\lambda+s)} \\ &\left(\iint_{Q_T} \mu_3 \left(g_1^2 + g_2^2\right) dx dt + \iint_{\omega \times (0,T)} u_7 v^2 dx dt \right). \end{aligned} \tag{68}$$

Proof. Recalling (13) and integrating $((\varphi + lv)^2 + \delta v^2)_t$ in Ω, we can easily prove the estimate

$$\begin{aligned} &-\frac{1}{2}\frac{d}{dt}\int_\Omega \left((\varphi + lv)^2 + \delta v^2\right) dx \\ &\leq -\int_\Omega \left(|\nabla\varphi|^2 + l\nabla\varphi \cdot \nabla v + \delta\widetilde{\Lambda}|\nabla v|^2\right) dx \\ &+\left(\frac{1}{2}\|d\|_{C(\overline{Q_T})} + \frac{1}{2}\|e\|_{C(\overline{Q_T})} + \frac{1}{4}\right)\int_\Omega (\varphi + lv)^2 dx \\ &+\left(\frac{\delta}{2}\|r\|_{C(\overline{Q_T})} + \frac{1}{2}\|e\|_{C(\overline{Q_T})}\right)\int_\Omega \varphi^2 dx \\ &+\left(\|q\|_{C(\overline{Q_T})} + \frac{1}{2\delta}\|d\|_{C(\overline{Q_T})} + \frac{1}{2}\|r\|_{C(\overline{Q_T})} + \frac{\delta}{4}\right)\delta\int_\Omega v^2 dx \\ &+\int_\Omega g_1^2 dx + \int_\Omega g_2^2 dx, \end{aligned} \tag{69}$$

where δ is a constant to be fixed. By virtue of Young inequality with $\delta = l^2/4\widetilde{\Lambda}$, we get

$$-\int_\Omega \left(|\nabla\varphi|^2 + l\nabla\varphi \cdot \nabla v + \delta\widetilde{\Lambda}|\nabla v|^2\right) dx \leq 0. \tag{70}$$

And by virtue of

$$\begin{aligned} \int_\Omega \varphi^2 dx &\leq \int_\Omega \varphi^2 dx + \int_\Omega (\varphi + 2lv)^2 dx \\ &= 2\int_\Omega (\varphi + lv)^2 dx + 2l^2 \int_\Omega v^2 dx, \end{aligned} \tag{71}$$

we rewrite (69) as

$$\begin{aligned} -\frac{1}{2}\frac{d}{dt}\int_\Omega \left((\varphi + lv)^2 + \delta v^2\right) dx &\leq c_2 \int_\Omega \left((\varphi + lv)^2 + \delta v^2\right) dx \\ &+\int_\Omega g_1^2 dx + \int_\Omega g_2^2 dx, \end{aligned} \tag{72}$$

where $c_2 = CB$ and B is given in (7). Hence we get

$$\begin{aligned} &\frac{d}{dt}\left(e^{2c_2 t}\int_\Omega \left((\varphi + lv)^2 + \delta v^2\right) dx \right. \\ &\left. +2\int_0^t \int_\Omega \left(g_1^2(x,\tau) + g_2^2(x,\tau)\right) dx d\tau \right) \geq 0, \end{aligned} \tag{73}$$

for all $t \geq 0$. For simplicity, we set $((\varphi + lv)^2 + \delta v^2) = \varpi(x,t)$. By the second estimate in Lemma 8 and the standard energy estimate (see, for instance, [28]), we have

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$$\begin{aligned}\int_\Omega \varpi(x,0)\mathrm{d}x &\le e^{\frac{c_2}{2}T}\int_\Omega \varpi\Big(x,\frac{T}{4}\Big)\mathrm{d}x + 2\iint_{\Omega\times(0,T/4)}\big(g_1^2+g_2^2\big)\mathrm{d}x\mathrm{d}t\\ &\le \frac{2}{T}e^{\frac{3c_2}{2}T}\iint_{\Omega\times(T/4,3T/4)}\varpi(x,t)\mathrm{d}x\mathrm{d}t + 2\iint_{\Omega\times(0,3T/4)}\big(g_1^2+g_2^2\big)\mathrm{d}x\mathrm{d}t\\ &\le \frac{2}{T}e^{\frac{3c_2}{2}T}\iint_{\Omega\times(T/4,3T/4)}\varpi(x,t)\mathrm{d}x\mathrm{d}t + Cs^{-k}e^{c_1 s}\iint_{Q_T}\mu_k\big(g_1^2+g_2^2\big)\mathrm{d}x\mathrm{d}t.\end{aligned} \tag{74}$$

It follows from the first inequality in Lemma 8 and Proposition 1 that

$$\begin{aligned}&\iint_{\Omega\times(T/4,3T/4)}\varpi(x,t)\mathrm{d}x\mathrm{d}t\\ &\le \iint_{\Omega\times(T/4,3T/4)}\big(2\varphi^2+\big(2l^2+\delta\big)v^2\big)\mathrm{d}x\mathrm{d}t\\ &\le Ce^{c_1 s}\Big(\iint_{\Omega\times(T/4,3T/4)}\big(u_3\varphi^2+u_4v^2\big)\mathrm{d}x\mathrm{d}t\Big)\\ &\le Ce^{C(B+\lambda+s)}\Big(\iint_{Q_T}u_3\big(g_1^2+g_2^2\big)\mathrm{d}x\mathrm{d}t + \iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t\Big).\end{aligned} \tag{75}$$

Thus, by virtue of (74) and (75) and $u_k \le \mu_k$, we obtain the following estimate

$$\begin{aligned}&\int_\Omega |(\varphi+lv)(x,0)|^2\mathrm{d}x + \delta\int_\Omega |v(x,0)|^2\mathrm{d}x\\ &\le Ce^{C(B+\lambda+s)}\Big(\iint_{Q_T}\mu_3\big(g_1^2+g_2^2\big)\mathrm{d}x\mathrm{d}t + \iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t\Big),\end{aligned} \tag{76}$$

which ends the proof of the proposition with (71). □

5. Null-Controllability for the Linear System

In this section, we consider the null-controllability for the linear system (5). Firstly, we find a control function $g \in L^2(Q_T)$ with $\operatorname{supp} g \subset \overline{\omega}\times[0,T]$ such that

$$\omega(x,T) = \psi(x,T) = 0, \text{ in } \Omega, \tag{77}$$

by constructing a sequence of optimal control problems. Then, we prove that the control function belongs to $L^r(Q_T)$ $(r \ge 2)$ based on the parabolic regularity. Finally, by utilizing an iteration method and the embedding theorem, we find that the control function belongs to the space $\mathcal{U}(\omega)$.

Proposition 3. *Let λ_0 be the constant given in Lemma 5 and s_1 be the constant given in Lemma 6. For any $(\omega_0,\psi_0) \in (H^1(\Omega))^2$, $\lambda \ge \lambda_0$, $s \ge \max\{s_1, 9\cdot 7\cdot T^2/8(e^{2\lambda\|\beta\|}-e^{\lambda\|\beta\|})\}$, there exists a control $g \in L^2(Q_T)$ with $\operatorname{supp} g \subset \overline{\omega}\times[0,T]$ such that the corresponding solution (ω,ψ) of (5) satisfies*

$$\omega(x,T) = \psi(x,T) = 0, \quad \text{in}\Omega, \tag{78}$$

Moreover,

$$\begin{aligned}&\|\omega\|_{L^2(Q_T)} + \|\psi\|_{L^2(Q_T)} + \|g\|_{L^2(Q_T)}\\ &\le Ce^{C(B+\lambda+s)}\big(\|\omega_0\|_{L^2(\Omega)} + \|\psi_0\|_{L^2(\Omega)}\big).\end{aligned} \tag{79}$$

Proof. To pave a way for further numerical approximation, we consider the following optimal control problem, which is similar to that introduced by Fursikov and Imanuvilov [4] and used in [21, 29, 30]

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$$\begin{aligned}\operatorname{Min} J_k(g_1,g_2) &= \frac{1}{2}\iint_{Q_T}\left(\mu_3^k\right)^{-1}\left(w^2+\psi^2\right)\mathrm{d}x\mathrm{d}t\\ &+\frac{1}{2}\iint_{Q_T}\left(m_{1k}\left(u_7^k\right)^{-1}g_1^2+m_{2k}\left(u_7^k\right)^{-1}g_2^2\right)\mathrm{d}x\mathrm{d}t,\end{aligned} \tag{80}$$

subject to

$$\begin{aligned}&L_1(\omega,\psi)=g_1, L_2(\omega,\psi)=g_2, \text{ in } Q_T, \frac{\partial\omega}{\partial n_B}=\frac{\partial\psi}{\partial n}=0, \quad \text{on } \Sigma_T,\\ &\omega(x,0)=\omega_0(x), \psi(x,0)=\psi_0(x), \quad \text{in } \Omega,\end{aligned} \tag{81}$$

and the terminal constraints

$$\omega(x,T)=\psi(x,T)=0, \quad \text{in } \Omega, \tag{82}$$

in Banach space $W_2^{2,1}(Q_T)^2\times L^2(Q_T)^2$, where the parameters $\lambda\geq\lambda_0$, $s\geq\max\{s_1, 9\cdot 7\cdot T^2/8(e^{2\lambda\|\beta\|}-e^{\lambda\|\beta\|})\}$ are fixed, $\mu_3^k=s^3(e^{\lambda\beta(x)}/\tau_1)^3(e^{2sm(x)/\tau_1}+e^{2s\widetilde{m}(x)/\tau_1})$, $u_7^k=s^7\ (e^{\lambda\beta(x)}/\tau_2)^7\ (e^{2sm(x)/\tau_2}+e^{2s\widetilde{m}(x)/\tau_2})$ with $m(x)$, $\widetilde{m}(x)$ defined in (14) and

$$\begin{aligned}&\tau_1=T\left(T-t+\frac{T}{k}\right), \tau_2=\left(t+\frac{T}{k}\right)\left(T-t+\frac{T}{k}\right),\\ &m_{1k}=\begin{cases}1, & x\in\overline{\omega},\\ k, & x\in\dfrac{\Omega}{\overline{\omega}},\end{cases} \quad m_{2k}=k, \quad x\in\Omega.\end{aligned} \tag{83}$$

According to the classical theory about optimal control problem (see [31]), since the control function g_1, g_2 are imposed on the whole domain Q_T, it is easy to prove that, for any $(w_0,\psi_0)\in(H^1(\Omega))^2$, the optimal control problem (80)–(82) has a unique solution, which we denote by $(w_k,\psi_k,g_{1k},g_{2k})$. Applying the Lagrange principle to the optimal control problem, we get the following necessary optimality condition (see [31, 32]), i.e., for each k, there exists co-state function (v_k,φ_k) satisfying the homogeneous boundary conditions in (13) such that

$$\begin{aligned}&L_1(w_k,\psi_k)=g_{1k}, L_2(w_k,\psi_k)=g_{2k}, \quad \text{in } Q_T,\\ &L_1^*(v_k,\varphi_k)=\left(\mu_3^k\right)^{-1}w_k, L_2^*(v_k,\varphi_k)=\left(\mu_3^k\right)^{-1}\psi_k, \quad \text{in } Q_T,\\ &m_{1k}\left(u_7^k\right)^{-1}g_{1k}+v_k=0, m_{2k}\left(u_7^k\right)^{-1}g_{2k}+\varphi_k=0, \quad \text{in } Q_T,\\ &w_k(x,T)=0, \psi_k(x,T)=0, \quad \text{in } \Omega.\end{aligned} \tag{84}$$

Noting that

$$\begin{aligned}&\left(L_1^*(v_k,\varphi_k),w_k\right)_{L^2(Q_T)}+\left(L_2^*(v_k,\varphi_k),\psi_k\right)_{L^2(Q_T)}\\ &=\left(L_1(w_k,\psi_k),v_k\right)_{L^2(Q_T)}+\left(L_2(w_k,\psi_k),\varphi_k\right)_{L^2(Q_T)}\\ &-\int_\Omega\left(w_0v_k(x,0)+l\psi_0v_k(x,0)+\psi_0\varphi_k(x,0)\right)\mathrm{d}x,\end{aligned} \tag{85}$$

and taking into account (84), we obtain

$$\begin{aligned}J_k(g_{1k},g_{2k}) &= -\frac{1}{2}\int_\Omega\left(w_0v_k(x,0)+l\psi_0v_k(x,0)+\psi_0\varphi_k(x,0)\right)\mathrm{d}x\\ &\leq\frac{1}{2}\left(\|w_0\|_{L^2(\Omega)}+l\|\psi_0\|_{L^2(\Omega)}\right)\left(\int_\Omega|v_k(x,0)|^2\mathrm{d}x\right)^{1/2}\\ &+\frac{1}{2}\|\psi_0\|_{L^2(Q_T)}\left(\int_\Omega|\varphi_k(x,0)|^2\mathrm{d}x\right)^{1/2}\\ &\leq\left(\|w_0\|_{L^2(\Omega)}+(1+l)\|\psi_0\|_{L^2(\Omega)}\right)\left(\int_\Omega|v_k(x,0)|^2\mathrm{d}x+\int_\Omega|\varphi_k(x,0)|^2\mathrm{d}x\right)^{1/2}.\end{aligned} \tag{86}$$

Recalling Proposition 2 and the definition of m_{1k}, we get

$$\begin{aligned}&\int_\Omega|v_k(x,0)|^2\mathrm{d}x+\int_\Omega|\varphi_k(x,0)|^2\mathrm{d}x\\ &\leq Ce^{C(B+\lambda+s)}\left(\iint_{Q_T}\mu_3\left(\mu_3^k\right)^{-2}\left(w_k^2+\psi_k^2\right)\mathrm{d}x\mathrm{d}t+\iint_{\omega\times(0,T)}u_7m_{1k}^2\left(u_7^k\right)^{-2}g_{1k}^2\mathrm{d}x\mathrm{d}t\right)\\ &\leq Ce^{C(B+\lambda+s)}J_k(g_{1k},g_{2k}),\end{aligned} \tag{87}$$

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by virtue of $\mu_3 \le \mu_3^k$, $u_7 \le u_7^k$ which can be proved by analogy with Lemma 8 by noting

$$T(T-t) \le T\left(T-t+\frac{T}{k}\right) \le 2T^2,$$
$$t(T-t) \le \left(t+\frac{T}{k}\right)\left(T-t+\frac{T}{k}\right) \le \frac{9T^2}{4}. \tag{88}$$

Hence, it follows from (86) and (87) that

$$J_k(g_{1k}, g_{2k}) \le Ce^{C(B+\lambda+s)}\left(\|w_0\|_{L^2(Q_T)} + \|\psi_0\|_{L^2(Q_T)}\right)^2. \tag{89}$$

By virtue of (89), we have a subsequence $\left\{\hat{w}_k, \hat{\psi}_k, \hat{g}_{1k}, \hat{g}_{2k}, \hat{v}_k, \hat{\varphi}_k\right\}_{k=1}^{\infty}$ such that

$$\begin{aligned}
&\left(\hat{w}_k, \hat{\psi}_k\right) \to (w, \psi) \text{ weakly in } \left(L^2(Q_T)\right)^2, \left(\hat{v}_k, \hat{\varphi}_k\right) \\
&\quad \to (v, \varphi) \text{ weakly}, \quad \text{in } \left(L^2(Q_T)\right)^2, \\
&\hat{g}_{1k} \to g = 0 \text{ in } L^2((\Omega/\omega)\times(0,T)), \hat{g}_{2k} \to g_2 = 0, \quad \text{in } L^2(Q_T).
\end{aligned} \tag{90}$$

Moreover, by passing to the limit in (84), we obtain that the pair (w, ψ) is a solution of (5) satisfying

$$w(x,T) = \psi(x,T) = 0, \quad \text{in } \Omega, \tag{91}$$

with the control function $g_1 = g = -\chi_\omega u_7 v \in L^2(Q_T)$ and χ_ω is the characteristic function of ω. Finally, passing limit in (89) and taking into account the third inequality in Lemma 8, we obtain the estimate (79). □

Our following goal is to prove $g = -\chi_\omega u_7 v \in \mathcal{U}(\omega)$ by Lemma 3 (embedding theorem) and the parabolic regularity. □

Proposition 4. *Let λ_0 be the constant given in Lemma 5 and s_1 be the constant given in Lemma 6. For any $(w_0, \psi_0) \in (C^{2+\theta}(\overline{\Omega}))^2$ satisfying the compatibility condition (9), $\lambda \ge \lambda_{\max} = \max\{\lambda_0, \ln(2^{M^*+1}-2)/\|\beta\|\}$ and $s \ge s_{\max} = \max\{s_1, 7\cdot 2^{M^*+1}T^2/e^{\lambda\|\beta\|}-1\}$ (M^* is a fixed finite positive integer), there exists a control $g \in \mathcal{U}(\omega)$ such that the corresponding solution of (5) satisfies*

$$w(x,T) = \psi(x,T) = 0, \text{in } \Omega. \tag{92}$$

Moreover,

$$\|g\|_{C^{\theta,\theta/2}(\overline{Q_T})} \le Ce^{C(B+\lambda+s)}\left(\|w_0\|_{L^2(\Omega)} + \|\psi_0\|_{L^2(\Omega)}\right). \tag{93}$$

Proof. Let $s_m = (1-(1/2)^{(m+1)})s$, $\hat{s}_m = (1/2)^{(m+1)}s$, $m = 1, 2\cdots$, and define the following weight functions

$$\begin{aligned}
\hat{u}_{k,m} &= \left(s\underline{\rho}\right)^k\left(e^{2s_m\underline{\alpha}} + e^{2\hat{s}_m\widetilde{\underline{\alpha}}}\right), \\
\hat{\mu}_{k,m} &= \left(s\overline{\rho_1}\right)^k\left(e^{2\hat{s}_m\overline{\alpha_1}} + e^{2\hat{s}_m\overline{\widetilde{\alpha}_1}}\right),
\end{aligned} \tag{94}$$

where $\rho, \alpha, \widetilde{\alpha}$ are defined in (14), $\rho_1, \alpha_1, \widetilde{\alpha}_1$ are defined in (63) and $\underline{f}(t) = \min_{x\in\overline{\Omega}} f(x,t)$, $\overline{f}(t) = \max_{x\in\overline{\Omega}} f(x,t)$. Then, with $(\overline{w}, \psi, g)$, (v, φ) given in Proposition 3, we denote

$$\begin{aligned}
(g_1^*)_m &= L_1^*\left(\hat{u}_{7,m}v, \hat{u}_{7,m}\varphi\right), \\
(g_2^*)_m &= L_2^*\left(\hat{u}_{7,m}v, \hat{u}_{7,m}\varphi\right), \\
(g_1)_m &= L_1\left(\hat{\mu}_{3,m}^{-1}w, \hat{\mu}_{3,m}^{-1}\psi\right), \\
(g_2)_m &= L_2\left(\hat{\mu}_{3,m}^{-1}w, \hat{\mu}_{3,m}^{-1}\psi\right).
\end{aligned} \tag{95}$$

By analogy with Lemma 8, it can be verified that

$$\begin{aligned}
\hat{u}_{7,1}^2 &\le Cs^{11}\mu_3, \text{ for } s \ge \frac{11}{4}\frac{T^2}{e^{2\lambda\|\beta\|}-1}, \\
\hat{u}_{9,1}^2 &\le Cs^{14}u_4, \text{ for } s \ge \frac{14}{4}\frac{T^2}{e^{2\lambda\|\beta\|}-1}.
\end{aligned} \tag{96}$$

In addition, for each k, (v_k, φ_k), (w_k, ψ_k) given in Proposition 3, by virtue of Proposition 1, we have

$$\begin{aligned}
&\iint_{Q_T}\left(u_3\varphi_k^2 + u_4 v_k^2\right)\mathrm{d}x\mathrm{d}t \\
&\le Ce^{C(B+\lambda)}\left(\iint_{Q_T}\left(\mu_3^k\right)^{-1}\left(w_k^2+\psi_k^2\right)\mathrm{d}x\mathrm{d}t + \iint_{\omega\times(0,T)} u_7 v_k^2\mathrm{d}x\mathrm{d}t\right).
\end{aligned} \tag{97}$$

Thus, for $m = 1$, passing to the limit in (84) and (97), we see that

$$\begin{aligned}
\iint_{Q_T}(g_1^*)_1^2\mathrm{d}x\mathrm{d}t &= \iint_{Q_T}\left(\hat{u}_{7,1}L_1^*(v,\varphi) - \left(\hat{u}_{7,1}\right)_t v\right)^2\mathrm{d}x\mathrm{d}t \\
&\le \iint_{Q_T}\left(\hat{u}_{7,1}\mu_3^{-1}w\right)^2 + \left(\hat{u}_{9,1}v\right)^2\mathrm{d}x\mathrm{d}t \le C\left(\iint_{Q_T}\frac{\hat{u}_{7,1}^2}{\mu_3}\mu_3^{-1}w^2\mathrm{d}x\mathrm{d}t + \iint_{Q_T}\frac{\hat{u}_{9,1}^2}{u_4}u_4v^2\mathrm{d}x\mathrm{d}t\right) \\
&\le Ce^{C(B+\lambda+s)}\left(\iint_{Q_T}\mu_3^{-1}\left(w^2+\psi^2\right)\mathrm{d}x\mathrm{d}t + \iint_{\omega\times(0,T)}u_7v^2\mathrm{d}x\mathrm{d}t\right).
\end{aligned} \tag{98}$$

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Passing to the limit in (89) and estimating $(g_2^*)_1$ in the same way, we arrive at

$$\begin{aligned}&\left\|(g_1^*)_1\right\|_{L^2(Q_T)}+\left\|(g_2^*)_1\right\|_{L^2(Q_T)}\\&\quad\le Ce^{C(B+\lambda+s)}\left(\left\|w_0\right\|_{L^2(\Omega)}+\left\|\psi_0\right\|_{L^2(\Omega)}\right),\end{aligned}\tag{99}$$

for $s\ge\max\{s_1,(15/4)(T^2/e^{2\lambda\|\beta\|}-1)\}$. Moreover, similar to the result in Lemma 1, we get

$$\begin{aligned}&\left\|\hat{u}_{7,1}v\right\|_{W_2^{2,1}(Q_T)}+\left\|\hat{u}_{7,1}\varphi\right\|_{W_2^{2,1}(Q_T)}\\&\le e^{C(B+\lambda+s)}\left(\left\|(g_1^*)_1\right\|_{L^2(Q_T)}+\left\|(g_2^*)_1\right\|_{L^2(Q_T)}\right).\end{aligned}\tag{100}$$

By Lemma 4 with $r=2$, we have $W_2^{2,1}(Q_T)\longrightarrow L^{r_1}(Q_T)$ for

$$r_1=\begin{cases}2(N+2)/(N-2),\ N>2,\\ \text{any constant } c>1,\ N\le 2,\end{cases}\tag{101}$$

which implies

$$\begin{aligned}&\left\|\hat{u}_{7,1}v\right\|_{L^{r_1}(Q_T)}+\left\|\hat{u}_{7,1}\varphi\right\|_{L^{r_1}(Q_T)}\\&\le Ce^{C(B+\lambda+s)}\left(\left\|w_0\right\|_{L^2(\Omega)}+\left\|\psi_0\right\|_{L^2(\Omega)}\right).\end{aligned}\tag{102}$$

On the other hand, we find that

$$\begin{aligned}\iint_{Q_T}(g_1)_1^2\mathrm{d}x\mathrm{d}t&\le C\left(\iint_{Q_T}\frac{u_7}{\hat{\mu}_{3,1}^2}\chi_\omega u_7v^2\mathrm{d}x\mathrm{d}t+\iint_{Q_T}\frac{\hat{\mu}_{5,1}\mu_3}{\hat{\mu}_{3,1}^2}\mu_3^{-1}\left(w^2+l^2\psi^2\right)\mathrm{d}x\mathrm{d}t\right)\\&\le Ce^{C(B+\lambda+s)}\left(\left\|w_0\right\|_{L^2(\Omega)}+\left\|\psi_0\right\|_{L^2(\Omega)}\right),\ \text{for } s\ge\max\left\{s_1,\frac{4}{3}\frac{T^2}{e^{2\lambda\|\beta\|}-e^{\lambda\|\beta\|}}\right\}.\end{aligned}\tag{103}$$

By analogy with above estimates, we can arrive at

$$\begin{aligned}&\left\|\hat{\mu}_{3,1}^{-1}w\right\|_{L^{r_1}(Q_T)}+\left\|\hat{\mu}_{3,1}^{-1}\psi\right\|_{L^{r_1}(Q_T)}\\&\le Ce^{C(B+\lambda+s)}\left(\left\|w_0\right\|_{L^2(\Omega)}+\left\|\psi_0\right\|_{L^2(\Omega)}\right).\end{aligned}\tag{104}$$

For $m\ge 2$, It is easy to prove that

$$\begin{aligned}&\hat{u}_{7,m}\hat{\mu}_{3,m-1}\le Cs^7\mu_3,\ \text{for } s\ge\frac{7\cdot 2^mT^2}{\left(e^{\lambda\|\beta\|}-1\right)^2},\\&\hat{u}_{9,m}\le Cs^2\hat{u}_{7,m-1},\ \text{for } s\ge\frac{2^{m-1}T^2}{e^{2\lambda\|\beta\|}-1},\\&u_7\le C\hat{u}_{7,m-1}\hat{\mu}_{3,m},\ \text{for } \lambda\ge\frac{\ln\left(2^{m+1}-2\right)}{\|\beta\|},\\&\hat{\mu}_{5,m}\hat{\mu}_{3,m-1}\le Cs^2\hat{\mu}_{3,m}^2,\ \text{for } s\ge\frac{2^{m+1}T^2}{e^{2\lambda\|\beta\|}-e^{\lambda\|\beta\|}}.\end{aligned}\tag{105}$$

As noted in the proof of Proposition 4.1 in [20], there exists M^* such that $W^{2,1}_{r_{M^*-1}}(Q_T)\longrightarrow L^{r_{M^*}}(Q_T)$ and $W^{2,1}_{r_{M^*}}(Q_T)\longrightarrow C^{\theta,\theta/2}(\overline{Q_T})$. Thus, processing as previously and taking into account above estimates, we have $g=-\chi_\omega u_7v\in C^{\theta,\theta/2}(\overline{Q_T})$ with $\lambda\ge\lambda_{\max}=\max\{\lambda_0,\ln(2^{M^*+1}-2)/\|\beta\|\}$ and $s\ge s_{\max}=\max\{s_1,7\cdot 2^{M^*+1}T^2/e^{\lambda\|\beta\|}-1\}$ by the embedding theory and the parabolic regularity. □

6. Local Null-Controllability for the Quasi-Linear System

In this section, we show the local null-controllability of the quasi-linear phase-field system (1) by above propositions and the fixed point theorem.

As classical discussion shows (we refer to [33] for more detailed information), we can write

$$\begin{aligned}f(w,\psi)-f(0,0)&=\int_0^1\frac{\mathrm{d}}{\mathrm{d}\sigma}f(\sigma w,\sigma\psi)\mathrm{d}\sigma\\&=\int_0^1\frac{\partial}{\partial\zeta}f(\sigma w,\sigma\psi)\mathrm{d}\sigma\cdot w\\&\quad+\int_0^1\frac{\partial}{\partial\eta}f(\sigma w,\sigma\psi)\mathrm{d}\sigma\cdot\psi.\end{aligned}\tag{106}$$

Denote $\widetilde{q}(w,\psi)=\int_0^1\partial f(\sigma w,\sigma\psi)/\partial\zeta\mathrm{d}\sigma$, $\widetilde{d}(w,\psi)=\int_0^1\partial f(\sigma w,\sigma\psi)/\partial\eta\mathrm{d}\sigma$,

$$\widetilde{e}(\eta)=\begin{cases}\dfrac{h(\eta)}{\eta},&\eta\ne 0,\\[2mm] h'(\eta),&\eta=0,\end{cases}\tag{107}$$

and set the following nonempty convex

$$K=\left\{(\zeta,\eta)\in\left(C^{2+\theta,1+\theta/2}(\overline{Q_T})\right)^2:\ \left(\|\zeta\|_{C^{2+\theta,1+\theta/2}}+\|\eta\|_{C^{2+\theta,1+\theta/2}}\right)\le 1,\ (\zeta_0,\eta_0)=(w_0,\psi_0)\right\}.\tag{108}$$

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It is easy to verify that K is a compact subset of $(L^2(Q_T))^2$ with small initial datum. For any $(\zeta, \eta) \in K$, consider the following linearized system of (1)

$$\begin{aligned} \omega_t + l\psi_t - \sum_{i,j=1}^{N} \frac{\partial}{\partial x_j}\left(a_{ij}(\zeta)\frac{\partial w}{\partial x_i}\right) + \widetilde{q}(\zeta,\eta)\omega + \widetilde{d}(\zeta,\eta)\psi = g, \quad \text{in } Q_T, \\ \psi_t - \Delta\psi + \widetilde{e}(\eta)\psi + r\omega = 0, \quad \text{in } Q_T, \\ \frac{\partial \omega}{\partial n_A} = \sum_{i,j=1}^{N} a_{ij}(\zeta) n_j \frac{\partial \omega}{\partial x_i} = 0, \frac{\partial \psi}{\partial n} = 0, \quad \text{on } \Sigma_T, \\ \omega(x,0) = \omega_0(x), \psi(x,0) = \psi_0(x), \quad \text{in } \Omega. \end{aligned} \tag{109}$$

Then, by setting $a_{ij}(\zeta) = b_{ij}(x,t)$, $\widetilde{q}(\zeta,\eta) = q(x,t)$, $\widetilde{d}(\zeta,\eta) = d(x,t)$ and $\widetilde{e}(\eta) = e(x,t)$, b_{ij}, q, d, e, r satisfy the condition in Section 2 related to the linear system (5). By Proposition 4, we can prove that (109) is local null-controllable and has the cost estimate

$$\|g\|_{C^{\theta,\theta/2}(\overline{Q_T})} \le Ce^{C(A+\lambda+s)}\left(\|w_0\|_{L^2(\Omega)} + \|\psi_0\|_{L^2(\Omega)}\right). \tag{110}$$

Combining the Kakutani's fixed point theorem, we have the following theorem.

Theorem 1. *Let $\lambda_{\max}$ and $s_{\max}$ be the constants given in Proposition 4. Assume that for every given initial datum $(w_0, \psi_0) \in (C^{2+\theta}(\overline{\Omega}))^2$ satisfying the compatibility condition (9), there exists a positive constant γ such that $\|w_0\|_{C^{2+\theta}(\overline{\Omega})} + \|\psi_0\|_{C^{2+\theta}(\overline{\Omega})} \le \gamma$. Then, for every $s \ge s_{\max}$ and $\lambda \ge \lambda_{\max}$, one can find a control $g \in \mathcal{U}(\omega)$ such that the corresponding solution (w, ψ) of (1) satisfies*

$$w(x,T) = \psi(x,T) = 0, \quad \text{in } \Omega. \tag{111}$$

Moreover, we have the cost estimate

$$\|g\|_{C^{\theta,\theta/2}(\overline{Q_T})} \le Ce^{C(A+\lambda+s)}\left(\|w_0\|_{L^2(\Omega)} + \|\psi_0\|_{L^2(\Omega)}\right). \tag{112}$$

Proof. For any $(\zeta, \eta) \in K$, put

$$\Phi((\zeta,\eta)) = \left\{(w,\psi) \in K: \exists g \in C^{\theta,\theta/2}(\overline{Q_T}) \text{ and a constant } C \text{ such that } (w,\psi,g) \text{ satisfies (109) – (112)}\right\}. \tag{113}$$

This defines a map $\Phi: K \longrightarrow 2^K$ with $(w_0, \psi_0) \in (C^{2+\theta}(\overline{\Omega}))^2$ small enough. Further, for any $(\zeta, \eta) \in K$, $\Phi((\zeta, \eta))$ is a nonempty convex and compact subset of $(L^2(Q_T))^2$ provided by Lemma 3. Also, Φ is upper semi-continuous. Therefore, by the Kakutani's fixed point theorem, there exists $(w, \psi) \in K$ such that $(w, \psi) \in \Phi((w, \psi))$ and this ends the proof of the theorem. □

7. Conclusion

In this paper, we derive the the local null-controllability for some quasi-linear phase-field systems with homogeneous Neumann boundary conditions and an arbitrary located internal controller under the frame of classical solutions. We first develop the corresponding Carleman inequality and obtain the observability estimation. Then, we derive the null-controllability for the linear system and the get the desired control function by constructing a sequence of optimal control problems. Finally, by the Kakutani's fixed point theorem, we have the local null-controllability for the quasi-linear system.

Data Availability

No data were used to support this study.

Disclosure

No potential conflict of interest was reported by the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: Land Price Distortion, Financial Development, and Regional Innovation

Discrete Dynamics in Nature and Society

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(1) Discrepancies in scope

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(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) Manipulated or compromised peer review

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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.

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Research Article

Land Price Distortion, Financial Development, and Regional Innovation

Pengcheng Zhou,[1] **Ruiqi Qin**,[2] **Baitang Luo**,[3] **and Hao Wen**[4]

[1]*Management College, Guangdong Polytechnic Normal University, Guangzhou 510665, China*
[2]*School of Finance, Zhongnan University of Economics and Law, Wuhan 430073, China*
[3]*HSBC Business School, Peking University, Beijing 518055, China*
[4]*School of Business and Administration, Zhongnan University of Economics and Law, Wuhan 430073, China*

Correspondence should be addressed to Ruiqi Qin; qrq_zuel@163.com

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As an important tool for local governments to implement regional development policies, the allocation of land resource plays an important role in promoting regional innovation and development. Based on the microdata of land transfer in 287 cities in China from 2007 to 2017, this study examines the relationship between land price distortion, regional financial development, and regional innovation ability. The results show that land price distortion promotes the improvement of regional innovation ability. There is a significant time-lag effect because it is mainly realized by increasing the fiscal revenue of local governments and providing implicit subsidies to enterprises. The larger the financial scale is, the better the financial structure is and the higher the financial efficiency will further strengthen such a positive effect. Further analysis shows that the impact of land price distortion on improving regional innovation ability is significantly different between central or western regions and the eastern regions. This study provides empirical evidence for promoting regional innovation ability by land price distortion, which is conducive to a better understanding of the importance of reasonable land resource allocation and financial market development in the process of high-quality economic development, providing a useful insight into China's future reform of land market and financial market.

1. Introduction

In the process of China's urbanization and industrialization in recent years, land resources have played an important role. As an essential production factor, land resource is an important tool for local governments to implement regional development policies. Reasonable allocation of land resource can attract external investment, increase fiscal revenue and public expenditure, and then realize the purpose of promoting urbanization and industrialization. However, as the main way of land resource allocation at present, the land market has been operating in a state of low efficiency. One of the main features is that the pricing mechanism of land resource has been distorted for a long time. That is, within the same city, the prices of commercial land, residential land, and industrial land have been seriously deviating. As China's development mode is gradually changing from the traditional factor-driven mode to the innovation-driven mode, how the distortion of land price affects regional innovation ability is an important topic related to the transformation of China's economic growth momentum and the stimulation of regional innovation potential.

According to existing studies, the reason for the distortion of land price is that local governments make full use of the power of land acquisition and transfer granted by the Land Management Law and implement differential pricing strategies for different types of land [1]. On the one hand, the motivation of "land finance," also called "tudicaizheng" in Chinese, urges local governments to make up for the decline of fiscal revenue (which was caused by the reform of tax sharing system) by selling residential lands at a high price to obtain land transfer fees. On the other hand, motivated by

promotion chances, local governments tend to sell industrial lands at a low price to attract industrial investment in order to develop the local economy and establish political achievements in a short five-year political tenure. The joint effects of land finance motivation and investment attraction motivation of governments finally lead to land price distortion.

No matter what the motivation of the local government is, land transferring is proved to have an important impact on regional innovation ability. Under the motivation of "land finance," the land transfer behaviour of local governments has objectively accelerated the urbanization process in China, and the financial revenue brought by it is conducive to promoting the improvement of infrastructure [2, 3], which will have a positive effect on the ability of regional innovation. However, at the same time, land finance behaviour also brings a series of negative effects, such as boosting the housing prices to rise too fast [4], inducing land illegal and corruption cases [5, 6], and crowding out enterprise innovation elements and destroying institutional environment [7], thus hindering regional innovation. Under the motivation of investment attraction, the industrial capital that was attracted will have positive effects on regional innovation [8]. However, at the same time, in order to realize the rapid economic growth during their political tenure, local officials may lower the quality of investment and trigger "race-to-bottom" competition, which sometimes inhibits regional innovation [9]. At present, the existing studies mainly consider the impact of land transfer behaviour under the single government motivation on regional innovation ability, but there is almost no empirical study on the impact of urban land price distortion on regional innovation ability by combining the two motivations. Therefore, this paper combines the two motivations into the analysis of regional innovation, which can give us a more comprehensive view of the impact of land price distortion. Our study argues that the distortion of land price will actually provide two types of subsidies to enterprises, both explicit and implicit, thus improving regional innovation ability.

In addition, as the main player of technological innovation, enterprise's R&D input is crucial for the improvement of regional innovation ability. Since the R&D activities require stable and large amounts of capital as support, financial market plays an important role in this process which should not be ignored [10–12]. Some scholars have argued that when local governments provide subsidies to enterprises, a certification effect will be released [13–18]. Developed financial markets can make use of such signal to reduce information asymmetry more effectively, thus reducing external financing constraints of enterprises and finally promoting regional innovation. Therefore, this paper holds the view that while land price distortion brings substantial subsidies to enterprises, regional financial market development will directly affect the effectiveness and diversity of external financing channels of enterprises in this process and then plays a positive role in moderating the effect of land price distortion to enhance regional innovation ability.

In order to clarify whether land price distortion promotes regional innovation, this paper uses the panel data of 287 prefecture-level cities from 2007 to 2017 to explore the influence of land price distortion on regional innovation ability. Furthermore, this paper also includes the effects of regional financial market development in the analysis of the impacts of land resource on regional innovation, explores the moderating effects of local financial market development in this process, and provides empirical evidence for it.

2. Literature Review

2.1. Land Price Distortion and Its Causes. "The Provisional Regulations on Assignment and Transfer of the Right to the Use of State-owned Lands in Urban Areas," issued in 1990, has granted prefecture-level and county-level governments the monopoly right in the primary market of state-owned lands. Therefore, the allocation of land resource has become an important tool for local governments to implement regional development policies or industrial policies [19], and they can promote urban development through carrying out various urban renewal projects [20]. However, as the most important resource allocation mechanism, the market for land transfer has been operating inefficiently in recent years. The most important manifestation is that the land prices are highly distorted; that is, in the same city, the price ratio between residential lands and industrial land has been deviating from the normal level for a long time and has kept expanding. Existing literature holds the view that the distortion of land price is caused by the local government's differentiated pricing strategies for different land types and different land transfer behaviours [1], while the differentiated land transfer strategies are caused by the local government's "land finance" motivation and investment attraction motivation. Under the land finance motivation, local governments tend to make up for the decline of fiscal revenue (which was caused by the tax sharing system) by selling residential lands at high prices to obtain land transfer fees. Meanwhile, in order to promote economic development and establish political achievements of local officials, local governments sell industrial lands at low prices to attract investment. The excessively high commercial or residential land prices and low industrial land prices together lead to land price distortion, which will have significant impacts on national economic development.

2.2. Land Price Distortion and Regional Innovation. Enterprises' innovation not only relies on internal factors like successful marketing-R&D integration and knowledge exchange within enterprises [21] but also depends on external resource input. Since land transferring is an essential behaviour of resource allocation, which greatly affects the production and business activities of enterprises, it will inevitably have indirect impacts on regional innovation activities. Currently, there are different opinions about the influences of land transferring on regional innovation activities under the land finance motivation. Some scholars' conclusions show that land finance will inhibit regional

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innovation because the improvement of urban infrastructure will bring significant capitalization effects, encouraging regional real estate bubbles [22]; for instance, Wen et al. have found that the construction of urban rail transit significantly uplifts the land price [23]. Miao and Wang have demonstrated that the existence of a regional real estate bubble will attract investment from nonreal estate enterprises and then discourage their innovation investment. Therefore, the behaviour of land finance has a potential inhibiting effect on regional innovation ability [7]. However, some scholars argue the opposite. For instance, fiscal revenue created by transferring residential and commercial lands can significantly promote the regional innovation ability because local governments can make use of such fiscal revenue to increase local science and education expenditure and make up the cost gap of investment attraction activities, thus promoting the improvement of regional innovation ability [24]. Through existing literature, our paper finds that the positive interaction between land finance and urban construction seems to provide favourable conditions for improving regional innovation ability. However, it is worth noting that although these studies provide evidence for the influences of land finance behaviour on regional innovation ability, they do not pay enough attention to the coeffects of another kind of motivation, the effects of investment attraction motivation.

Existing literature has identified the tools with which local government officials attract investment, such as tax incentives, adjusting the structure of government expenditure, improving infrastructure, and relaxing environmental regulatory standards. Driven by the motive of investment attraction, local governments can also attract industrial investment by selling industrial lands in large quantities [1], thus driving economic development and establishing political achievements to gain advantages in promotion competition [25]. On the one hand, investment attraction policies will have a positive impact on the local innovation ability. For example, government subsidies and tax incentives will have an incentive effect on enterprises' innovation activities [26, 27]. On the other hand, the results of investment attraction will also have a direct positive impact on local technological innovation [8]. However, according to the research of Romer and Jones, innovation capital and talents are the most important factors affecting regional innovation ability [28, 29]. Therefore, the industrial lands sold by local governments at low prices for the purpose of investment attraction actually provide implicit subsidies to local enterprises, which may encourage enterprises' R&D activities. However, under the motivation of investment attraction, local governments will compete to lower the land prices in order to expand the scale of investment attraction. Such excessive transfer of industrial lands has also been confirmed by many scholars, including corruption, environmental pollution, and destruction of the institutional environment [30, 31], and these influences are undoubtedly negative to regional innovation ability.

Although these two kinds of land transferring behaviour and their influences on regional innovation ability have been fully recognized, discussing one of the two kinds of transferring behaviour separately is not enough to explain the effects of price distortion on regional innovation ability. As the two types of transferring behaviour together lead to the distortion of the land price and deeply affect China's economic development, it is reasonable to guess that not only do these two kinds of differentiated land transferring behaviours lead to the distortion of land price, but also their potential mechanism will undoubtedly have significant impacts on the regional innovation ability. Our paper hopes to make some marginal contribution from this perspective.

2.3. Financial Market Development and Regional Innovation. The improvement of regional innovation ability is complex progress [32], which is not only affected by land resource but also affected by local financial market development. An efficient financial market can effectively alleviate the financing constraints faced by enterprises and plays a guiding role in the resource allocation process of a country or region. Therefore, the development of the local financial market will also have significant impacts on regional innovation ability, and it is necessary to include it in our analysis.

As for the impacts of the financial market on innovation activities, existing studies mainly discuss two aspects: on the one hand, the development of the financial market can alleviate information asymmetry and guide allocation of resources rationally. Chowdhury and Maung found that the development of the financial market can alleviate information asymmetry in R&D investment and then improve output efficiency [11]. Maskus, Neumann, and Seidel studied the influence of domestic and international financial market development on industrial R&D expenditures by taking 22 manufacturing industries in 18 OECD countries from 1990 to 2003 as research objects. The results show that various financing channels of domestic financial market development have a positive effect on industrial R&D expenditures [10]. On the other hand, the development of regional financial market can reduce financing costs by alleviating financing constraints caused by credit bias. Rajan and Zingales, Demirguc-Kunt, and Maksimovic found that financial development has a positive impact on enterprises' financing channels, thus promoting the growth of industries and enterprises which are dependent on external financing [33, 34]. Claessens and Laeven proposed that the development of the financial market of a country affects the channels for enterprises to obtain external financing and determines the resources available for investment, thus affecting the growth of enterprises. The demand for houses or lands ascends as the total credit allocation increases within the region, which will further boost the expectations of local lands, and this will no doubt help improve enterprises' ability to get bank loans or other liabilities while mortgaging lands as collateral. According to the conclusion of existing research, the development of regional financial development can help ease the financing constraints of enterprises and meet the capital needs of enterprises to carry out R&D activities, thus playing a moderating role in the process of land price distortion affecting regional innovation ability.

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Our paper tries to make some contributions from this perspective.

Another potential explanation is that higher financial market development implicates an easier way for local governments to get financing. As local governments seek to expand infrastructure investment, a huge number of urban construction investment companies are established during the past twenty years whose duty is to help local governments finance from capital markets, including loan market and bond market, since the central government has prohibited local governments from financing from banks directly. By transferring lands to urban construction investment companies and mortgaging lands to banks as collateral, local governments can get bank loans through these companies and invest in infrastructure construction, which will help improve cities' innovation ability.

To sum up, the existing literature only considers the influences of land transferring behaviour under a certain motivation of local governments on regional innovation ability but fails to recognize the joint effects of two motivations on regional innovation ability. In addition, existing studies often separate the relationship between financial development, land price, and regional innovation, but there is an inseparable relationship between the land resource and regional financial markets. At present, there is no literature systematically analyzing such a relationship. Therefore, the innovation of our paper is to clarify the inner correlation between land price distortion, regional financial development, and regional innovation ability.

3. Theoretical Framework and Hypothesis

According to the analysis of the existing studies, we find that the distortion of land price is actually caused by the local government's land finance motivation and investment attraction motivation. However, due to the availability of data, most studies only focus on the total income of land transferring but fail to distinguish income generated from different types of land. Since local governments have different transferring strategies for different types of lands, we believe that the total income from land transferring actually covers two different government behaviours. As Tao found, local governments tend to sell commercial and residential lands at high prices and sell industrial lands at low prices [1]. The former generates what we call "land finance" revenue, while the latter contributes little to fiscal revenue due to the low or even "zero" price of industrial lands. In addition, existing studies usually explain the impacts of local governments' land finance behaviour on regional innovation ability from the perspective of "expenditure bias," but as local governments' total revenue increases, governments' expenditure on other subjects should not decrease. However, some existing studies also found positive relationships between land finance and governments' public capital investment. By increasing the city's capital stock, the infrastructure is improved, and the cities are expanded. As the revenue created by land finance increases, local governments tend to finance more from bank loans or bond markets because they believe they have the ability to repay such huge amounts of debts. By doing so, the cities are expanded, and infrastructures are constructed, which have incurred population inflow. Thus, at least in less developed cities, regional innovation abilities are improved.

As for the impacts of land prices on regional innovation under the motivation of investment attraction, this paper argues that it is necessary to take financing constraints of enterprises in R&D activities into account, as selling industrial lands at low prices have provided an effective tool for enterprises to alleviate their financing constraints. In the early stage of project investment, local governments can control the factor market and lower the price of industrial lands to attract enterprises to settle in, thus reducing their costs. In the process of project implementation, enterprises can mortgage the lands to the bank at market prices higher than the purchasing costs to obtain loans. After the completion of the project, the enterprise can transfer the land use right at a market price far higher than the acquisition cost. The huge intermediate price difference creates a huge additional income for the enterprise, forming a huge substantial subsidy for the enterprise investment. As we know, enterprises are the channels and carriers for the agglomeration of production factors. The establishment of new enterprises or the expansion of existing enterprises will further promote the growth of urban population, capital level, information and knowledge, and other factors. So if local governments allocate more resources, especially land resources, to enterprises, the enterprise cluster will thus be formed, and regional innovation ability will be further improved.

Although there is a considerable amount of literature studying the impact of government subsidies on enterprise innovation, such studies only study the impacts of direct government R&D subsidies on enterprise. There is still a lack of systematic evidence on the impact of implicit subsidies caused by land price distortion on regional innovation. By distorting land prices, local governments sell industrial lands at a low price to enterprises, which may help ease the financial constraints on enterprises' innovation activities. On the other hand, local governments transferring lands at a low price to enterprises also encourage the enterprise cluster, thus increasing enterprises' R&D investment and enhancing regional innovation ability.

Besides, most innovation demands are generated in the process of industrial production, and industrial production provides an important interaction place for the dissemination of new knowledge and the use of new technology, so there is an inseparable relationship between industrial base and urban innovation. The stronger the industrial base, the more likely it is to provide carrier and support for innovation activities and the more conducive to promoting urban innovation. In the early stage of industrialization and urbanization, China's commercial and residential land use mode of "generating wealth from land" helped local governments quickly accumulate huge wealth needed by urbanization and ensured the infrastructure construction of industrial production. The "land to attract capital" method of industrial land utilization helps the government to attract a large amount of manufacturing capital in a short time.

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Together, they can greatly promote the formation of urban industrial base and guarantee the basic industrial carrier needed for innovation activities.

If the above mechanism does exist, there should be a lag effect. Based on the above theoretical analysis, this paper proposes the following hypothesis:

> H1a: The distortion of land prices can significantly improve the ability of regional innovation, which has a lag effect (direct effect).

Although the explicit subsidies provided by local governments can directly alleviate the financing constraints of enterprises to some extent, they are nothing compared to the large R&D inputs of enterprises. Therefore, another important function of government subsidies lies in the certification effect, that is, the government's recognition of a certain R&D project. This would actually boost investors' expectations about the success rate of the project, making companies more likely to obtain external financing. As mentioned above, one of the functions of financial markets is to alleviate information asymmetry. So when local governments sell residential lands at high prices and use the revenue to subsidize local enterprises, the developed financial market will be able to reduce the information asymmetry more effectively through this kind of "certification effect" and identify high-quality research and development projects, improving the possibility of subsidized enterprises' access to external finance and strengthening the positive effects of land price distortion.

In addition, industrial lands purchased from governments allowed enterprises to obtain bank loans by mortgaging the land. In fact, commercial bank loans are still the main financing source for China's enterprises at present, and mortgage loans are the main type of credit. The low price of industrial lands will inevitably reduce the value of collateral. As a result, in the central and western regions where enterprises rely heavily on land mortgage loans, the decline of collateral value will undoubtedly increase the financing difficulty of enterprises. Another major function of financial markets is to broaden the financing channels, so when local governments sell industrial lands to enterprises at low prices, a more developed financial market can reduce enterprise's dependence on mortgage loan, easing external financing difficulties of enterprises and further enhancing the positive effects of land price distortion. Therefore, hypothesis 2 is proposed in our paper:

> H2a: The promotion of regional financial development level can strengthen the promotion effect of land price distortion on regional innovation level.

Generally speaking, the relation between variables studied in this paper is shown in Figure 1.

4. Empirical Strategy and Variables

4.1. Baseline Regression. According to the above analysis, under land finance motivation and investment attraction motivation, local governments obtain fiscal revenue by selling residential land at high prices and selling industrial lands at low prices to enterprises to attract investment. This paper uses the following econometric model to reflect the impact of land price distortion on regional innovation:

$$\ln\text{ppantents}_{it} = \beta_0 + \beta_1 \text{distort}_{it} + \gamma \text{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \tag{1}$$

Considering the influences of land price distortion on regional innovation ability may have a time-lag effect, we further include the lagged term of land price distortion into the model:

$$\begin{aligned} \ln\text{ppatents}_{it} &= \beta_0 + \beta_1 \text{distort}_{i,t-1} + \gamma \text{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \\ \ln\text{ppatents}_{it} &= \beta_0 + \beta_1 \text{distort}_{it} + \beta_2 \text{distort}_{i,t-1} \\ &\quad + \gamma \text{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \end{aligned} \tag{2}$$

In the above models, $\ln\text{ppatents}_{it}$ is the variable to measure regional innovation ability, which represents the natural logarithm of the number of patent grants per 10,000 people in i city in t year. The improvement of innovation ability requires enterprises to go through a series of processes, including R&D inputs, outputs, and transformation into economic value. Some of the existing studies mainly use R&D input or patent application data to measure the innovation ability of the enterprise. However, since R&D inputs do not certainly produce outputs, the amount of R&D inputs or patent application can only unilaterally reflect the subjective intention of regional market players to conduct R&D and innovation activities, while the number of patents granted reflects the regional innovation output after official audit. Therefore, based on the comprehensive measurement of authority and availability of data, we suggest that the number of patents granted can objectively reflect the innovation ability of a region. The key explanatory variable in this paper is the distortion degree of land prices. Existing studies mainly measure the distortion degree with industrial land prices, but this method only analyzes the distortion phenomenon from the perspective of industrial lands, without taking into account the price of residential lands. Instead of being limited to a single type of land, this paper uses the ratio of the average land price of residential land P_r and the price of industrial land P_i to measure land price distortion. If the degree of land price distortion can promote the development of regional innovation ability, then the value of β_1 should be significantly positive.

control_{it} is a collection of control variables. In addition, annual dummy variables are used in the model to reflect the time fixed effect μ_i, so as to control the influence of the macroenvironment changes on the overall innovation ability. The individual fixed effect λ_t of cities is also used to control the unobserved differences between cities.

4.2. Moderating Effects. In order to further study the different impacts of land price distortion under the effects of different financial market development, we add the interaction term to the baseline Model (1) and reestimate the following equation:

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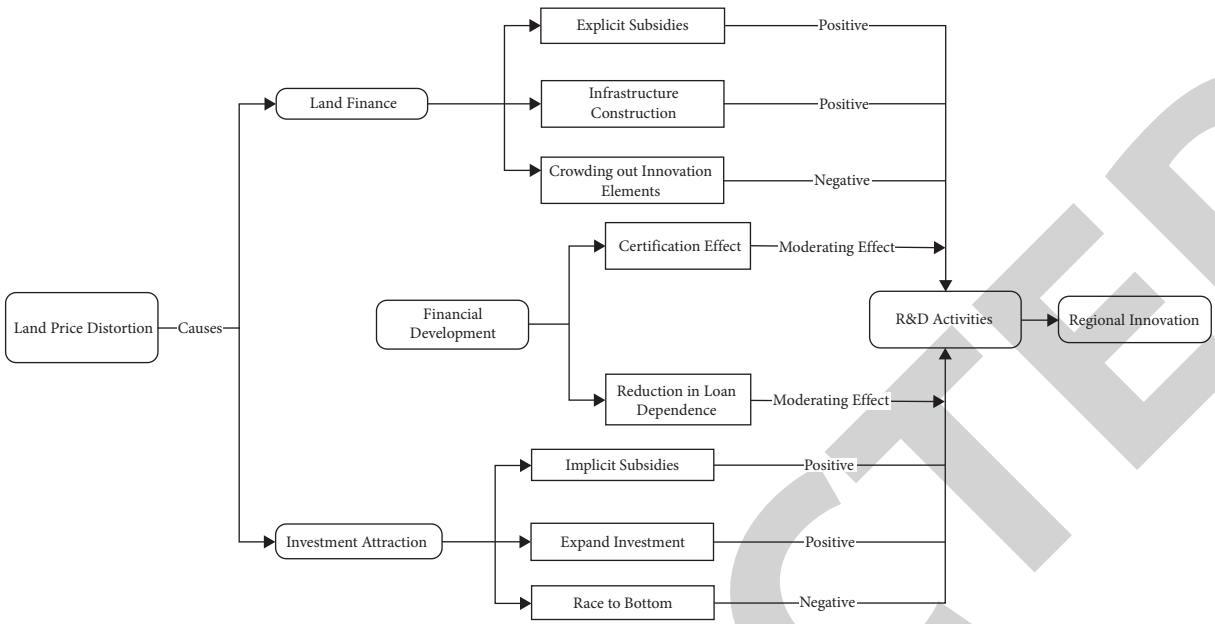

Figure 1: The relationship between land price distortion, local financial development level, and regional innovation level.

$$\ln ppatents_{it} = \beta_0 + \beta_1 distort_{it} + \beta_2 distort_{it} * F_{it} + \beta_3 F_{it} + \gamma controls_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \quad (3)$$

In the analysis of moderating effect, F_{it} is the variable to measure the regional financial market development level. This paper comprehensively measures the level of local financial development from financial development scale (fin_scale), structure (fin_stru), and efficiency (fin_effi). Among them, the financial scale is measured by the ratio of the total deposits and loans of financial institutions to the nominal GDP of the year in each city. The financial structure is measured by the ratio of the loan balance of the financial institutions to the nominal GDP. Financial efficiency is based on the ratio of loan balance to deposit balance of financial institutions. In the case that land price distortion will enhance regional innovation ability, if higher local financial development level will strengthen the positive effects of land price distortion, β_2 should be significantly positive.

4.3. Variables and Descriptive Statistics. The dependent variable in this paper is the ability of regional innovation, which is the natural logarithm of the number of patent grants per 10,000 people per year in the region. The data are obtained from the China Urban Statistical Yearbook of each region. Explanatory variables are divided into three categories. One category is the core explanatory variable, namely, the distortion degree of land prices ($distort_{it}$), which is measured by the ratio of the average price of residential lands to the average price of industrial lands. The land price data are crawled from China Land Market website. On the basis of the Yearbook, this paper adjusts the statistical calibre of residential lands and industrial lands and deals with the missing value of some cities or some years.

Another category is the control variables. On the basis of existing literature, the following control variables are selected in our paper: disposable income per capita (di_per_capita), which reflects the economic development level of the city. We also control the degree of local government's dependence on land finance by calculating the ratio of residential land transfer fees to budgetary fiscal revenue (dependon). The proportion of general high school students and vocational students to population (local_hr_pop) is used to control the influence of human capital on regional innovation, savings per capita (sav_person) is used to control the investment potential of a place, and industrial dust (dust) is used to control the impact of the urban environment. The proportion of fiscal expenditure to GDP (govern scale) is used to control the impact of government input. Government fiscal pressure (fin_press) is used to control the potential fiscal expenditure behaviour of local governments. Government R&D expenditure (*lnsci*) is used to control R&D investment. Among them, the financial pressure of local governments is measured by the ratio between the amount of fiscal deficit of current year and fiscal budget expenditure, but when fiscal revenue is greater than fiscal expenditure, the value of this variable is 0, indicating that the city has no financial pressure in this year. The data on residential land transfer fees are obtained from the land transfer data from 2008 to 2017 published by China Land Market website.

The third category is the moderating variable, which is the level of local financial market development. We measure the level of financial market development from multiple perspectives, specifically including three indicators of local financial development scale, structure, and efficiency. All the data come from China City Statistical Yearbook.

Descriptive statistical results of variables are shown in Table 1. It can be found that the average price ratio of

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Table 1: Descriptive statistics.

Variables	Number of observations	Mean	Std. dev.	Min.	Max.
lnppatents	3429	1.27	1.023	0.011	5.379
distort	3157	9.19	7.086	1.003	70.515
fin_scale	3414	2.17	3.434	0.560	193.559
fin_stru	3414	0.86	1.612	0.075	90.157
fin_effi	3434	0.64	0.213	0.085	5.613
fin_press	3433	0.52	0.228	0	0.973
dependon	3148	0.00	0.002	0	0.084
local_hr_pop	3444	0.07	0.027	0.019	0.206
sav_person	3444	2.34	2.416	0.119	24.517
dust	3444	31103	71040	34	3257261
govscale	3444	0.18	0.100	0.043	1.485
di_per_capita	3444	17378	6393	5534	48646
lnsci	3308	9.64	1.565	3.526	15.211

residential lands to industrial lands in China is around 9, indicating the serious distortion of the current land prices. At the same time, the distortions vary from place to place, with the ratio of the two types of land in the worst places reaching 70. What is more, the difference in other variables is also significant, which illustrates the seriousness of the current imbalanced development among regions. In order to exclude the influences of such extreme value, we have made 1% tail indentation for all continuous variables before regression.

5. Empirical Results

5.1. Baseline Regression. In the baseline regression, we first explore the effects of the core explanatory variable, namely, the land price distortion. The results are shown in Table 2. Considering that the impact of land price on business activities may have a lag effect, we also introduce a lag period of land price distortion degree into our model. The results of column (1) and column (2) show that the current and lagged land price distortions have a positive impact on the regional innovation ability, and both of them are significant at the level of 1%. The results in column (1) show that, for every 1 unit increase in land price distortion, patent outputs per 10,000 people increase by 0.41%. The results in column (2) show that an increase of 1 unit in land price distortion in the last year will increase the patent output per 10,000 people by 0.44%. This lag effect also further confirms the inference of our paper on the mechanism of land price distortion, that is, explicit subsidies provided by local governments to local education or R&D activities and implicit land price subsidies provided to local enterprises, since subsides always take effects after one year. In column (3), we have included current and lagged terms of land price distortions into the model, and both of them are significantly positive at the level of 5%. Moreover, the absolute value of the lagged term is larger than the current term, so the improvement of innovation ability mainly benefits from land price distortion in the last year. Our conclusion shows that the land price distortion caused by governments has a positive promoting effect on the regional innovation ability, and this effect will not only have a direct impact in the current period but also have a significant lag effect. Therefore, hypothesis 1 is verified.

Table 2: Baseline regression results.

Dependent variable: lnppatents	Baseline (1)	Baseline (2)	Baseline (3)
Distort	0.0044***		0.0034**
	(0.002)		(0.002)
L.distort		0.0048***	0.0042***
		(0.002)	(0.002)
fin_press	0.1522	0.0685	0.0778
	(0.106)	(0.103)	(0.103)
Dependon	128.5377	358.0801	117.4494
	(316.270)	(276.815)	(315.232)
local_hr_pop	0.0601	0.5533	0.5324
	(1.028)	(1.050)	(1.047)
sav_person	0.0856***	0.0537***	0.0529***
	(0.018)	(0.017)	(0.017)
Dust	−0.0000	−0.0000	−0.0000
	(0.000)	(0.000)	(0.000)
Govscale	−1.0907***	−0.8713***	−0.8570***
	(0.244)	(0.248)	(0.243)
di_per_capita	0.0000***	0.0000***	0.0000***
	(0.000)	(0.000)	(0.000)
lnsci	0.1402***	0.1249***	0.1228***
	(0.019)	(0.018)	(0.018)
Constant	−0.8143***	−0.6187***	−0.6083***
	(0.217)	(0.216)	(0.213)
Observations	3,020	2,736	2,736
R-squared	0.780	0.761	0.762
Number of cities	287	287	287

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

5.2. Moderating Effect Regression. We introduce the interaction term between the land price distortion and the level of local financial market development in this part. The estimation method and the selection of control variables are consistent with the baseline regression. Among them, we measure the level of local financial market development from three aspects, financial efficiency, financial structure, and financial scale, to ensure the comprehensiveness of the study.

The results are shown in Table 3. In all models with interaction terms, the coefficients of interaction terms between financial efficiency, financial structure, and financial scale and the distortion degree of land price are significantly positive at the level of 5%. This indicates that land price distortion has a more significant effect on the improvement of regional innovation levels in the regions with large scale, high efficiency, and well-structured financial markets. That may be because local governments can send a positive signal to investors, namely, the "certification effect," by providing subsidy support to enterprises through distorting land prices. In the region with a more developed financial market, this signal can more effectively alleviate the external financing constraints of enterprises. Therefore, hypothesis 2 has also been verified.

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Table 3: Regression results of moderating effect of financial development level.

Dependent variable: lnppatents	Moderating effect (1)	Moderating effect (2)	Moderating effect (3)
distort	0.0040***	0.0039**	0.0040**
	(0.001)	(0.002)	(0.002)
distort*fin_effi	0.0250***		
	(0.006)		
fin_effi	0.1305***		
	(0.033)		
distort*fin_stru		0.0064***	
		(0.002)	
fin_stru		0.0251***	
		(0.008)	
distort*fin_scale			0.0025**
			(0.001)
fin_scale			0.0101***
			(0.004)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	3,020	3,011	3,011
R-squared	0.781	0.780	0.779
Number of cities	287	287	287

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

5.3. Robustness Test

5.3.1. Replacing the Sample. In our robustness test, the land price data of 103 key cities from 2012 to 2017 published in Yearbook (Lhasa was excluded due to the lack of other data) were used for reestimation. Data source, control variables, model setting, and estimation method are all kept unchanged.

Table 4 reports the results after narrowing the number of individuals in the sample and the time span. Results in column (1) and column (2) show that the core explanatory variable regression coefficient is still significantly positive, which means that, in these 103 cities, land price distortion can still play the role of promoting regional innovation ability. However, compared with the baseline regression of 287 cities, although the sign of the regression coefficient of the core explanatory variable remains positive, its absolute value increases. This may be because the enterprises that can be set up in the 103 key cities are usually possessed with strong research and development capabilities or financial support. Therefore, when the land price is distorted, the government's subsidies for such enterprises can play a more effective role. At the same time, compared with other cities, as the infrastructure environment and industrial chain of these 103 key cities are more complete and the industrial base has been formed, the explicit and implicit subsidies from the government to the enterprises can be transformed into innovation achievements more effectively. This is evidenced by the fact that the absolute value of the regression coefficient of the current term of the core explanatory variable in baseline regression (3) is greater than that of the first-order lag term.

5.3.2. Changing the Estimation Method. In order to avoid model misspecification and endogeneity of missing variables, this paper uses the lagged term of the dependent variable to alleviate this problem. However, the correlation between the first-order lag term and the random error term will lead to biased OLS estimation, so we adopt the estimation method of systematic GMM to deal with the endogeneity problem caused by the lag term of the explained variable. Table 5 reports the estimated results obtained by using the systematic GMM method. The regression coefficients of the core explanatory variables are significant at the 1% level when the lag term is included, and they all pass the residual autocorrelation test and the overidentification test of instrumental variables. This result proved the conclusion that such positive effects are caused by land price distortion of last year. Therefore, it can be considered that the system GMM estimation method alleviates the endogeneity problem, and our result is robust.

5.3.3. Endogeneity Test. In the robustness test section above, we have used the systematic GMM method to solve the endogeneity problem from the estimation method. In terms of model setting, some may argue that the land price distortion caused by the government will affect the financing conditions of enterprises through the intermediary channel of the local financial market, which means the development level of the local financial market will be affected by land price distortion and then affect regional innovation ability. In other words, there might be a mediating effect rather than a moderating effect between these variables. Therefore, the possible mediating effect was tested in this paper. Tables 6–8, respectively, report the test results of mediating effect of three indicators to measure the level of local financial market development. It can be seen that the regression coefficient of the core explanatory variable is not significant, indicating that land price distortion does not have an impact on the local financial development level. Moreover, the three models testing the intermediary effect do not pass the Sobel test, so it can be considered that the intermediary effect does

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Table 4: Baseline regression of 103 key cities.

Dependent variable: lnppatents	Baseline (1)	Baseline (2)	Baseline (3)
distort	0.0160***		0.0117***
	(0.005)		(0.004)
L.distort		0.0197***	0.0133***
		(0.005)	(0.005)
Constant	1.0585***	1.0191***	1.0507***
	(0.375)	(0.376)	(0.372)
Observations	477	477	477
R-squared	0.470	0.468	0.475
Number of cities	103	103	103

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

Table 5: Estimate results of system GMM method.

Dependent variable: lnppatents	SYS-GMM (1)	SYS-GMM (2)	SYS-GMM (3)
distort	0.0018		0.0022*
	(0.001)		(0.001)
L.lnppatents	0.9099***	0.9096***	0.8681***
	(0.066)	(0.087)	(0.065)
L.distort		0.0040***	0.0034***
		(0.001)	(0.001)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	3,017	2,733	2,733
Number of cities	287	287	287
AR1	0.000	0.000	0.000
AR2	0.324	0.369	0.365
Hansen P	0.402	0.783	0.961

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

Table 6: Results of financial efficiency mediating effect test.

Connotation of the model dependent variable	Total effect lnppatents	Mediating effect (1) fin_effi	Mediating effect (2) lnppatents
Distort	0.0044***	−0.0001	0.0044***
	(0.002)	(0.001)	(0.002)
fin_effi			0.0599
			(0.038)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	3,020	3,024	3,020
R-squared	0.779	0.079	0.779
Number of cities	287	287	287
Sobel			−0.857

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

not exist. Therefore, setting the relationship between land price distortion and the level of local financial market development as a moderating effect is not only in line with the realistic background but also supported by economic theory and empirical results, and it can be considered that there should be no endogeneity bias in model setting in this paper.

5.4. Regional Heterogeneity. Considering the vast territory of China, resource endowment and economic development differ greatly among regions, and the special political and economic system will further amplify the regional differences, which is bound to have different influences on regional innovation by land price distortion. Therefore, this paper classifies 287 cities according to eastern and central and western regions to explore the regional heterogeneity of land price distortion on regional innovation ability.

We divided the samples into two parts, the eastern region and the central and western region, to test the effects of land price distortion under such two conditions, respectively. The empirical results in Table 9 show that there is indeed a difference in the effect of land price distortion on

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Table 7: Results of financial scale mediating effect test.

Connotation of the model dependent variable	Total effect lnppatents	Mediating effect (1) fin_scale	Mediating effect (2) lnppatents
Distort	0.0044***	−0.0114	0.0045***
	(0.002)	(0.011)	(0.002)
fin_scale			0.0015***
			(0.000)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	3,020	3,015	3,011
R-squared	0.779	0.018	0.778
Number of cities	287	287	287
Sobel			−0.816

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

Table 8: Results of financial structure mediating effect test.

Connotation of the model dependent variable	Total effect lnppatents	Mediating effect (1) fin_stru	Mediating effect (2) lnppatents
Distort	0.0044***	−0.0001	0.0045***
	(0.002)	(0.001)	(0.002)
fin_stru			0.0037***
			(0.001)
Controls	Yes	Yes	Yes
City	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	3,020	3,024	3,011
R-squared	0.779	0.079	0.778
Number of cities	287	287	287
Sobel			−0.774

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

Table 9: Regional heterogeneity analysis.

Dependent variable lnppatents	East regions (1)	West regions (2)	East regions (3)	West regions (4)
Distort	0.0021	0.0053**		
	(0.003)	(0.002)		
L.distort			0.0020	0.0071***
			(0.002)	(0.002)
Controls	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Observations	1,086	1,934	985	1,751
R-squared	0.816	0.778	0.796	0.764
Number of cities	101	186	101	186

Notes. Robust standard errors in parentheses; *, **, and *** represent the significance level of 10%, 5%, and 1%, respectively.

regional innovation ability between the eastern region and the central and western regions. In the three models, the land price distortion in the eastern region has no significant effect on the regional innovation ability either in the current period or in the lagging period. In the current model and the lagging model, the distortion of land price in the central and western regions has a significant promoting effect on the regional innovation ability.

As for the reason of such results, we think that due to the fact that the revenue of central and western cities is usually less than the eastern region, their off-budget income from transfer payments (now called government-managed funds) not only can be used to provide subsidies for enterprise but also can be used for the construction of infrastructure; therefore, the economic benefits will be more significant than cities in the eastern regions where there is an improved infrastructure environment, a complete industrial chain, and market demand. We also suppose that, with the deepening of economic development and industrialization, urban innovation will gradually change from integrated innovation to original innovation. At this stage, all innovation activities are groping forward, and it is difficult for the government to

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predict which direction will produce innovation, so the efficiency of the use of government funds will be reduced. The generation of original innovation results needs to rely more on the prosperity of corporate capital and venture capital. In addition, with the improvement of innovation infrastructure and diversification of innovation funding sources, innovation activities will be less dependent on government funding. In addition, enterprises located in the eastern region tend to have higher R&D capacity, and the fierce market competition will also bring them internal R&D motivation to stand out in the competition, so the distortion of land price is not enough to become the external motivation for enterprises to improve their innovation ability.

6. Conclusions

This study collates the panel data of 287 prefecture-level cities from 2007 to 2017, analyzes the impact of land price distortion on regional innovation ability, and explores the moderating effects of financial development in this process by combining the data on financial market development of prefecture-level cities. The phenomenon of land price distortion is reexamined from its causes and results. The empirical results strongly support the hypothesis proposed by the theoretical analysis and provide empirical evidence that "land price distortion promotes regional innovation." Different from previous studies, this paper not only studies the impact of land price distortion on regional innovation ability and its potential mechanism from the perspective of land price but also includes the effects of local financial market development into the analysis, which provides a more comprehensive perspective for the study of regional innovation.

Our study found that the distortion of land price is caused by local government' behaviour of selling commercial and residential lands at high prices and industrial lands at low prices. In fact, it is governments' land finance motivation and investment attraction motivation that causes land price distortion, which enables governments to use such revenue to increase the investment in R&D subsidies and to make up for the financial gap caused by attracting investment. After controlling R&D input-related variables, we have found that land price distortion has a significant positive effect on regional innovation ability, and such a positive effect is significantly time-lag. After introducing the level of regional financial market development into our study, we find that larger financial scale, better financial structure, and higher financial efficiency will further strengthen the positive effect of land price distortion on the regional innovation ability since the development of regional financial market can not only broaden the financing channels of enterprises but also enable enterprises to obtain external financing through the "certification effect" of government subsidies, thus alleviating the financing constraint problem. In the analysis of regional heterogeneity, we find that in eastern region the positive effect of land price distortion is not as significant as that in the central or western regions. In the process of this study, we have noticed that a huge amount of data can be further used to explore the relationship between land policy and innovation; as a result of this, Social Network Analysis may be a possible method for further research in this field [35].

It is notable that the distortion of land price is actually a rational response of local governments to the institutional pressure featured by regional resource constraints and explicit goals of political performance. In the current stage, relying on the wealth accumulated by land finance and the investment brought by land transferring, the environment of regional innovation is optimized, and the positive effect of land price distortion on regional innovation ability plays a dominant role in this process. But in fact, such excessive and short-term profit-seeking development mode of the governments is becoming serious [9]. In the long run, local governments' behaviour of "Cherry Picking," that is, selectively supporting a particular industry or enterprise, and the pursuit of rapid political and economic interests may make the negative impact of land price distortion occupy the dominant position, so in reality, government should not ignore its negative effects in the process of regional development. According to the analysis of causes of land price distortion, compared with the direct regulation of land price, managing the land transferring motivation of local governments is a more fundamental way of governance. On the one hand, since land revenue belongs to the government-managed funds, it does not have sustainability, which means that it is necessary to build new tax to regulate intergovernmental financial distribution relationships and reduce the local government's dependence on land finance. At the same time, it is also essential to improve the distribution mechanism of government-managed funds so as to ensure that local governments can rationally use the fiscal revenue from land transferring and realize high-quality growth of the regional economy. On the other hand, for the purpose of attracting investment, the low-price transferring of industrial lands may easily lead to the race-to-bottom competition between local governments, expanding the area of industrial land transferring, lowering the industrial land price, and reducing the quality of investment, which will seriously harm the sustainable development of China's economy in the long run. Therefore, it is urgent to accelerate the reform of the land market, establish a reasonable land transferring system, and give more preferential treatment or subsidies to high-quality investment projects. In addition, on the premise of strictly preventing systemic financial risks, an effective regional financial market is also needed [36]. Local governments should help broaden the financing channels of technology-based enterprises, develop multilevel capital markets, reduce financing constraints of local enterprises, and increase the efficiency of financial resource allocation to release their financial constraints.

Data Availability

The data were collected by an Internet web crawler technology and are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Spatial-Temporal Analysis of Crash Severity: Multisource Data Fusion Approach

Amirhossein Taheri,[1] **Arash Rasaizadi**,[1] **and Seyedehsan Seyedabrishami**[2]

[1]*Transportation Planning Engineering, Tarbiat Modares University, Tehran, Iran*
[2]*Transportation Planning Engineering at the School of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran*

Correspondence should be addressed to Seyedehsan Seyedabrishami; seyedabrishami@modares.ac.ir

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High severity crashes are one of the negative consequences of suburban transportation for a range of factors. Fatalities, injuries, and medical costs, as well as road and car damage and mental side effects, are more important consequences of severe crashes. The goal of this research is to figure out what factors contribute to different crash severity levels, in order to reduce the likelihood of such crashes. This study is unique in that it tries to investigate the capabilities of various discrete choice methods in order to explore which one performs best given the current database and research restrictions. Furthermore, the data fusion approach allows this study to take advantage of a wide range of characteristics that influence crash severity. To achieve this objective, the current study used several types of discrete choice models, such as ordered logit (OL), multinominal logit (MNL), and mixed logit (ML) models, to examine the factors influencing the severity of crashes in the suburban highway area. The data are related to crashes and traffic counters in Khorasan Razavi province in the northeast of Iran. Spatial-temporal analysis of crash data with a data fusion approach has been conducted to prepare a multisource data set with a wide spectrum of independent variables to acquire reliable results using logit models. Independent descriptive variables include geometric design, time-related, weather and environmental conditions, land use, traffic attributes, vehicle characteristics, and driver characteristics. ML provided the best fit with the available data set when compared to other discrete choice techniques. In addition, in all three logit models, coefficients of geometric design, vehicle characteristics, driver characteristics, land use, and weather and environmental conditions are significant, demonstrating the significance of using multisource data in defining factors impacting crash severity.

1. Introduction

Road traffic crashes are one of the most serious health problems, accounting for the ninth leading cause of death worldwide [1]. Nearly 1.35 million people are killed and 20 to 50 million people are injured in road traffic accidents each year around the world [2]. Over the past decade, the travel demand has increased dramatically by the population growth and urban infrastructure developments [3]. Global road traffic deaths are expected to rise by more than 35 percent between 2010 and 2020 as a result of continued economic expansion and greater motorization [4]. Road traffic crashes will also become the sixth largest cause of death by 2030 if no action is taken [5, 6].

The issue of road traffic injuries varies greatly between different parts of the world. Approximately 90% of those killed in road crashes live in low- and middle-income nations [5]. Iran is in the Eastern Mediterranean region, which has the world's second highest traffic-related fatality rate [7]. Furthermore, road traffic crashes are the second leading cause of death, the first leading cause of years of life lost due to premature mortality (YLL), the second leading cause of disability-adjusted life years (DALYs) after cardiovascular diseases, and the most common cause of injury in Iran [7, 8]. According to studies, road traffic crashes claim the lives of 13.5 percent of Iranians, a high percentage compared to the rest of the globe and the Eastern Mediterranean region [9, 10]. More over half of all road traffic fatalities occur

among those aged 15 to 44, who are considered the community's economically productive group [5, 11]. In this regard, it is critical to use accurate and valid techniques to investigate the contributing factors that lead to crashes.

Crash prevention necessitates a thorough understanding of the numerous factors that influence road crashes [12]. On the other hand, recent improvements in intelligent transportation systems have made it possible to collect data in a more consistent and appropriate manner [13, 14]. The data used in this study were collected over a four-year period (2013–2016) from all roadways in the Khorasan Razavi province in Iran's northeast. Unlike the majority of research considered in the literature review section, we used a unique approach in this study and aimed to compare various prominent logit family models, including ordered logit (OL), multinominal logit (MNL), and mixed logit (ML), in order to reach the best results. The efficiency of a comprehensive approach for identifying and analyzing crash-related data is another noteworthy aspect of this study. The data from crashes and traffic counters were integrated and classified into geometric design, time-related, weather and environmental conditions, land use, traffic attributes, vehicle characteristics, and driver characteristics variables, which were then used and evaluated in the logit family models. This diverse set of factors is quite useful in generating reliable and accurate results. Finally, the study's significant contributions are the collection of diverse spatial-temporal variables, the creation of a crash data set, and the use of data fusion and statistical modelling tools on this data set to obtain dependable results and set wise safety policies.

2. Literature Review

Previous studies have defined road safety indicators [15–20] and have examined influential factors affecting road safety indicators [19, 21, 22]. For example, Anastasopoulos and Mannering [23] consider the effect of pavement, traffic, and geometric characteristics on crash injury severity by using random-parameter logit and fixed-parameter logit models. The model comparison shows the statistical superiority of the random-parameter logit model compared to the fixed-parameter logit model. Also, models based on individual crash data provide a better overall fit relative to the models based on the proportions of crashes by severity type.

In Azimi et al. study [24], crash severity is explored for large trucks specifically. Independent variables consist of driver action, driver age, driver condition, driver distraction, vision obstruction, vehicle defect, the vehicle involved, road surface condition, road alignment, roadway grade, weather condition, and lighting condition. Results show that the impacts of lightning conditions and driving speed had significant variation across observations. This variation could be attributed to driver actions, state, and vision obstruction.

Wu et al. [25] use roadway segment length, average daily traffic (ADT), average annual precipitation, average annual snowfall, percentage of trucks, number of interchanges, speed limit, friction number of pavement surface, number of horizontal curves, ADT of trucks, and number of grade breaks as independent variables. Penmesta et al. [26], for example, used MNL to model and identify important road characteristics (or locations) based on crash injury severity, as well as identify drivers who are more likely to contribute to crashes given road feature.

The current study offers significant advantages over much of the previous research and can cover existing gaps. To begin with, analyzing numerous models onto a data set to obtain the best results is rare in prior studies. In addition, the majority of these research reported their findings using only one of the logit models, but we used three distinct logit models (OL, MNL, and ML) in our study. The usage of a wide variety of variables is the second plus point that distinguishes this paper.

As previously stated, we look into the effects of independent variables, including geometric design, time-related, weather, and environmental conditions, land use, traffic attributes, vehicle characteristics, and driver characteristics variables on crash severity. It is also worth noting that most previous studies exploring the key factors that contribute to crash severity have only looked at limited categories of the independent variables [27–29]. As a result, the current study provides a comprehensive result that can be used to improve the analysis.

Furthermore, in developing nations like Iran, crash severity analysis using a broad range of independent factors is a relatively new field. These research could help developing countries make the transition to development, making this paper even more valuable. The following sections provide more information on the data and the study's context.

3. Methodology

Crash severity models are designed to predict the likelihood that a crash will fall into one of the severity levels, given that the crash has occurred. The three crash severity models are described in this section: the ordered logit, multinomial logit, and mixed logit models.

3.1. Ordered Logit. One of the essential elements in creating crash severity models is the ordered nature of crash data (for example, in the field of severity; damage, injury, and fatal) [30]. In such models, the most frequent technique is to employ a latent variable Z to model the ordered entity of the data. This invisible variable is allocated to each observed crash as a linear function [31].

$$Z = \beta x + \varepsilon, \tag{1}$$

where x denotes the vector that specifies the discrete order of each crash recorded, β is a vector that can be used to estimate parameters, and ε denotes the error. The following is the definition of the observed ordered data of the severity of crashes, y [32]:

$$y = i \ if \ Z \geq \mu i - 1, \tag{2}$$

where μ are the estimated limit parameters that define y and μ is a parameter determined by β, which is the same as the

model parameters. If μ_0 is set to 0, the probability function will be as follows [32]:

$$P(y = i) = \varphi(\mu_i - \beta X) - \varphi\left(\mu_{i-1} - \beta X^1\right). \quad (3)$$

The upper and lower bounds for the severity of the crash are indicated by and, respectively. An ordered logit model is created by examining the logistic distribution of observations for the error section.

The ordered logit technique, on the other hand, has two flaws. First, the under-reporting of accident severity data makes probability models vulnerable to incoherent and biased parameter estimates. In many circumstances, the presence of a negative x coefficient does not provide us with a correct understanding of the data's current reality. A thorough examination of the data is essential to obtain a better prediction.

3.2. Multinominal and Mixed Logit. Let the utility that individual n derives from alternative j in choice scenario t be denoted as [33]

$$U_{njt} = \beta' x_{njt} + \varepsilon_{nit}. \quad (4)$$

x_{njt} is a vector of seen qualities, n is a vector of utility coefficients that vary randomly between people, and njt is a random term representing the unobserved utility component. 0/1 terms can be included in the vector x_{njt} to allow alternative-specific constants, individual attribute levels, and continuous attributes [33].

The unobserved term njt is supposed to have a value of iid extreme. Under this premise, the logit formula calculates the likelihood that individual n will choose alternative i in choice circumstance t, conditional on n.

The researcher does not observe the utility coefficients of each individual but is aware that they vary between individuals. F, which is dependent on parameters, is the cumulative distribution function of n in the population. Distinct elements may follow different distributions, the distribution can be continuous or discrete (including some being fixed), and the aspects can be linked to one another [34].

Given the researcher's information, the choice probability for the person's sequence of choices with continuous F is

$$L_{nit}(\beta_n) = \frac{e^{\beta' n^x nit}}{\sum_j e\beta' n^x njt}. \quad (5)$$

A mixed logit model's probability function is an integral of a multinomial logit model's probability function on a density function of parameters [35]. The density associated with F is denoted by f. If F is discrete, the mixed logit formula is as follows:

$$Pnit = \int L(\beta) f(\beta \mid \theta) d\beta. \quad (6)$$

McFadden and Train [36] demonstrated that any choice model could be used with any distribution of parameters. F considers different distributions such as normal, log-normal, and triangular. In the mixed logit model, the normal distribution is the most commonly utilized distribution. A mixed logit can approximate preferences to any degree of accuracy. This is the end outcome, which means that there are no theoretical constraints on the decision in the mixed logit model [37].

Table 1: Summary of crash severity data.

Variable description	Damage		Injury		Fatal		All
	Count	%	Count	%	Count	%	
Crash severity	175	38.21	253	55.24	30	6.55	485

4. Data

Khorasan Razavi province is one of the most crowded provinces located in the northeast of Iran. The diverse attributes of this province have caused to see a different and wide range of weather characteristics, from narrow roads in the relatively mountainous location of the north and northeast of the province to wide roads with a good level of service located in the desert environment of the south of the province. Road and climate diversities make this province a good sample for accident severity models. This study analyzes crash and traffic data for four years, from 2013 to 2016. Table 1 shows the candidate independent variables in the data set.

The dependent variable explored in this study is the severity of crashes examined at three levels of damage, injury, and fatal crashes. The total number of observed crashes in the data is 485. Table 1 shows the share of each crash severity. Also, Table 2 shows independent variables in the data set.

To integrate information related to crashes and traffic attributes such as traffic volume and average speed, recorded by traffic counters, circles are drawn to the centre of each traffic counter with different radius. Next, crashes and adjacent traffic information extracted from traffic counters are combined. This information was integrated by ArcGIS software. Due to the low number of crashes, the larger radius of the circle to the centre of each traffic counter leads to more included crashes. Finally, logit models were calibrated for a 2500 m radius for spatial analysis. Regarding the use of traffic data in modelling, it should be noted that traffic data are considered one hour before the occurrence of crashes for temporal features. Figure 1 shows an output of ArcGis software.

5. Result

In this study, crash severity is modelled by three logit family models: ordered, multinomial, and mixed logit. In this section, achieved results and related interpretations are presented.

5.1. Ordered Logit Model. Table 3 shows the result of calibrating the ordered logit model for crash severity.

Table 2: Independent variables in the data set.

No.	Variable	Feature	Description
1	Road type 1	Geometric design	Main, two-way, one-way
2	Road type 2	Geometric design	Nonseparate two-way road/separate two-way with physical separator/ One-way
3	Road type 3	Geometric design	Freeway – highway – intersection – main street – side street – main road – rural road – side road – square – Turn
4	Time of crash	Time-related	Afternoon, morning, night, noon, sunrise, sunset
5	Road characteristics	Geometric design	Level difference between asphalt and shoulder – nonstandard transverse and longitudinal slope – nonstandard safety guard on the side of the road – lack of safety guard on the side of the road - lack of shoulder and parking – sharp angle arch – road subsidence – road marking defect – road lighting defect – road asphalt defect – defect of horizontal signs – defect of vertical signs - existence of an obstacle – narrow width of the passage - other – no defect
6	Lighting condition	Weather and environmental conditions	Day-night with enough light – night without enough light - sunrise – Sunset
7	Surface condition	Weather and environmental conditions	Waterlogged – wet-dry and normal – oily and dirty – sandy – bituminous – frost and snow – other
8	Shoulder condition	Geometric design	Asphalt shoulder – dirt shoulder – no shoulder
9	Sight obstacle	Geometric design	Panel – mound – tree and plant – building – slope – sandstorm – vertical arc – fog and smoke – sunlight – headlight of the vehicle in front – vehicle while moving – vehicle stopped – blizzard – frost glass of the vehicle – other –no obstacles.
10	Maintenance condition	Geometric design	Repair with adequate marks – repair without sufficient marks - not repaired
11	Road equipment failure	Geometric design	Passenger safety protection – road surface – signs – no damage
12	Land use	Land use	Educational-administrative and commercial-recreational-industrial-non-residential-residential-agricultural-other
13	Location of the crash	Geometric design	Main road – off-road – medium refuge – shoulder – roadside – Other
14	Weather condition	Weather and environmental conditions	Cloudy – rainy – snowy – clear – stormy – dusty – foggy
15	Geometric condition of the road	Geometric design	Tunnel – straight uphill – straight, downhill – straight, flat – bridge – uphill turn – flat turn
16	Sign condition	Geometric design	Double – cross section – continuous – does not have
17	Speed limits (Km/h)	Traffic attributes	(0–40)-(40–60)-(60–80)-(80–100)-(100–120)
18	Vehicle defect	Vehicle characteristics	Tire smoothness – lack of snow deflectors in case of emergency – suspension device defect – lack of wheel chains in case of emergency – brake system defect – lighting system defect - handling system defect – other – No defect
19	Effective driver characteristics	Driver characteristics	Drug use – tiredness and drowsiness – weakness due to old age – unhurried haste and acceleration – lack of familiarity with the road – lack of recognition of the right of way – alcohol consumption – effective organ failure – Other
20	Identified effective factor in the crash	Mix	Deviation to the right – deviation to the left – sudden opening of the vehicle door – exceeding the speed limit – violation to the left due to overtaking – sudden change of direction – reversing – moving in the opposite direction – pedestrian error – bypassing in a forbidden place – passing from the forbidden place – inability to control the vehicle – failure to pay attention to the front – failure to observe the right of way – failure to observe the distance –failure to observe the transverse distance – defects in cargo regulations – wrong turning – wrong towing – Other
21	The first part of the crash	Vehicle characteristics	Ambulance – bus – livestock – road construction equipment – agricultural equipment – tanker carrying hazardous materials – trailer – firetruck – police car – bicycle – riding – motorcycle – pedestrian – minibus – vantage – truck – Other
22	Points of collision of the first party of the crash	Vehicle characteristics	Front – front and rear – front and right side – front and left side – front, rear and right side – front, rear and left side – front, rear, right side, and left side – back – back and right side – back and side left – rear, right side, and left side – right side – right side and left side – left side

Table 2: Continued.

No.	Variable	Feature	Description
23	First party crash violation	Driver characteristics	Stopping off-road – stopping at the level of the road – sudden stop – moving forward – moving rear – drifting – overtaking – Sudden start – turning right – turning left – Other
24	Age of the first party of the crash	Driver characteristics	(0–18)-(18–40)-(40–60)-(60–80)-(80–120)
25	Gender of the first party of the crash	Driver characteristics	Male – Female
26	The second part of the crash	Vehicle characteristics	Ambulance – bus – animals – road construction equipment – agricultural equipment – tanker carrying hazardous materials – trailer – firetruck – police car – bicycle – riding – motorcycle – pedestrian – minibus – vantage – truck – truck – Other
27	Points of collision of the second party of the crash	Vehicle characteristics	Front – front and rear – front and right side – front and left side – front, rear and right side – front, rear and left side – front, rear, right side, and left side – back – back and right side – back and side left – rear, right side, and left side – right side – right side and left side – left side
28	Age of the second party of the crash	Driver characteristics	(0–18)-(18–40)-(40–60)-(60–80)-(80–120)
29	Gender of the second party of the crash	Driver characteristics	Male – Female
30	Pedestrian status as the second party in the crash	Driver characteristics	Off-road – getting on or off the vehicle – while pushing the vehicle – while working on the vehicle – standing on the side of the road – sudden running on the road – crossing the road from the permitted route – crossing road obstacles – crossing in the opposite direction of the vehicle – crossing in line with the vehicle – other
31	Familiarity with the road of the first party of the crash	Driver characteristics	Native/non-native/unspecified
32	Variables related to traffic volume	Traffic attributes	The volume of passing vehicles of class 1[2] – volume of passing vehicles of class 2[3] – volume of passing vehicles of class 3[4] – volume of passing vehicles of class 4[5] – volume of the passing of vehicles of class 5[6] – volume of the passing of heavy vehicles – volume of the passing of total vehicles – average weight of heavy vehicle traffic volume, medium heavy vehicle traffic volume, standard deviation of heavy vehicle volume, heavy vehicle traffic volume, minimum heavy vehicle traffic volume, maximum traffic volume of heavy vehicles, weighted average volume and transit traffic of all vehicles, average volume and transit traffic of all vehicles, standard error of volume and transit traffic of all vehicles, skew volume and transit traffic of all vehicles, minimum volume and transit traffic of all vehicles, maximum volume and transit traffic of all vehicles.
33	Headway	Traffic attributes	Weighted average headway of all vehicles, average headway of all vehicles, standard deviation headway of all vehicles, skew headway of all vehicles, minimum headway of all vehicles, maximum headway of all vehicles
34	Average speed	Traffic attributes	Average weight average speed of all vehicles, standard deviation average speed of all vehicles, skew average of speed of all vehicles, the minimum average speed of all vehicles, the maximum average speed of all vehicles

[1]Independent and identically distributed. [2]Truck and bus. [3]Car. [4]Motorcycle. [5]Trailer and loader. [6]Van and mini-truck

Independent variables consist of traffic, geometric, human, vehicle, weather, land use, and time variables in this model.

Results show that the minimum headway as a traffic attribute variable is one of the influential variables on crash severity. As the minimum headway increases, the severity of crashes decreases because it gives the driver more time to decide and react before the crash. The nonseparate two-way road has a positive effect on increasing the severity of crashes; this means that on nonseparate two-way roads, there is a possibility of colliding with higher intensity due to the lack of protection between the two routes. Recreational land use has a positive effect on increasing the severity of crashes on suburban roads. Sudden changes in the speed at recreational land use sites on suburban roads increase the probability of more severe collisions and crashes. Snowy weather with a coefficient of −1.198 reduces the severity of crashes because the mental prerequisite of drivers in snowy weather is caution and drivers in snowy weather drive more cautiously. The negative coefficient for the negative slope turn means a decreasing trend in the severity of crashes. The

Figure 1: Integration of traffic attributes and crashes in ArcGIS.

Table 3: Calibration result of ordered logit model.

Choice	Variable	Coefficient	*t*-value
Damage Injury Fatal	Dummy variable, if the shoulder of the road is made lf soil = 1, otherwise = 0	0.410	4.05
	Minimum headway	−0.00017	−2.73
	Dummy variable, if the vehicle has a continuous technical defect = 1, otherwise = 0	−0/705	−1/69
	Dummy variable, if the left turn of the vehicle is the cause of the crash = 1, otherwise = 0	0.722	3.45
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0	0.637	7.03
	Dummy variable, if the road has protection = 1, otherwise = 0	0.431	2.10
	Dummy variable, if the land use is recreational = 1, otherwise = 0	0.891	5.87
	Dummy variable, if there be a middle refuge = 1, otherwise = 0	0.563	3.19
	Dummy variable, if it is snowy = 1, otherwise = 0	−1.198	−4.46
	Dummy variable, if it is negative slope turn = 1, otherwise = 0	−1.511	−5.08
	Dummy variable, if the bus is involved in an crash = 1, otherwise = 0	−0.624	−2.15
	Dummy variable, if the truck is involved in an crash = 1, otherwise = 0	−0.884	−3.18
	Dummy variable, if the land use is agricultural = 1, otherwise = 0	0.780	5.39
	Dummy variable, if the trailer is involved in the crash = 1, otherwise = 0	−1.447	−5.01
Number of observations	3262		
LL0	−2749.101		
LLβ	−2650.906		
p2	0.035		

presence of vehicles in the negative slope turn equals low speeds. If the vehicle is a bus, truck, or trailer, the severity of crashes is lower than other vehicles. The lower speed of these vehicles can justify this finding. Agricultural land use is also effective in more severe crashes. The presence of agricultural machinery and more road damage in this land use are the two main factors that increase the severity of crashes in more agricultural land use areas.

5.2. Multinnominal Logit Model. Table 4 shows the results of calibrating the multinominal logit model for the severity of crashes.

The variable "narrow width of the passage" increases the severity of accidents. Office commercial land use has a significant effect on the occurrence of damaging crashes. In suburban roads, places with office-commercial land use have heavy and crowded traffic, which can be effective in low-severity crashes (damage). "Speed limit of 40 km/h for vehicles" is one of the traffic attribute variables that affect the occurrence of damage crashes. "A malfunction of the vehicle's braking system" has a positive effect on the event of damage crashes. It can be expected that drivers are aware of the defect of the brake system and, as a result, use caution in their driving. "Driver operating under the age of eighteen" is involved in the occurrence of damaging crashes. Despite the higher excitement of people at this age, the fear of possible crashes and the consequences of driving without a license overcomes that excitement to some extent, causing drive more cautiously and then leading to less severe crashes

Table 4: Calibration result of multinomial logit model.

Choice	Variable	Coefficient	t-value
Damage	Constant	−0.08	−0.39
	Dummy variable, if the path is narrow = 1, otherwise = 0	0.368	2
	Dummy variable, if the road is straight and flat = 1, otherwise = 0	0.2	1.87
	Dummy variable, if the shoulder of the road is made lf soil = 1, otherwise = 0	0.463	3.95
	Dummy variable, if it is an official-commercial land use = 1, otherwise = 0	1.085	2.93
	Dummy variable, if the speed range is between zero and 40 km/h = 1, otherwise = 0	0.744	2.88
	Dummy variable, if the brake system has failure = 1, otherwise = 0	1.415	1.94
	Dummy variable, if the left turn of the vehicle is the cause of the crash = 1, otherwise = 0	0.857	3.59
	Dummy variable, if the driver is under the legal age of 18 = 1, otherwise = 0	1.873	1.79
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0	0.571	4.87
	Dummy variable, if the driver's haste and acceleration according to the driver's self-declaration or the testimony of witnesses is the cause of the crash = 1, otherwise = 0	0.18	1.95
	Dummy variable, if the driver's unfamiliarity with the road is effective = 1, otherwise = 0	0.788	1.83
Injury	Dummy variable, if it is rainy = 1, otherwise = 0	0.433	2.94
	Dummy variable, if the vehicle has a continuous technical defect = 1, otherwise = 0	0.941	2.02
	Dummy variable, if the road has protection = 1, otherwise = 0	−0.608	−2.4
	Dummy variable, if the land use is recreational = 1, otherwise = 0	−1.528	−7.5
	Dummy variable, if the land use is residential = 1, otherwise = 0	−1.444	−9.66
	Dummy variable, if there be a middle refuge = 1, otherwise = 0	−1.092	−4.82
	Dummy variable, if it is snowy = 1, otherwise = 0	0.629	2.2
	Dummy variable, if it is negative slope turn = 1, otherwise = 0	0.652	1.92
	Dummy variable, if the bus is involved in an crash = 1, otherwise = 0	0.86	2.72
	Dummy variable, if the truck is involved in an crash = 1, otherwise = 0	0.908	3.05
	Dummy variable, if the driver's gender is male = 1, otherwise = 0	0.492	2.64

Table 4: Continued.

Choice	Variable	Coefficient	t-value
Fatal	Constant	−0.913	−1.89
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0	0.571	4.87
	Dummy variable, if the driver's haste and acceleration according to the driver's self-declaration or the testimony of witnesses is the cause of the crash = 1, otherwise = 0	0.18	1.95
	Dummy variable, if the driver's unfamiliarity with the road is effective = 1, otherwise = 0	0.788	1.83
	Dummy variable, if it is rainy = 1, otherwise = 0	0.433	2.94
	Dummy variable, if the vehicle has a continuous technical defect = 1, otherwise = 0	0.941	2.02
	Dummy variable, if the crash time is in the afternoon = 1, otherwise = 0	−0.434	−1.73
	Dummy variable, if the land use is agricultural = 1, otherwise = 0	−0.515	−1.8
	Dummy variable, if the speed range is between 80 and 100 km/h = 1, otherwise = 0	−0.503	−1.8
	Dummy variable, if the cause of the crash is overtaking = 1, otherwise = 0	1.714	2.97
	Dummy variable, if the trailer is involved in the crash = 1, otherwise = 0	0.954	2.14
Number of observations	3262		
LL0	−2157.3		
LLβ	−1866.8		
p2	0.129		

(damage). "Nonseparated two-way road" as a geometric design variable has become significant in both damaging and fatal crashes. "Driver's unfamiliarity with the road" is an effective and significant factor in both damage and fatal crashes.

In most cases, unfamiliar drivers drive cautiously, which makes the accident less severe. In some cases where these drivers drive recklessly, their unfamiliarity with the road leads to high-severity crashes that lead to fatal crashes. "Rainy weather" has a direct effect on both injuries and fatalities. "The slippery road surface after rain" directly is effective in the occurrence of injuries and fatalities (higher severity). "Residential land use" is effective in preventing the occurrence of injuries. In fact, in suburban areas with residential land use, such as residential towns, the vehicle speed is generally slower, and drivers drive more cautiously, which effectively reduces injuries. "Snowy weather" has a positive effect on the occurrence of injuries due to limited visibility and slippery road surface. "Negative slope turn" has a positive impact on the injuries. A negative slope automatically makes it more difficult to control the vehicle. Both buses and vans are expected to be among the heavy vehicles involved in severely injured crashes. In fact, due to these two vehicles' larger dimensions and weight, their collision causes an accident with severe injuries. The same interpretation applies to trailers for fatal crashes. The "male driver" positively affects injuries; there are two reasons for this: male drivers are more likely to drive on suburban roads than female drivers. The second reason is that male drivers drive more recklessly than female drivers. "The occurrence time of the accident in the afternoon, 2 to 5 pm", has a negative effect on the occurrence of fatal crashes. Adequate light in the afternoon and heavier traffic in the afternoon reduce the severity of the accident. "Agricultural land use" is effective in the occurrence of fatal crashes due to two important reasons: the presence of agricultural machinery (safety deficiency of these devices such as lighting) and further damage of roads with this land use. The "speed range of 80–100 km/h" has a negative effect on fatal crashes. One of the justifiable reasons could be the average speed limit for suburban roads, which is 90 km/h on two-way and 110 km/h on freeways. The speed range shows that this range is less than the average permitted

Table 5: Calibration result of mixed logit model.

Choice	Variable	Coefficient	t-value
Damage	Constant	−0.141	−0.60
	Dummy variable, if the path is narrow = 1, otherwise = 0	0.460	1.93
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0 (average)	0.978	3.01
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0 (standard deviation)	1.703	2.35
	Dummy variable, if the road is straight and flat = 1, otherwise = 0 (average)	0.280	2.32
	Dummy variable, if the road is straight and flat = 1, otherwise = 0 (standard deviation)	0.826	2.20
	Dummy variable, if the shoulder of the road is made lf soil = 1, otherwise = 0	0.548	3.81
	Dummy variable, if it is an official-commercial land use = 1, otherwise = 0	1.276	2.95
	Dummy variable, if the speed range is between zero and 40 km/h = 1, otherwise = 0	0.832	2.61
	Dummy variable, if the brake system has failure = 1, otherwise = 0	1.628	1.89
	Dummy variable, if the left turn of the vehicle is the cause of the accident = 1, otherwise = 0	0.971	3.29
	Dummy variable, if the driver is under the legal age of 18 = 1, otherwise = 0	2.059	1.79
	Dummy variable, if the driver's haste and acceleration according to the driver's self-declaration or the testimony of witnesses is the cause of the accident = 1, otherwise = 0	0.232	2.07
	Dummy variable, if the driver's unfamiliarity with the road is effective = 1, otherwise = 0	0.996	1.91
	Dummy variable, if the motorcycle is one of the parties to the accident = 1, otherwise = 0	3.437	6.81
Injury	Dummy variable, if it is rainy = 1, otherwise = 0	0.465	2.28
	Dummy variable, if the vehicle has a continuous technical defect = 1, otherwise = 0	1.048	1.91
	Dummy variable, if the road has protection = 1, otherwise = 0	−0.693	−2.36
	Dummy variable, if the land use is recreational = 1, otherwise = 0	−1.768	−6.81
	Dummy variable, if the land use is residential = 1, otherwise = 0 (average)	−2.548	−2.85
	Dummy variable, if the land use is residential = 1, otherwise = 0 (standard deviation)	2.251	1.73
	Dummy variable, if there be a middle refuge = 1, otherwise = 0	−1.285	−4.87
	Dummy variable, if it is snowy = 1, otherwise = 0	0.779	2.30
	Dummy variable, if the bus is involved in an accident = 1, otherwise = 0	1.046	2.64
	Dummy variable, if the truck is involved in an accident = 1, otherwise = 0	1.097	2.92
	Dummy variable, if the driver's gender is male = 1, otherwise = 0	0.594	2.69

Table 5: Continued.

Choice	Variable	Coefficient	t-value
	Constant	−2.270	−9.05
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0 (average)	0.978	3.01
	Dummy variable, if two-sided road is nonseparate = 1, otherwise = 0 (standard deviation)	1.703	2.35
	Dummy variable, if the driver's haste and acceleration according to the driver's self-declaration or the testimony of witnesses is the cause of the accident = 1, otherwise = 0	0.232	2.07
	Dummy variable, if the driver's unfamiliarity with the road is effective = 1, otherwise = 0	0.996	1.91
	Dummy variable, if it is rainy = 1, otherwise = 0	0.465	2.28
Fatal	Dummy variable, if the vehicle has a continuous technical defect = 1, otherwise = 0	1.048	1.91
	Dummy variable, if the accident time is in the afternoon = 1, otherwise = 0	−0.461	−1.80
	Dummy variable, if the land use is agricultural = 1, otherwise = 0	0.564	1.80
	Dummy variable, if the speed range is between 80 and 100 km/h = 1, otherwise = 0	−0.551	−1.90
	Dummy variable, if the cause of the accident is overtaking = 1, otherwise = 0	1.722	2.87
	Dummy variable, if the trailer is involved in the accident = 1, otherwise = 0	1.017	2.19
	Dummy variable, if the motorcycle is one of the parties to the accident = 1, otherwise = 0	3.437	6.81
Number of observations	3262		
LL0	−2884.955		
LLβ	−2157.268		
p2	0.135		

value (100 km/h) of suburban roads. The "motorcycle" is effective in both damaging and fatal crashes. In Iran, many motorcycles are without safety equipment, riding at an unauthorized speed and in the middle sections of the route.

5.3. Mixed Logit Model. Table 5 shows the output of the combined logit model of accident severity, which includes geometric design, time-related, weather and environmental conditions, land use, traffic attributes, vehicle characteristics, and driver characteristics variables, which were examined at three levels of severity: damage, injury, and fatal.

Like the multinominal logit model, the variable "path width" positively affects damaging crashes. "Road shoulder" is one of the geometric design variables that plays an effective role in the occurrence of damage crashes. The presence of the shoulder itself is an influential factor in decreasing the severity of crashes or avoiding it. Still, the soil characteristic of the shoulder leads to an accident with severe damage. Like the multinominal logit model, office-commercial land use significantly affects the occurrence of damaging crashes, and "40 km/h speed limit for vehicles" is one of the traffic variables that affect the event of damage crashes. "Vehicle brake system malfunction" is effective in the occurrence of damage crashes. The "underage driver (under the age of eighteen)" is involved in damage crashes. The "nonseparated two-way road" as a geometric design variable is significant in fatal and fatal crashes, similar to the multinomial logit model. The "driver's unfamiliarity with the road" is an effective and influential factor in both fatal and fatal crashes, and "rainy weather" directly affects both injuries and fatalities. The "motorcycle" is one of the influential variables in the occurrence of crashes on suburban roads. The variable "continuous technical defect in the vehicle" is effective in both injury and fatal crashes. The vehicle driver is often aware of this problem but ignores it, such as broken lights

and tire defects, leading to more severe crashes. The "residential land use" is effective in preventing injuries. Like the multinominal logit model, "snowy weather" positively affects the occurrence of injuries due to limited visibility and slippery road surface. The "bus" and the "truck" cause crash with severe injuries. The "the time of the accident in the afternoon, from 2 to 5 pm" decreases the probability of fatal crashes, and "agricultural land use" is effective in fatal crashes. The multinominal logit model, "speed range of 80–100 km/h", has a negative effect on fatal crashes.

6. Conclusion

The high severity of crashes is one of the negative consequences of suburban transportation. People killed, injuries and hospital expenditures, road and vehicle damage, and psychological repercussions are all part of the serious crash costs. This study used the descriptive logit model family to try to figure out what factors influence the severity of crashes on the Khorasan Razavi province's suburban roads in Iran's northeast. Crash severity is classified into three categories: damage, injury, and fatal. We had the opportunity to analyze one of the most comprehensive databases with the integration of crash data and data obtained from traffic counters over a four-year period, including geometric design, time-related, weather and environmental conditions, land use, traffic attributes, vehicle characteristics, and driver characteristics as independent variables. The following conclusions are drawn from interpreting our data using three logit models (OL, MNL, and ML) and comparing their results:

(1) The ordered logit model has a p2 of 0.035, the multinominal logit model has a p2 of 0.129, and the mixed logit model has a p2 of 0.135. In terms of p2, there is a progression from the ordered logit model to the multinominal logit model and then to the mixed logit model.

(2) When it comes to crash severity, the geometric design, vehicle characteristics, driver characteristics, land use, and weather and environmental condition variables are more likely to be crucial. Because the above factors showed significance in all of the logit models examined in this study. As a result, developing countries, such as Iran, should pursue methods that place a greater emphasis on these influential factors in order to mitigate the severity of crashes.

(3) Based on the findings of this study, the following policies can be mentioned as effective in Khorasan Razavi province that can help reduce the severity of crashes. Variables in geometric design, such as "road shoulders" and "nonseparated two-way road", can be improved. Educating society's underage sections can help to promote good behavior and prevent many of the human-related impact elements from occurring in the future. Anticipate efficient traffic management strategies in adverse weather conditions. The traffic police will be stricter in the future when it comes to vehicle defects. To avoid vehicle characteristics-related factors, traffic police can be stricter once it regards to vehicle defects. It is also proposed that traffic attributes such as "speed limit" can be better controlled by increasing the number of traffic cameras and police officers.

The conclusions of this study could be improved by a number of future research directions. First, to give a quantitative comparison of such diverse situations, it would be useful to assess the model's geographic transferability versus models in developed countries [38]. It is also worthwhile considering temporal employability to see if findings are consistent throughout time or if they alter from year to year. Furthermore, more research can be done to identify why crash data are underrepresented in the data collection; one option is to expand the data set's geographical coverage. Finding methods to boost crash records, such as developing upsampling algorithms to simulate missing observations, could be significant [39]. Finally, evaluating the contribution of various proposed transportation policies in the event that they are implemented in the Khorasan Razavi province in the future would be advantageous.

Data Availability

Access to data is restricted due to third-party rights.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: The Dimensional Structure of Tourism Festival and Special Event Innovation and Their Impacts on Tourists' Behavioral Intentions

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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Research Article

The Dimensional Structure of Tourism Festival and Special Event Innovation and Their Impacts on Tourists' Behavioral Intentions

Chaojun Li and Ping He

Tourism and Historical Culture College, Zhaoqing University, Zhaoqing, Guangdong 526061, China

Correspondence should be addressed to Ping He; thisisheping@gmail.com

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The tourism festival and special event innovation are the important factors influencing the creation of superior value, the achievement of customer loyalty, and profitable growth. Based on the perspective of product supply and consumer demand integration analysis, this paper constructed an integrated model of tourism festival and special event innovation and its impacts on tourists' behavioral intentions. The basic data was obtained through the tourist survey on Zhangjiajie International Country Music Festival, and the exploratory factor analysis, confirmatory factor analysis, and structural equation modeling were used to empirically test the relationship between various dimensions of tourism festival and special event innovation and their impacts on tourists' behavioral intentions. The results show the following: (1) tourism festival and special event innovation includes six dimensions of performance, accessibility, self-service technology, aesthetic environment, tourist community, and loyalty program; (2) performance, self-service technology, and aesthetic environment have a significant positive impact on overall innovation, while accessibility, tourist community, and loyalty program have no significant impact on overall innovation; and (3) overall innovation has a significant positive impact on tourists' satisfaction, brand equity, and tourists' behavioral intentions. Moreover, tourists' satisfaction and brand equity play a partial intermediary role in the impacts of overall innovation on the tourists' behavioral intentions. The article concludes with research limitations and future research directions.

1. Introduction

Festivals and special events with thousands of years of history and tradition have shown a trend of integration with tourism at this stage. Tourism festivals and special events have become a huge global industry and an important tool for governments and related companies to attract tourists to create profits [1]. According to the history and trends of the development of world tourism festivals and special events, tourism festivals and special events generally experience three stages of development: localization, internationalization, and innovation [2]. Tourism festivals and special events are highly concerned. For example, China's tourism festivals and special events present a development trend of large amounts and rich forms. Hosting the International Horticultural Exhibition, the Olympic Games, and the World Expo has promoted the rapid development of China's tourism festivals and special events from the localization stage to the internationalization and innovation stage. Meanwhile, China's tourism festivals and special events also show the characteristics of insufficient innovation power, loose organizational structure, and government-oriented goal orientation. However, they face the dilemma of wanting to innovate and difficult to innovate [3]. In the theoretical cycle, researchers have recognized that innovation is a key factor in successfully hosting tourism festivals and special events [4, 5] and is an important means for tourism festival and special event organizers to achieve and maintain high competitiveness and achieve rapid growth [6–9]. Unfortunately, as pointed out by Thomas and Bowdin [10], tourism festival and special event innovation has not received enough attention; for example, what do tourism festival and special event innovation bring to tourism companies? What does it bring to the tourism festival and special event tourists? Does it improve the perception of service quality or enhance the perceived value? Has it improved the overall image or

improved its overall competitiveness? These basic key questions about tourism are lacking in empirical answers.

Based on the above questions, this paper built an integrated model of tourism festival and special event innovation and its impacts on tourists' behavioral intentions using the related theories of product innovation and service marketing with the perspective of product supply and consumer demand integration analysis. Through the tourist surveys on Zhangjiajie International Country Music Festival, as well as the exploratory factor analysis, confirmatory factor analysis and structural equation modeling were used to empirically test the relationship between various dimensions of tourism festival and special event innovation and overall innovation, tourists' satisfaction, and brand equity and its impacts on tourists' behavioral intentions so as to respond to the basic key questions about tourism festivals and special events.

2. Literature Review and Theoretical Model Construction

2.1. Definition of Related Concepts

2.1.1. Festivals and Special Events. Festivals and special events are a popular activity of planning beforehand and could motivate consumers' enthusiastic anticipation, participation, and celebration [11]. The scope of the festivals is wide, covering large-scale events, festivals, and special events. Festivals have distinct cultural, economic, and tourism characteristics, while careful planning, strict management, and coordination are necessary conditions for success. Besides, the MICE (meetings, incentives, conventions, and exhibitions) commonly refers to tourism events, which refers to a comprehensive activity based on various types of conferences, expositions, cultural celebrations, festival celebrations, and sports events. At present, the definition of tourism festivals and special events has not yet reached a consensus. Based on the perspective of tourism product demand, tourism festivals and special events are defined as a special form of tourism by some scholars. From the perspective of product supply, tourism festivals and special events are defined as a special tourism product by other authors. In a broad sense, the tourism festivals and special events recognized by scholars are basically equivalent to the MICE concept. Therefore, tourism festivals and special events can be defined as a comprehensive activity that can bring comprehensive benefits to the organizers and participants and is oriented by the development of tourism and based on various conferences, expositions, cultural celebrations, entertainment events, and sports events.

2.1.2. Product Innovation and Product Innovative Nature. At the level of product innovation theory, radical or incremental innovation of tangible products is the focus of traditional product innovation research [12, 13]. Service methods, store environments, and information technology management innovation are the focus of service innovation research [14–17]. Product innovation refers to the development of new tangible products or intangible services to meet external market demand. Product innovation has completely different meanings for businesses and consumers [8, 18], with the former focusing on radical innovation and the significance of radical innovation for sales revenues [19], while the latter focusing on the novelty of product innovation and innovation in product usage patterns [20]. In short, product innovation is the development of new product or the development of new market; product innovation refers to the novelty and uniqueness of new products to consumers. Adopting the novel consumer ideas is a major research thought for product innovation [21–24].

2.1.3. Tourism Festival and Special Event Innovation and Tourism Festival and Special Event Innovative Nature. There are mainly transactions of intangible services and festival experiences involved between the festival and special event organizers and the festival and special event tourists. From the perspective of tourists, the innovation of tourism festivals and special events includes the venues and environment of tangible festivals special events, intangible festival and special event performances, and services and experiences. In the eyes of tourists, tourism festival and special event innovation depend on the novelty of tourism products and their consumption patterns. As such, capturing the cognition and perception of tourists on innovation points of tourism festival and special event products is the key to understanding tourism festival and special event innovation. Product innovation is differentiated by the innovative nature of the products. For instance, consumers often look at and judge the innovation of products from the perspectives of novelty, uniqueness, difference, innovation, and functional changes [19, 25, 26]. In order to understand the basic attributes of tourism festival and special event innovation from the perspective of tourists, this study defines tourism festival and special event innovation as the perception of the tourism festival and special event tourists on the novelty and uniqueness of tourism festival and special event products.

2.2. Dimensional Structures of Tourism Festival and Special Event Innovation. Thinking analysis logic based on what, how, who, and where is the basic path of innovation research [14, 27–30]. It gradually developed into four basic paradigms of innovation researches: what paradigm focusing on supply, how paradigm focusing on services, where paradigm focusing on scenes, and who paradigm focusing on relations [22]. Authors in different disciplines have conducted extensive studies on innovation based on these perspectives and paradigms [28, 31, 32]. Sawhney et al. [28] believe that the single-dimensional research paradigm does not get rid of the shackles of traditional innovation theory. Originating from multidimensional logic and integrated researches are the fundamental way to break through the traditional innovation studies. On the basis of criticizing traditional research methods, they put forward the perspective of deepening the supply, service, scene, and relationship integration of cognition and innovation. They believed that

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enterprise innovation was the process of creating one-dimensional or multidimensional changes based on a four-dimensional perspective to create customer values. For different types of enterprises, their production, service, and value characteristics are different, so their reflection in the four-dimensional innovation points is different [14].

Tourism festival and special event innovation can be traced back to the staged performance type models [33]. The festival and special event performance is a form of staged performance, mainly including skill and passion performances. Skill performances allow tourists to enjoy the performances of skilled performers in a natural and unpredictable state. Passionate performances allow tourists to participate in performance projects in an unpredictable state. The novelty and uniqueness of tourism festival and special event performances reflect the innovation of tourism festivals and special events.

The innovation of the tourism festival and special event process stems from Berry et al.'s [14] service innovation model. This model pays special attention to the impact of accessibility and self-service technology on process innovation. Under the conditions of tourism festivals and special events, tourists obtaining the help of the festival and special event service staff will be restricted by various objective conditions, and accessibility will be especially important. This is the most overlooked aspect of tourism festival and special event organization. Self-service technology can enhance the convenience of separation and inseparability services and provide new service experiences and service benefits for tourism festival and special event tourists.

Tourism festival and special event scene innovation can be traced back to the aesthetic environmental quality model [34, 35]. Tourism festival and special event scene innovation is a pleasing and sensory pleasing perception of the festival and special event tourists on the festival and special event scene designs. The psychological interests of tourists are enhanced by perfecting the aesthetic design consistent with the theme of the festivals and special events. Tourism festival and special event aesthetic scene innovation is the perception of the novelty and uniqueness of the physical and mental emotions brought by the environment of the festivals and special events.

The innovation of tourism festival and special event relations originates from the symbiotic relationship model between enterprises and consumers [36]. Customer-enterprise relationships and customer-customer relationships are the two pillars of the theory of enterprise social connections [35]. In view of product innovation, the innovation of tourist loyalty program is the feeling of the festival and special event tourists on the novelty and uniqueness of the festival and special event plans, aiming to help tourists to establish contact with tourism festivals and special events; tourism community innovation is the sense of tourists on the professionalism and the novelty and uniqueness of the non-geographical restriction tourist communities, aiming at establishing and facilitating the connections between the festival and special event tourists.

With the help of the relative achievements of service quality and customer assets, the attributes and characteristics of tourism festival and special event innovation can be further understood in depth [22]. First, the multidimensional nature of service quality is similar to the tourism festival and special event innovation. The quality of the subject and guest interaction and the quality of the physical environment are both issues of importance. Although the quality of service is valued by the festival and special event organizers and managers, it is inevitable that there will be biases in understanding the tourism festival and special event innovation based on the service quality model. Similar to the traditional definition of service quality of customers, frontline employees, and service environment interaction quality, the core content of tourism festival and special event performances is neglected. Based on the excellent evaluation criteria (good or bad, high and low), the service quality model excludes the innovative attributes (new, uniqueness, and creation) from the innovation model of tourism festival and special event products. Besides, it is difficult to fully understand the connotation of tourism festival and special event innovation. Second, the multidimensional value of customer assets is similar to the innovative value of tourism festival and special event innovation. Value, relationship, and brand equity are the three perspectives for understanding customer assets. Value assets are the product consumption evaluations that consumers make after weighing expenses and acquisitions. This dimension is closely related to the supply, service, and scenarios preset by this study. Relationship assets are the relationship between customers and enterprises formed based on maintenance activities and relationship training. This dimension is closely related to the predetermined tourist community and tourist loyalty of this study.

This study drew on the innovative model analysis frameworks and ideas of Sawhney et al. [28], combining tourism festival and special event organizers, to understand tourism festival and special event innovation from the perspectives of supply innovation, service innovation, scene innovation, and relationship innovation. In addition, the marketing logic of tourism festival and special event services and experiences requires us to integrate companies, managers, and consumers to make the innovation points concerned by the festival and special event tourists as the most basic consideration for tourism festival and special event innovation [14]. Based on the above conclusions, we construct a conceptual model of tourism festival and special event innovation from the perspective of integration.

2.3. Research Hypotheses and Theoretical Models

2.3.1. The Relationship between Various Dimensions of Tourism Festival and Special Event Innovation and Overall Innovation. Early innovation studies are mainly based on Schumpeter's theory of technological innovation [37], taking obtaining patented technologies as the main indicator of product innovation; therefore, the technical indicators had naturally become the basic reference for innovation [38]. With the development of the innovation research paradigm, the consumer's psychological cognitive process and the cognitive dimension of product innovation had begun to be

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incorporated into the research horizon [39]. Deighton [33] constructed a staged performance-type model and empirically found that stage performance was the hardcore of the performance products of the festival and was the true embodiment of product innovation. Berry et al. [14] empirically studied the impact of accessibility and self-service technology on service innovation. The results showed that accessibility and self-service technology could enhance customers' perception of the overall innovation of service products. [40] indicated that customer-enterprise relationship and customer-customer relationship innovation had a direct and significant impact on product innovation. Rogers [20] regarded overall innovation as an overall evaluation of customers on innovative products. Rogers [20] also believed that consumers made attitude and behavior selection processes based on the evaluation of consumer needs and product innovation, reflecting the relationship between the product innovation points and overall innovation. Fang [21] regarded overall innovation as an attitude of organizations or enterprises adopting new ideas. It was empirically found that the key elements of overall innovation reflected the support or negative attitude of different types of customer groups for adopting new products. It can be seen that customer perception of innovation points has a significant impact on overall innovation. Based on the six dimensions of product innovation, this study proposed the following assumptions regarding the relationship between tourism festival and special event innovation and overall innovation:

(H1a) The perception of tourists on the festival and special event performances has a significant positive impact on the overall innovation of tourism festivals and special events.

(H1b) The perception of tourists on accessibility has a significant positive impact on the overall innovation of tourism festivals and special events.

(H1c) The perception of tourists on self-service technologies has a significant positive impact on the overall innovation of tourism festivals and special events.

(H1d) The perception of tourists on the aesthetic environment has a significant positive impact on the overall innovation of tourism festivals and special events.

(H1e) The perception of tourists on tourist community has a significant positive impact on the overall innovation of tourism festivals and special events.

(H1f) The perception of tourists on loyalty program innovation has a significant positive impact on the overall innovation of tourism festivals and special events.

2.3.2. The Relationship between Tourism Festival and Special Event Overall Innovation and Tourist Variables. Kirca et al. [39] studied the impact of organizational innovation on product quality perception and consumer loyalty and found that organizational innovation had a direct and significant impact on consumer variables. In their studies, organizational innovation was defined as organizational culture or corporate philosophy and was the degree of openness of the organization to new ideas. Product innovation was closely related to the specific attributes and characteristics of new products. The study results of Kirca et al. [39] and Rogers [20] confirmed that customer satisfaction and customer loyalty were functions of product innovation. Behavioral intentions have been confirmed by most studies as important outcome variables of customer loyalty. In the tourism works of literature, a large number of studies have confirmed that there is a significant correlation between tourists' satisfaction, revisiting tendency and word-of-mouth publicity [41]. Service quality, perception value, and tourists' satisfaction are the core variables established by the transaction marketing paradigm tourist loyalty researches; tourist trust and tourist commitment are the core variables established by the relationship marketing paradigm tourist loyalty researches [41]. In other words, whether it is transaction marketing or relationship marketing paradigm, attitude constructs are an important antecedent variable of behavioral intentions.

To better create the theoretical relationship between tourism festival and special event innovation and tourist variables, this study focuses on two important attitude-type constructs of tourists' satisfaction and brand equity. The relationship marketing theory believes that customer satisfaction is a response after consumers are satisfied and is a prerequisite emotional condition for positive word-of-mouth, repeated purchases and product loyalty [42]; brand equity is a cognitive key asset that maximizes long-term performance [43]. The study by Rogers [20] showed that customer satisfaction had a positive impact on brand equity. Therefore, incorporating the two attitude constructs of customer satisfaction and brand equity into the innovation-results chain will help to better understand the impact of tourism festival and special event innovation on the cognitive and emotional aspects of tourists.

Based on the above understanding, the following assumptions are made regarding the relationship between overall innovation and tourist variables:

(H2a) The tourists' festival and special event overall innovation perception has a significant positive impact on the satisfaction of the festival and special event experience.

(H2b) The tourists' festival and special event overall innovation perception has a significant positive impact on the brand equity of festivals and special events.

(H2c) The tourists' festival and special event overall innovation perception has a significant positive impact on their behavioral intentions.

(H3) Tourists' satisfaction has a significant positive impact on the brand equity of festivals and special events.

(H4) Tourists' satisfaction has a significant positive impact on their behavioral intentions.

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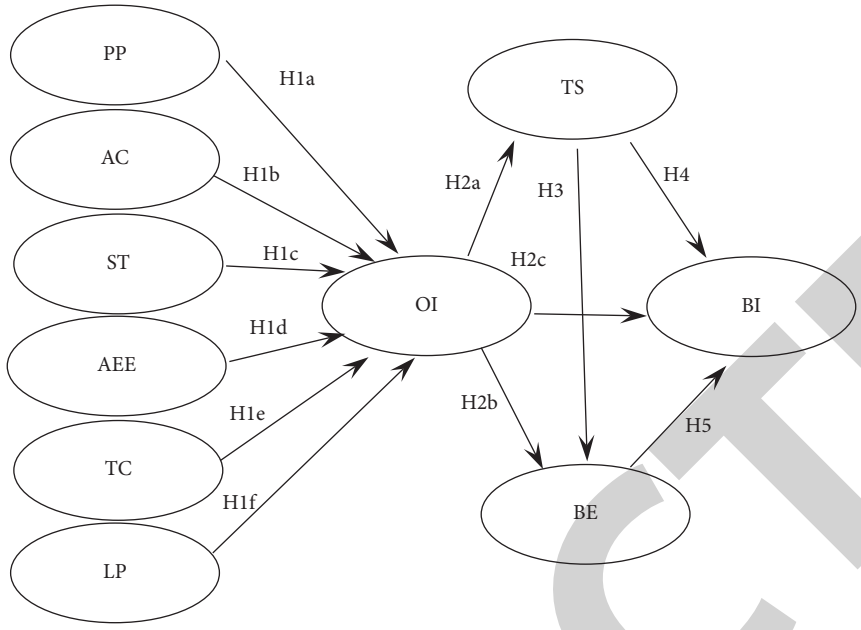

Figure 1: Theoretical model. *Note.* Potential variables in the set model are represented by corresponding English letters to save space. Among them, PP represents performance; AC represents accessibility; ST represents self-service technology; AE represents aesthetic environment; TC represents tourist community; LP represents loyalty program; OI represents overall innovation; TS represents tourist satisfaction; BE represents brand equity; and BI represents behavioral intentions. In Figures 2 and 3 as follows, the latent variables are also represented by the corresponding English letters, whose meanings are completely consistent with the set theoretical model.

(H5) Brand equity has a significant positive impact on tourists' behavioral intentions.

From the above research hypotheses, we have formed the theoretical model set in this study, as shown in Figure 1.

3. Research Design and Data Collection

3.1. Questionnaire Design. The related studies on the six-dimensional conceptual model supporting tourism festival and special event innovation are mainly conceptual [14, 28, 35], lacking the test of empirical research conclusions. Therefore, this study first develops and validates the tourism festival and special event innovation scale. The scale of six dimensions of tourism and festival innovation is mainly derived from existing research results. The performance dimension scale mainly refers to the Deighton [33] scale; the accessibility dimension scale and the self-service technology dimension scale are mainly from the Berry [14] scale; the aesthetic environment dimension scale mainly refers to Berry [14] and Zeithaml's (2003) scale; the tourist community dimensional scale and the tourist loyalty program dimension scale mainly refers to Oliver [36] and Zeithaml's (2003) scales after appropriate adjustment. The questionnaire was measured using the Likert 7-point scale. "1" means very disagreeable; "7" means very agreeable; "2–6" means "disagree," "disagree a little," "neutral," "agree a little," "agree generally," "agree."

In order to examine the relationship between the overall innovation and the tourists' variables, the overall innovation scale of the tourism festivals and special events selected by this study came from the research results of Fang [21] because this scale could fully reflect the consumers' overall attitude and recognition for innovative products. Similar to the attitude scale, the overall innovation scale is a semantic differential scale consisting of a series of bipolar adjectives (e.g., innovative-not innovative, interesting-boring, and novel-not novel), using the bipolar 7-point Likert scale to measure the overall innovation of tourism festivals and special events.

Tourists' satisfaction, as an emotional construct, was used to capture the emotional component of the tourists' attitude. The Cronin [44] scale was chosen for this study because it could be used to measure three important emotional responses of consumers (happiness, delight and satisfaction) to consumption objects. The Brady [44] scale was chosen for brand equity because this scale followed the Aaker [45] consumer brand equity conceptual paradigm and proposed four major indicators indirect measuring brand equity: image, attitude, quality, and consumer satisfaction. The behavioral intention questionnaire was derived from the Brady et al.'s [44] scale, which was used to measure festival and special event tourist recommendations, revisiting, and the budget for festival and special event expenses. Tourists' satisfaction, brand equity, and behavioral intentions questionnaires were also in the form of a bipolar 7-point Likert scale.

3.2. Research Object. The research object of this paper is Zhangjiajie International Country Music Festival. Zhangjiajie International Country Music Festival, which has been held for three times to now, is an international music festival activity founded by Zhangjiajie, a world natural heritage site

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and a national folk music culture and art township, aiming to build Zhangjiajie into an international country music brand and a sacred place of country music. Each session invited 30 national and folk music groups with typical country music characteristics and representing the world level from no less than 20 countries. Its interactivity, openness, specificity, artistry, and internationality have gradually become a benchmark of the international country music festival. It was evaluated as a successful practice of using cultural soft power to enhance the national image by the Ministry of Culture and Tourism of the People's Republic of China, and its creativity and innovation cover various aspects from the endorsement of the cartoon mayor to the form of performance of country music and then to the exchange of foreign culture. This study selected the Zhangjiajie International Country Music Festival case, took the tourists of the Zhangjiajie International Country Music Festival as the survey objects, and empirically tested the tourism festival and special event innovation model and the relationship between tourism festival and special event innovation and tourist variables.

3.3. Data Collection. In the sample survey of this paper, seven music performance venues including Huanglongdong Ecological Square Scenic Spot, Baofeng Lake, Shuirao Simen, Laomowan, Tianzishan, Tianmenshan, and Xibu Street were selected as survey sites by using the quasi-time-space ratio sampling method. The survey time was from August 31 to September 4, 2013. The questionnaires were kept and implemented by the staff, emphasizing the choice of survey timing to improve the quality of the questionnaires filled in by the interviewees. A total of 1,500 questionnaires were distributed in this survey and 864 questionnaires were collected, with a recovery rate of 57.6%, in which the invalid questionnaires were 708 after excluding invalid questionnaires, so the effective rate was 81.94%. After the survey was over, the questionnaires were counted to form a database. Through a detailed investigation of the demographic characteristics of the survey samples, the data obtained from the surveys were found to have a good distribution in demographic characteristics. From the perspective of gender, the gender ratio was basically balanced; the age was mainly 25–40 years old. From the perspective of education level, it was mainly junior college and undergraduate. From the perspective of occupational composition, civil servants, employees of enterprises and institutions, and freelancers were main. From the monthly income of family per capita, it was mainly above 4,000 yuan.

3.4. Analysis Method. This paper used SPSS19.0 and LISREL8.7 software for analysis. The main methods were (1) using the internal consistency of the Cronbach α coefficient consideration scale; (2) confirmative factor analysis (CFA) analyzing and testing the aggregation validity and discriminant validity of each scale, providing a basis for structural model analysis; and (3) analyzing the causal link between variables by means of structural models and the impacts of tourism festival and special event innovation on tourists' satisfaction, tourists' behavioral intentions, and brand equity.

4. Empirical Analysis

4.1. Research 1: Measurement of the Dimension Structure of Tourism Festival and Special Event Innovation. In order to measure and test the dimensional structures of tourism festival and special event innovation, this paper follows the basic procedure of scale development; that is, based on literature review, the test item development, test item purification, factor analysis, factor naming, factor validity, and reliability test were carried out and the tourism festival and special event innovation scale was developed and verified.

4.1.1. Test Items Development. The test items were obtained in this study through the following methods: (1) comprehensively sorting out the innovation types, related research results at home and abroad of product innovation and service marketing, to establish and improve the test item database as much as possible; (2) fully referring to the questions related to six-dimensional scale of tourism festival and special event innovation (see the questionnaire design section for details); (3) based on the needs of the tourism festival and special event innovation dimension framework, combined with relevant theories to modify or develop some test items to adapt to the development of tourism festival and special event in the Chinese context; and (4) bringing the test items to 30 tourism management and exhibition professional teachers to supplement and improve them. Through the above research process, a preliminary scale consisting of 40 questions was compiled. The tourism festival and special event innovation include four aspects of supply, process, scene, and relationship innovation, which can be further and can be decomposed into six dimensions: performance, accessibility, aesthetic environment, self-service technologies, tourist community, and loyalty program.

4.1.2. Project Purification, Exploratory Factor Analysis, and Factor Naming. Following the test item purification standard, using SPSS19.0 for exploratory factor analysis, after the factor purification operation, 15 questions were deleted from 40 questions, and the remaining 25 questions constitute a scale that can be used for analysis. Statistics showed that the KMO (Kaiser–Meyer–Olkin) value of the 25 items was 0.942 and the significant level of Bartlett's spherical test was less than 0.001, indicating that it was suitable for factor analysis. The eigenvalues showed that the mean value of the first six factors was greater than 1, indicating that there were six factors. The gravel map showed that the first six factors varied greatly and started to slow down from the seventh factor, indicating that the extraction of six common factors was appropriate. The contribution rate of variance interpretation showed that the cumulative interpretation rate of the first six common factors was 68.73%, which exceeded the critical value of 60%. The overall Cronbach α-value was 0.87, indicating that the data results were better. The factor load

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Table 1: Exploratory and confirmatory factor analysis results.

Common factors (constructs)	Correlation coefficient matrix																Factor load		CR		AVE	
	S1 ($n = 354$)						S2 ($n = 354$)										S1	S2	S1	S2	S1	S2
	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10						
Performance	1						1										74–87	75–88	90	93	65	68
Accessibility	68	1					74	1									70–86	75–86	87	91	62	65
Self-service technology	66	62	1				79	71	1								69–85	74–89	89	92	62	70
Aesthetic environment	61	66	48	1			68	68	55	1							65–77	74–81	83	86	51	59
Tourist community	69	67	61	69	1		84	74	74	78	1						62–80	68–84	84	90	53	65
Loyalty program	68	65	73	47	59	1	78	73	75	60	75	1					65–82	72–88	82	89	54	67
Overall innovation							58	46	45	46	52	47	1					72–91		91		66
Tourist satisfaction							27	26	21	41	35	27	41	1				81–92		88		81
Brand equity							46	38	30	48	51	40	56	55	1			72–89		89		69
Behavioral intention							32	34	24	51	43	26	52	71	64	1		63–90		86		65

In Study 1, the sample size was 354, χ^2 (df) = 898.27 (385), χ^2/df = 2.33, $p < 01$; CFI = 98; NNFI = 98; AGFI = 79; and RMSEA = 068. In Study 2, the sample size was 354, χ^2 (df) = 2153.12 (978), χ^2/df = 2.20, $p < 01$; CFI = 98; NNFI = 98; AGFI = 73; and RMSEA = 063. *Note*. (1) According to the requirements of triangular mutual certification, this study divided the total sample size (708) into two, to conduct exploratory factor analysis (EFA) and CFA analyses, and to be represented by S1 and S2, respectively. S2 was also the basis for the study of the relationship between overall innovation and tourist variables; (2) CR was construct reliability, which meant constructive reliability; AVE was average variance extracted, which meant average extraction variance; (3) To save layout space, all decimal digits of all values were omitted in the table.

was higher than 0.5, indicating that the overall factor extraction effect was better (see Table 1).

Combining literature reviews and interviews, based on exploratory factor analysis, tourism festival and special event innovation consists of six dimensions (dimensions), and 25 test indicators (test statements) were formed under the corresponding dimensions. The test items affiliated by first factor included "the performer's skills were unique," "the performer's skill was novel," "the show was full of passion," "the performer's performance style was unique," and "the performance of festivals and special events changed and enhanced my travel experiences and could be named as "performance." The naming of other factors is shown in Table 1.

4.1.3. CFA Analysis, Factor Naming, and Reliability Test. According to the requirements of the triangle mutual certification, the remaining 1/2 sample size ($n = 354$) was subjected to CFA analysis using LISREL8.7 software. Statistics showed that the average values of the six dimensions of the festival and special event innovation were 4.69, 4.87, 4.58, 5.35, 5.19, and 4.52, respectively; the standard deviations were 1.13, 1.16, 1.25, 1.05, 1.07, and 1.13, and the relationship coefficient was between 0.47 and 0.73. Psychological measurement attributes such as factor loading, construction reliability, and average extraction variance were measured by CFA analysis (see Table 1S2 for specific results). The construction reliability of all factors was between 0.82 and 0.90, which was higher than the critical value of 0.60; the factor load was between 0.68 and 0.89, which was higher than the critical value of 0.50, indicating that the scale had good convergence. The average extraction variance was between 0.59 and 0.70, which was higher than the 0.50 threshold and further validated the aggregation validity of the tourism festival and special event innovation scale. By comparing the correlation coefficient between the average extracted variance with each construct, the validity of the discriminant can be tested. Table 1 shows that all the extracted squared differences between constructs are larger than the correlation coefficient, which verifies the discriminant validity of the tourism festival and special event innovation scale. In addition, as shown in Table 1, the RMSEA threshold of 0.08, the CFI and NNFI threshold of 0.90, and the AGFI threshold of 0.90, absolute fit, incremental fit, and brief fit indicate that the tourism festival and special event innovation measurement model is acceptable. Under complex multidimensional conceptualization conditions, AGFI value is lower than the critical value, which is acceptable [46].

The above exploratory and confirmatory factor analyses, respectively, confirmed and verified the six dimensions of performance, accessibility, self-service technology, aesthetic environment, tourist community, and loyalty program of tourism festival and special event innovation, which verified the 6-dimensional structure of tourism festival and special event innovation proposed by this study.

4.2. Research 2: The Relationship between the Overall Innovation of Tourism Festivals and Special Events and the Tourists' Behavioral Intentions. In order to test the relationship between tourism festival and special event innovation and tourists' satisfaction and behavioral intentions, this paper used structural equation modeling to conduct empirical tests. According to the structural equation model analysis methods and steps, the measurement model analysis must first be carried out to carry out the reliability and validity test, and then the structural model analysis was carried out to test the relationship between the variables.

4.2.1. Sample Overall Reliability Test. The internal consistency of the Cronbach α coefficient consideration scale is generally used. Reliability is checked by whether the measurement results match the actual values. Statistics show that the overall reliability of the questionnaire in Study 2 is 0.885, which is much larger than the critical standard value of 0.6.

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Table 2: Three models' fitting indices and their comparison.

	Model	χ^2	df	χ^2/df	$\Delta\chi^2$	Δdf	RMSEA	NNFI	CFI	GFI	AIC criteria	Tagmeme
Partially mediating	Model A	2385.46	1007	2.37	—	—	0.062	0.98	0.98	0.96	2623.38	1
Full mediating	Model B	2403.52	1009	2.38	18.06	2	0.063	0.98	0.98	0.96	2635.47	2
	Model C	2535.87	1009	2.51	132.35	2	0.062	0.97	0.98	0.96	2756.82	3

Note. (1) Model A is the preset theory model, partial mediating model, and baseline model; model B is the satisfaction nested model, model C is the brand equity nested model, and both are full mediating models; (2) the baseline model is compared with the nested model through the chi-square value difference; (3) the model order is determined by the chi-square test and the AIC criteria.

This indicates that the internal consistency of the measurement index is strong, the reliability is high, and the questionnaire has good homogeneity reliability.

4.2.2. Measurement Model Evaluation. Statistics showed that the average values of performance, accessibility, self-service technology, aesthetic environment, tourist community, loyalty program, overall innovation, tourists' satisfaction, brand equity, and behavioral intentions were 4.69, 4.87, 4.58, 5.35, 5.19, 4.52, 5.12, 6.13, 5.85, and 6.01; the standard deviations were 1.13, 1.17, 1.25, 1.05, 1.07, 1.13, 1.21, 1.00, 1.07, and 1.01, respectively; the correlation coefficient is between 0.21 and 0.84. Among them, the average value of brand equity, tourists' satisfaction, and behavioral intentions were much higher than other constructs.

In order to further test the measurement validity and the degree of discrimination between the indicators of the overall innovation, tourists' satisfaction, brand equity, and behavioral intentions, to carry out CFA analysis, the measurement model A was constructed using LISREL8.7, and the various fitting indicators are the fitting indexes of model A in Table 2.

Test of goodness of model fitting: Table 2 shows that the value of χ^2/df of model A is 2.37 and the value of RMSEA is 0.062. The values of NNFI, CFI, and GFI are both greater than the critical value of 0.9, indicating that model A fits well and is a fully acceptable model.

Reliability and validity test: when the construction reliability is greater than 0.7, the measurement reliability of the question items to the constructs is higher. When the factor load is greater than 0.5, it is significant at the P value of 0.01, and when the average extraction variance is greater than 0.5, the aggregation validity is better. When the average extraction variance is greater than 0.5, the correlation coefficient between constructs is smaller than the average extraction variance, which satisfies the discriminant validity [47]. Table 1 (S2 part) shows that the factor load is between 0.63 and 0.91 (threshold value is 0.5), the construction reliability of all factors is between 0.86 and 0.92 (threshold value is 0.7), and the average extraction variance is between 0.59 and 0.81 (threshold value is 0.5), which has fully verified the convergent validity of the 10 major construct scales. In addition, all the extracted squared differences between the 10 constructs are larger than the correlation coefficients, and the discriminant validity of the 10 constructive scales has also been verified.

Confirmatory factor analyses showed that the 10 latent variables had good validity and reliability; therefore, the next structural model analyses could be carried out.

4.2.3. Structural Model Evaluation. This study includes two important mediator variables: brand equity and tourists' satisfaction. Previous studies have shown that brand equity and consumer satisfaction can enhance the predictive power of overall innovation on the consumers' behavioral intentions [42,43]. In order to test the role of mediation, this study compared the partial mediating model (i.e., the research setting theoretical model; see Figure 1) with the full intermediate model (two nested models; see Figure 2). The first competitive nested model is a satisfaction model developed based on brand equity research: consumer satisfaction plays a full mediating role in the relationship between overall innovation, brand equity, and behavioral intentions [48]; the second competitive model is a brand equity model developed based on market performance research: brand equity plays a full mediating role in the relationship between overall innovation, consumer satisfaction, and behavioral intentions [45].

Following the research idea of Hair et al. [46], the mediating effect was tested by a series of chi-square difference tests. CFA and chi-square difference analyses were performed using LISREL 8.7 software to compare the fit of different structural models. The difference between the chi-square values of the partial mediating model (i.e., the set theory model) and the full mediating model (two nested models) proved that the introduction of the partial mediating model reduced the chi-square value (see Table 2). This shows that the two attitude constructs of tourists' satisfaction and brand equity coexist in the relationship model of innovation and behavioral intentions as mediating variables.

As shown in Table 2, the fitting indexes χ^2/df values of the three models are all less than 3, and the values of RMSEA are less than 0.08, and the values of NNFI, CFI, and GFI are all greater than 0.9, indicating that the model fits the data well. Based on the model comparison principle of Hair et al. (2006), the comparison of the two models depends on the corresponding changes of $\Delta\chi^2$ and Δdf. The model simplification is better when the chi-square value change $\Delta\chi^2$ caused by the increase of the degree of freedom Δdf is smaller than the critical value of χ^2 when the degree of freedom is Δdf, $\alpha = 0.01$. Using the above principle, it can be considered that model A is the optimal model of the set model of research.

4.2.4. Hypothesis Testing. After the reliability and validity of the measurement model were confirmed, the previous latent variables and their question items were imported into the set structural model to test the research hypothesis, and the

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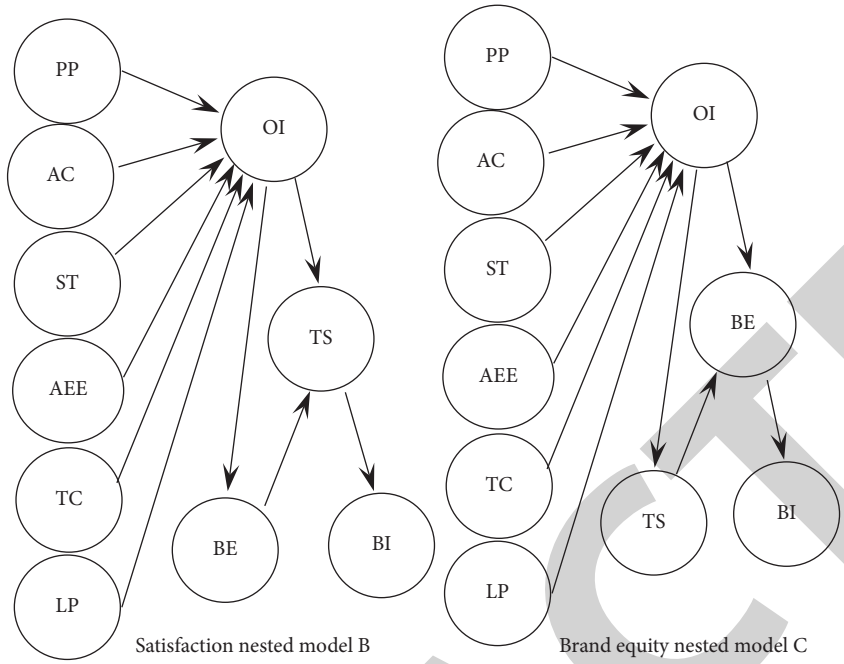

Figure 2: Full mediating model (competitive nested model).

Table 3: Setting model verification indicators and relationship hypothesis test results.

Hypothesis	Relationship between variables	Path name	Standardized path coefficient	t-value	Standard error	Hypothetical result test
H1a	Performance⟶ overall innovation	$\lambda_{2,1}$	0.721	8.871***	0.057	Supported
H1b	Accessibility⟶ overall innovation	$\lambda_{3,1}$	−0.053	-0.452	0.078	Not supported
H1c	Self-service technology⟶ overall innovation	$\lambda_{4,1}$	0.273	2.695***	0.061	Supported
H1d	Aesthetic environment⟶ overall innovation	$\lambda_{5,1}$	0.355	4.173***	0.069	Supported
H1e	Tourist community⟶ overall innovation	$\lambda_{6,1}$	−0.042	−0.223	0.091	Not supported
H1f	Loyalty program⟶ overall innovation	$\lambda_{7,1}$	0.144	1.135	0.103	Not supported
H2a	Overall innovation⟶ tourist satisfaction	$\beta_{3,2}$	0.392	6.752***	0.072	Supported
H2b	Overall innovation⟶ brand equity	$\beta_{4,2}$	0.392	6.518***	0.046	Supported
H2c	Overall innovation⟶ behavioral intention	$\beta_{5,2}$	0.543	7.752***	0.067	Supported
H3	Tourist satisfaction⟶ brand equity	$\beta_{4,3}$	0.387	6.871***	0.054	Supported
H4	Tourist satisfaction⟶ behavioral intention	$\beta_{5,4}$	0.671	11.293***	0.069	Supported
H5	Brand equity⟶ behavioral intention	$\beta_{6,5}$	0.268	4.544***	0.076	Supported

Note. *** indicates being significant at $p < 0.01$.

model was estimated by the maximum likelihood method. The test indicators and verification results of the set model are shown in Table 3. It can be seen from Table 3 that H1a, H1c, H1d, H2a, H2b, H2c, H3, H4, and H5 have all passed the statistical tests, but H1b, H1e, and H1f do not pass the statistical test. Therefore, in order to better fit the conceptual model with the data, it is necessary to correct the set model based on the test results and MI.

In order to optimize the theoretical model, the preset model needs to be modified according to the test results of the set model and the MI index. The paths that have not been verified shall be gradually eliminated until all paths pass the tests. The modified model fit indexes show that the RMSEA is 0.047, χ^2/df is 2.016, AGFI is 0.895, and GFI, CFI, TLI, IFI, and NFI are all above 0.900; each fitting index has reached an excellent level and is comprehensively better than conceptual models. The path coefficients passed the tests, which proved that compared with the theoretical models, the modified models were more consistent with the inherent logical relationship of the data and did not violate the

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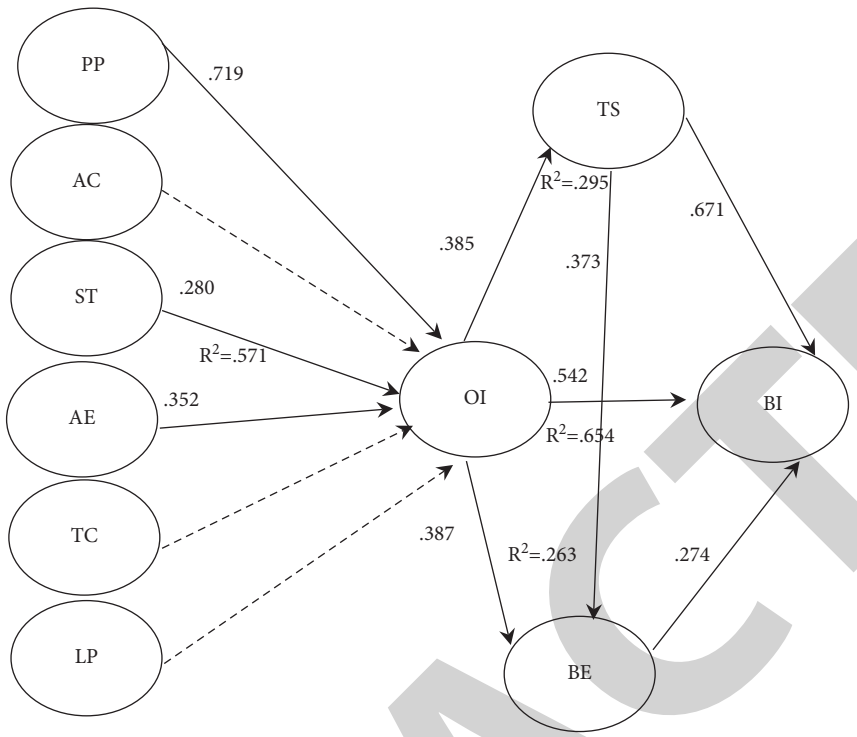

Figure 3: Corrected theoretical model. *Note*. The solid line indicates significant; the dotted line indicates not significant.

theoretical basis. The results of the modified models are shown in Figure 3.

It can be seen from Figure 3 that the modified model has better prediction ability and the relationship among the latent variables in the model is stable, indicating that the modified model has good rationality.

From the explained variance of each latent variable in Figure 3, the explained variance of overall innovation and behavioral intentions exceeding 50% is 57.1% and 65.4%, respectively; the explained variance of tourists' satisfaction and brand equity being above 20% is 29.5% and 26.3%, respectively, indicating that the relationship between the latent variables of the modified model is stable, and each path better explains the relationship between the latent variables.

5. Conclusions and Discussion

5.1. The Multidimensional Nature and Characteristics of Tourism Festival and Special Event Innovation. Innovation is the process of developing opportunities, but innovative products and market development do not necessarily lead to good results. Aldebert et al. [2] believed that the integrity of the understanding of the dimensional structure of innovation determined the market outcomes of innovation. At present, a large number of festivals and special events become a mere formality, short-lived, fleeting, indicating that deepening the understanding of tourism and festival innovation has become the key to promoting tourism product development and marketing.

The "what" paradigm, "how" paradigm, "where" paradigm, and "who" paradigm of traditional innovation researches focus on the dimensions of supply, services, scenarios, and relationships of innovation, respectively [22]. Researchers from different disciplines have conducted extensive researches on innovation based on the above perspectives and paradigms [28]. For example, traditional product innovation focuses on technology-driven products to enhance novelty and uniqueness and is a product innovation concept of the perspectives of supply and enterprise production and management. This study integrated the two perspectives of product supply and customer demand and drew on the theory of product innovation and service marketing to construct a conceptual model of tourism festival and special event innovation. The EFA and CFA analyses, respectively, confirmed and verified the six dimensions of tourism festival and special event innovation: performance, accessibility, self-service technology, aesthetic environment, tourist community, and loyalty program, which verified the 6-dimensional structure of tourism festival and special event innovation proposed by this study. This finding confirms Sawhney et al.'s [28] idea that "innovation is a one- or multidimensional change based on a multidimensional perspective to create value for customers" and confirms Masayuki et al.'s [22] idea that "multidimensional integration is the fundamental way out for innovation." It can be seen that tourists have objective requirements for novelty and uniqueness in tourism performance, accessibility, self-service technology, aesthetic environment, tourist community, and loyalty program, which provides an empirical basis for tourism festival and special event innovation.

This study highlights the importance of managing the controllable part of the aesthetic environment, which is

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similar to Aaker's [45] conclusion that product innovation should be presented in a visual way to increase the brand's external visibility. In other words, in the process of tourism and festival innovation, the innovation of intangible tourism and festival experience should make great efforts in the direction of visualization to cope with fierce competition in the market.

5.2. The Relationship between the Overall Innovation of Tourism Festivals and Special Events and the Tourists' Behavioral Intentions. According to verifying the 6-dimensional structure of tourism festival and special event innovation (i.e., answering "what is tourism festival and special event innovation"), this study also explored the impact of tourism festival and special event innovation on the behavioral intentions of tourists and further answered the question of "what can festival and special event innovation result in." Through empirical research, the following conclusions are drawn:

(i) Among the six dimensions of tourism festival and special event innovation, performance, aesthetic environment, and self-service technology have a significant positive impact on overall innovation, while accessibility, tourist community, and loyalty program have no significant impact on overall innovation. As can be seen from Figure 3, the path coefficient of performance to overall innovation is as high as 0.719, which confirms that performance is the core content of tourism festival and special event innovation and is consistent with the findings of Danneels and Kleinschmidt [18], Deighton [33], and Thomas and Bowdin [10]. The path coefficients of aesthetic environment and self-service technology to overall innovation are 0.352 and 0.280, respectively, indicating that the aesthetic environment and self-service technology are important contents of tourism festival and special event innovation, which is consistent with the research conclusions of Bitner [34] and Zeithaml and Bitner [35]. However, this study found that the accessibility, tourist community, and loyalty program innovation have no significant impact on the overall innovation. This conclusion is inconsistent with the conclusion of Thomas and Bowdin [10]. The possible reasons are as follows: the tourists of Zhangjiajie Music Festival are immersed in the shocking performance of the festival, which affects the importance evaluation of other dimensions of festival innovation and then affects the reliability and validity of the construct indicators; the performance, aesthetic environment, and self-service technology have more direct and important impacts on the festival and special event satisfaction, which are "incentives" to improve the perception of tourists on innovation, while the accessibility, tourist community, and loyalty program are "health factors" that enhance the perception of tourists on innovation. Therefore, the accessibility, tourist community, and loyalty program in this study having no statistically significance do not deny their importance in the festival and special event innovation.

(ii) The overall innovation of tourism festivals and special events has a significant positive impact on tourists' satisfaction, brand equity, and tourists' behavioral intentions. As can be seen from Figure 3, the path coefficients of overall innovation to tourists' satisfaction, brand equity, and behavioral intentions are 0.385, 0.387, and 0.542, respectively, which confirms the importance of tourists' perception of overall innovation in tourism product innovation. This conclusion is consistent with the research conclusions of Moreau et al. [19] and Fang's [21] overall innovation improving customer satisfaction and Kirca's [39] overall innovation improving customer behavioral intentions level. This profoundly reveals the generation process of the tourists' behavioral intentions, indicating that the tourists' behavioral intentions are the results of the feedback effects of the tourism festival and special event consumption and emotional experience process.

(iii) Tourists' satisfaction and brand equity play a partial intermediary role in the impacts of overall innovation on the behavioral intentions of tourists. This conclusion is somewhat different from the researches by Keller and Lehmann [48] and Aaker [45]. The possible reason is that the researches did not regard tourists' satisfaction and brand equity as partial mediating variables, but this study found that the partial mediating model is a better model through comparing the full mediation model with the partial mediation model. From this perspective, the research conclusions of this paper more deeply reflect the action mechanism of the tourism festival and special event overall innovation variables on the behavioral intentions variables of tourists, which is also consistent with the findings of Dosi [38] and Kirca et al. [39] that brand equity and consumer satisfaction could improve the predictive power of overall innovation on consumer behavioral intentions. Tourists' behavioral intentions (recommendation and repeated purchases) are important indicators of impacts and competitiveness of tourism festivals and special events. In the context of tourism festivals and special events, emotional satisfaction has a greater impact on the behavioral intentions of tourists than cognitive factors. Tourists' satisfaction has a significant impact on brand equity, indicating that brand equity can be seen as a result variable for tourists' satisfaction, which is consistent with Johnson et al.'s [43] research conclusions that tourists' satisfaction is improving market performance.

5.3. Management Inspiration. Taken together, the theoretical model provides us with an effective understanding tool

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for how tourists evaluate tourism festival and special event innovation based on innovation points. From the perspective of market development, tourism festival and special event organizers or enterprises should innovate around the points of the festival and special event innovation to enhance the satisfaction of tourists. The study results show that the six dimensions of tourism festival and special event innovation play different strategic roles in innovation management. As a service innovation tool, this framework model advocates the creation of new service and environmental benefits by providing access to convenient transportation, self-service technology, new scene design, and unique social interaction opportunities. For the relationship dimension (tourist community and the loyalty program) as a relationship, innovation tool requires new incentives to build friendship and caring consciousness among the loyal tourists. For the festival and special event marketing organizers, through the fine and innovative management of the tourism festival and special event innovation dimensions, it will help to enhance the satisfaction of tourists, establish an innovative and radical brand image, and enhance the long-term performance of the market.

6. Research Limitations and Prospects

As an exploratory study, although the concept model of tourism festival and special event innovation and the impacts mechanism model of tourism festival and special event innovation on tourists' behavioral intentions have been constructed, the scientific and systematic empirical tests have been done, and from the perspective of tourists, the problems: "what is tourism festival and special event innovation and what results have arisen?" have been answered; there are further researches that should be carried out due to limitations of ability and finance.

First of all, the interview work before the development of the tourism festival and special event innovation scale needs to be strengthened. The six dimensions obtained in this study may not fully reflect the entire composition of the tourism festival and special event innovation system. Second, the types of tourism festivals and special events are different, and the types of consumption are different, then the importance of innovation points may be different. The types of tourism festivals and special events as a regulated variable may have different effects and can be the direction of future researches. Thirdly, the data obtained in this study belongs to the category of static research. It is best to establish a dynamic database to better track the mechanism of the tourist community and loyalty program in the innovation of the festivals and special events.

In the future researches, it is necessary to improve the design of the scale and improve the basic test item question bank for tourism festival and special event innovation to make the tourism festival and special event innovation scale be more aligned with the actual development of China's festival and special event industry; at the same time, through different types of tourism festival and special event and diachronic investigations, deepening the tourism festival and special event innovation and understanding about the impact mechanism on tourists' behavioral intentions is required so as to enhance the internal and external validity of the researches.[48]

Data Availability

All data, models, and codes generated or used during the study appear in the submitted article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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Retraction

Retracted: Impacts of the Weighted Deduction Policy for R&D Expenses on Innovation Additionality of Firms: Empirical Evidence from China

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] J. Xu and T. Wang, "Impacts of the Weighted Deduction Policy for R&D Expenses on Innovation Additionality of Firms: Empirical Evidence from China," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 6363608, 13 pages, 2022.

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Research Article

Impacts of the Weighted Deduction Policy for R&D Expenses on Innovation Additionality of Firms: Empirical Evidence from China

Junling Xu and Tong Wang

School of Public Administration, Central China Normal University, No. 152 Luoyu Road, Wuhan, Hubei 430079, China

Correspondence should be addressed to Junling Xu; angelaxu03@126.com

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Based on the data of 3894 companies disclosed in the 2014–2017 Small and Medium Enterprises (SME) Board and Growth Enterprise Market (GEM) Annual Reports, our research evaluates the impacts of the weighted deduction policy for research and development (R&D) expenses on innovation additionality in the "Propensity Score Matching" (PSM) approach, from the moderation perspective of marketization, market competition, and political connections. The empirical findings are as follows: (1) The weighted deduction policy for R&D expenses has a positive effect on the additionality of input and output. The policy has an "additionality effect" on invention patents and utility patents, but it is not significant on appearance patents. (2) Low degree of marketization and high degree of market competition have positive moderating effects on the additionality of input and output. (3) Political connections strengthen the incentive effect of the weighted deduction policy for R&D expenses on the additionality of input and output. From the perspective of additionality, our research results enrich the literature on studies of incentive effects of policy innovation and also provide empirical support for the adjustment of the weighted deduction policy for R&D expenses.

1. Introduction

The implementation of the innovation-driven strategy is inseparable from the support of fiscal and tax policies. Previous studies showed that expenditure policies, such as financial subsidies and government procurement, may distort the allocation of resources, thus leading to rent-seeking and ignoring substantive innovation. In particular, when financial subsidies are improperly implemented, for example, when the scope of subsidies is too wide or the total is too large, the policy effect will be changed from the level of regulating social and economic activities to the burden of inhibiting economic development [1–3]. As a tax preferential policy, the weighted deduction policy for R&D expenses has been continuously valued once it is launched. It has witnessed expanding application scope (Finance and Taxation [2013] No. 70), lowering the implementation threshold (Finance and Taxation [2015] No. 119), and increasing the percentage of additional deductions (Finance and Taxation [2017] No. 34, Finance and Taxation [2018] No. 99, etc.). In practice, in the government's support for R&D of firms, scientific and technological innovation has been gradually enhanced.

Most literature on other countries' firms argued that preferential tax policies have reduced innovation costs, increased the operating cash flow of firms, and promoted firms' investment on innovation [4–8]. Some studies on Chinese firms also showed that preferential tax policies are conducive to the innovation investment of firms [9, 10]. Part of the research was based on changes in the weighted deduction policy for R&D expenses and found that the incentive effect of preferential treatment on R&D investment of firms is obvious [11–14]. Some studies analyzed preferential tax policies from the perspective of input, while few studies evaluated firm innovation output, and the conclusions are quite different. As has been demonstrated, the output of innovation and efficiency of firms have been significantly improved; the incentive effect of weighted deduction policy for R&D expenses is heterogeneously the result of firm ownership, firm scale, and whether it is a high-

tech enterprise [15]. On the output side, at the same time, the weighted deduction policy for R&D expenses only promotes the increase of the R&D output scale but has no significant impact on the output intensity, as demonstrated by the authors of [16]. Their research emphasized the verification of policy effects from the full perspective of the enterprise innovation chain.

Additionality effect and signal function are two frontier concepts that have gradually developed to reduce cognitive biases in evaluation. The "additionality" policy evaluation is based on scientific causal inference and has strong persuasive power. At present, most policy evaluations follow the additionality framework proposed by Georghiou, that is, the additionality changes in input, output, and behavior that government support brings to firms. The SME Board and GEM are important platforms to support the national independent innovation strategy. They provide institutional support for the innovation of small- and medium-sized firms and high-tech industries mainly by establishing the following mechanisms: the risk-sharing and profit-sharing financing mechanisms, equity incentive mechanisms, a survival-of-the-fittest mechanism for prior and subsequent screening, and so forth. With such a support, they may further enhance the function of the capital market to serve small- and medium-sized firms. Therefore, we introduce the additionality effect analysis framework and collect the annual report data of 3894 companies (2014–2017) on the SME Board and GEM to verify the incentive effect of weighted deduction policy for R&D expenses on innovation input and output. We also incorporate signal transmission and political connections into the analysis of the moderating effect of the additionality effect of innovation, by adopting the PSM approach to deal with endogeneity problems. At the end of the study, the empirical results support all hypotheses in this article except for H5b and H6b. The research design demonstrates the comprehensiveness of policy incentives, while research findings provide empirical basis for the improvement of the policy.

2. Theoretical Analysis and Hypothesis

2.1. Analysis of the Incentive Effect Mechanism of the Weighted Deduction Policy. Tax incentives are a common policy stimulus used by governments of various countries, and the weighted deduction policy for R&D expenses is considered the most inclusive and fair among them. The incentives of the policy to firms are realized through two transmission channels, which directly stimulate firms' innovation investment and indirectly stimulate market support for firms [17]. Previous studies have proved that the weighted deduction policy for R&D expenses stimulates firms to further increase innovation input, thereby increasing innovation output. At the same time, Lerner found that the government's science and technology plan conveys corporate innovation quality signals to venture investors and reduces information asymmetry [18]. Feldman proposed that government funding has a "halo effect," which can send a quality signal to the market that companies have development potential [19]. The support of the government plays a role in signal transmission to a certain extent. It can guide the convergence of advantageous resources in the market, provide new resource support channels for firm's innovation [20], induce firms to change their original behaviors, and further innovate in the original or new fields, thus increasing R&D investment [21]. In addition, as a government support policy, it also serves as a signal; that is, it can transmit information on the potential innovation quality of firms to the market, attract funds from external financing institutions, further ease financing constraints, increase R&D investment, and thereby increase firm's innovation output. Accordingly, we propose Hypothesis 1 and Hypothesis 2.

H1: Keeping other factors unchanged, the deduction of R&D expenses can significantly improve additionality investment.

H2: Keeping other factors unchanged, the deduction of R&D expenses can significantly improve the output increment.

2.2. The Moderating Effect of Intermediary Factors on the Incentive Effect of Weighted Deduction Policy

2.2.1. Degree of Marketization. Areas with a high degree of marketization have a high level of market finance, broad corporate financing channels, and easy access to support from external financial institutions such as banks. The company has a better R&D environment or strong independent R&D motivation [22]; these advantages will greatly promote corporate innovation and improve political connections, thus producing the effect of "better plus better." For example, He Kang considered the impact of heterogeneous factors on the effect of the weighted deduction policy for R&D expenses and concluded that weighted deduction policy for R&D expenses has a better incentive effect on firm innovation in highly market-oriented regions. Some scholars hold different views. Yet, in regions with low marketization, financial markets and factor markets are not mature enough; companies have to face large financing constraints, high risks of intellectual property infringement, high levels of information asymmetry, and high costs for investors to screen companies. Those inferior situations have led to insufficient willingness to innovate, thus eventually reducing firm innovation [23]. However, at the same time, it can better reflect the incentive effect of policies on the innovation capabilities of firms. For example, Ren and Song used a sample of listed Chinese manufacturing companies to empirically test the hypothesis that the degree of marketization is low and the policy effect of R&D plus deduction is better [24].

In low-market areas, where the market is not well developed, the resources of firms must be obtained through informal channels, and government support is particularly important. For firms under low marketization, specifically, they have uneven good and bad, low technological innovation information circulation, and serious information asymmetry. Those characteristics have weakened the signals released by the firm. However, the government can transmit the potential positive information of the firm to the market

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through supporting policies, which can increase the recognition of the firm by external institutions, reduce the screening cost of external investors, promote investment willingness, so as to promote the concentration of resources to firms enjoying preferential policies, and enhance the innovation power of firms [25]. Based on this, we make assumptions H3a and H3b.

H3a: Low marketization has a positive regulatory effect on the additionality effects of the weighted deduction policy for R&D expenses.

H3b: Low marketization has a positive regulatory effect on the additionality output effect of the weighted deduction policy for R&D expenses.

2.2.2. Market Competition. Market competition is a significant indicator in the external environment of a company. For different market competitions, firms have accordingly adopted survival strategies. For example, in the fierce market competition, in order to avoid being screened out by the "survival-of-the-fittest" mechanism, companies are willing to disclose more information about their own operations, management, innovation, and so forth and transmit "market signals" to external resource exchanges to get a pool of resources [26]. However, this signal is just a single one, and the evaluation of innovation capability cannot be directly presented through financial data, nor can it rely solely on the evaluation of third-party institutions. In addition, China's market development has not yet been fully matured, with the government still playing an important role in market management, and companies need to send more valuable signals to achieve resource acquisition [27]. Through the layer-by-layer screening of firms that have received government resource support, the support policy can transmit signals of the firm's potential innovation capabilities, which can help firms obtain more market support and promote firm innovation. Wu et al. found that the increased market competition can significantly stimulate the incentive effect of preferential tax policies on R&D investment [28]. In a low market competition environment, as the firm's market share stays relatively stable, the firm holds a low innovation willingness for future survival and development. Conversely, it prefers to maintain its monopoly position, so it sends signals with the motivation of obtaining resources for an expanded scale. With such "signals," though, it is still difficult for the firm to perform well in promoting innovation [29]. Accordingly, this article assumes H4a and H4b.

H4a: High market competition has a positive regulatory effect on the additionality effect of the weighted deduction policy for R&D expenses.

H4b: High market competition has a positive regulatory effect on the additionality output effect of the weighted deduction policy for R&D expenses.

2.2.3. Political Connections. From the perspective of signal transmission, political connections exert a certain signal function. It can release information that companies have scarce resources and good reputation and improve the continuity and stability of the company's external resource acquisition, so as to increase R&D investment, thus promoting innovation [30]. Here, we have to notice that, as relatively abstract "relationship resource," political connections have just sent unclear signals. They have been regarded, on the contrary, more as a means for the government to regulate resources than as the "signal-sender" as mentioned above. The weighted deduction policy for R&D expenses is one of the carriers for the government to reduce taxes and pass on resources to support firm innovation. Such a policy, whether to be applied or not, can be an objective indicator to measure whether a company has scarce resources. At the same time, the policy itself has the signal function of certifying quality. For firms that have undergone strict rules "selection," they have shown the characteristics of high-quality innovation in the way of sending a double-guarantee-signal to investors in the market. In addition, in the view of political leadership, investors take into consideration not only the resources and innovation quality owned by firms but also the guiding role of politics. When firms are highly politically connected, their relationship resources can reduce the information asymmetry between government and themselves. Once they have enjoyed government preferential policies, firms will have a clearer understanding of policy procedures and policy connotations, and it is easier to identify policy utilization points, so as to send a signal to the market to comply with the political orientation, attract external investment, and increase investment in innovation, thus promoting firm innovation [31]. At the same time, however, this factor may also have a negative effect on corporate innovation. Some scholars pointed out that maintaining political connections requires companies to spend a lot of time, capital, and labor costs, as well as some hidden costs. In that way, companies spend more management expenses, erode R&D investment, and ultimately lead to a decline in corporate innovation and performance [32]. Therefore, political connection cost may offset the effect of signal transmission and weaken the effect of policy incentives. Based on that, this article makes exploratory research:

H5a: Political connections have a positive regulatory effect on the additionality investment of the weighted deduction policy for R&D expenses.

H5b: Political connections have a negative regulatory effect on the additionality investment of the weighted deduction policy for R&D expenses.

H6a: Political connections have a positive regulatory effect on the output increment of the weighted deduction policy for R&D expenses.

H6b: Political connections have a negative moderating effect on the output increment of the weighted deduction policy for R&D expenses.

3. Research Design

3.1. Sample and Data Selection. The empirical objects are listed firms on the SME Board and GEM. The sample data come from the CSMAR database, the official website of the State Intellectual Property Office, and cninfo.com. The time span is from 2014 to 2017. Afterwards, this research

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determines 1601 valid samples of the "processing group"; they are firms that enjoy the policy of deduction for R&D expenses. Among those samples, 2293 are identified as effective ones of the "control group." They are firms without the endowment of the policy of deduction for R&D expenses. See Table 1 for details. Data processing in this article includes the following: (1) The financial industry and industries that are not covered by the policy are deleted. (2) ST, PT, and delisted companies are eliminated. (3) Companies with missing key variables and abnormal financial indicators are eliminated. Data processing is completed by Stata15.

3.2. Variable Selection

3.2.1. The Explained Variable

Additionality Investment. After applying PSM, the ATT value is the R&D investment of the firms that enjoy the policy (processing group) minus the R&D investment of the firms that do not enjoy the policy (control group). With reference to Feng et al. [33], we use the logarithm of the absolute value of R&D investment to measure R&D investment.

Increase in Output. After applying PSM, the ATT value is the patent output of the firms enjoying the policy (processing group) minus the patent output of the firms not enjoying the policy (control group). Based on the availability, verifiability, and reality of data, researchers mostly use the number of patent applications as an indicator to measure innovation output. We further subdivide patents into invention patents, utility patents, and appearance patents.

3.2.2. Explaining Variables. The explanatory variable we selected is whether the company enjoys the weighted deduction policy for R&D expenses. This variable is presented in the form of a dummy variable. The firm that enjoys the weighted deduction policy for R&D expenses is the treatment group, which is recorded as enjoy1 = 1, and the firm that does not enjoy the weighted deduction policy for R&D expenses, only with the support from the policy, is the control group, which is recorded as enjoy1 = 0.

3.2.3. Control Variables. Firm scale, firm growth, capital intensity, current debt ratio, asset-liability ratio, intangible assets, technical assets, marketization degree, market competition, political connection, equity concentration, equity checks and balances, degree of separation of two powers, time, and region are used as control variables for propensity score matching. The specific variables are shown in Table 2.

3.2.4. Covariate. In order to better estimate the covariates that can significantly distinguish the treatment group from the control group, we establish a logit model, introduce the control variables that were initially screened into the model, and select the covariates according to the significance to introduce the PSM model to establish the final model. After calculation, the variables in Table 3 are selected.

Table 1: Observed statistics.

Years	Treatment	Control	Total
2014	275	556	831
2015	338	568	906
2016	430	586	1016
2017	558	583	1141
Total	1601	2293	3894

3.3. Propensity Score Matching Method. After a policy is implemented, we intend to evaluate the policy to obtain its implementation effect. Essentially, we attempt to answer the following question: What will happen if the policy is not implemented? At the same time, the preferential policy needs to comply with certain conditions, and it is the firm that makes the decision whether to adopt it or not. This shows that the firm does not enjoy the policy randomly. The firm that can enjoy the policy may have higher R&D expenditure and innovation output, which makes the adoption of the traditional multiple regression estimation of the system. It will produce systematic bias and overestimate the incentive effect brought by the policy. In order to overcome the two problems above, PSM can be used to isolate a cleaner policy effect.

The specific research steps are as follows: First, use processing variable grouping. This paper uses whether to enjoy the policy as the basis for grouping. Second, find matching variables. Third, construct a logit model and obtain specific covariates. Test whether the basic assumptions are met. Fourth, estimate the propensity score value and perform matching. In order to make the research results more stable, this paper adopts four methods: one-to-one matching, nearest neighbor matching, radius matching, and kernel matching [34].

$$\begin{aligned} PS_i &= P(x_i) \\ &= Pr(D_i = 1 \mid x_i) = \frac{\exp(\beta x_i)}{[1 + \exp(\beta x_i)]}. \end{aligned} \tag{1}$$

Fifth, calculate the ATT value:

$$\begin{aligned} \mathrm{ATT} &= E_{P(x_i)|D=1}[(E(PS_1 - PS_0)) \mid D = 1,\ P(x_i)] \\ &= E_{P(x_i)|D=1}[(E(PS_1)) \mid D = 1,\ P(x_i) - E(PS_0) \mid D = 1,\ P(x_i)]. \end{aligned} \tag{2}$$

4. Empirical Results and Analysis

4.1. Descriptive Statistical Analysis. It can be seen from the research results that the average R&D investment of the treatment group is 8.62, the median is 8.57, the minimum value is 5.51, and the maximum value is 12.67, while the control group's values are 8.50, 8.51, 2.67, and 12.04, respectively. The overall value of the R&D investment of the treatment group is higher than that of the control group,

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Table 2: Variable description table.

Variable	Variable symbol	Variable name	Measure
Dependent variable Additionality investment	Inputd41	R&D investment	Logarithm of absolute value of R&D investment (control group-treatment group) is the ATT value
Output additionality	Invent_all1	Patent output	The absolute value of the number of patent applications (same as above)
	Invent1	Patent	The absolute value of the number of invention patent applications (same as above)
	Utility1	Utility patent	The absolute value of the number of utility patent applications (same as above)
	Face1	Appearance patent	The absolute value of the number of appearance patent applications (same as above)
Core variables Whether to enjoy the policy	Enjoy1	Whether to enjoy the deduction policy for R&D expenses	Enjoy the policy as enjoy1 = 1 and not enjoy the policy as enjoy1 = 0
Control variable	Size1	Firm size	Logarithm of total assets plus 1
	Grow	Corporate growth	Current operating income-last operating income/last operating income
	Capdensity	Capital intensity	Fixed assets/total assets
	Capdensity1	Capital intensity 1	Total assets/employee pairs
	Shortd	Current debt ratio	Current liabilities/total assets
	Fuzhaiper	Assets and liabilities	Total liabilities/total assets
	Wuxingcap	Intangible assets	Total intangible assets
	Tec	Technical assets	Intangible assets/total assets
	Marketdex	Marketization	Use Fan Gang and Wang Xiaolu to calculate data
	Compete	Market competition	Sales expenses/operating income
	Politic	Political connection	It is assigned a value of 1 if it is politically connected and a value of 0 if it is not politically connected
	Shrcr1	Equity concentration	The largest shareholder's shareholding ratio
	Shrcr5	Equity checks and balances	Shareholding ratio of the top two largest shareholders/shareholding ratio of the top five largest shareholders
	Shrcr7	Equity checks and balances 1	The largest shareholder's shareholding ratio/the top five largest shareholder's shareholding ratio
	Separation	Separation of two rights	Difference between control rights and management rights
	Time	Time dummy	The value of the year before 2016 is 0, and the value of the year of 2016 and after is 1
	Area	Regional dummy variable	Set three dummy variables according to the east, middle, and west
	Sic_men	Industry dummy variables	Excluding industries that do not enjoy the policy, set up according to the classification of national economic industries

Table 3: Variable screening table.

Variable	Estimated coefficient	Standard error	z	p
Technical assets	−7.20	1.82	−3.95	0.001
Current debt ratio	−0.81	0.30	−2.68	0.01
Intangible assets	0.28	0.08	3.60	0.001
Asset intensity	−1.24	0.36	−3.42	0.001
Equity checks and balances	0.18	0.07	2.74	0.01
Marketization	0.22	0.03	7.52	0.001
Firm size	−0.42	0.09	−4.46	0.001
Separation of two Rights	0.02	0.01	2.61	0.01
Time	0.27	0.09	3.03	0.001
Technology Service industry	1.49	0.48	3.08	0.001
Manufacturing	1.39	0.28	4.94	0.001
Public administration	1.57	0.41	3.88	0.001
Information software industry	1.35	0.30	4.46	0.001
Construction industry	0.91	0.39	2.30	0.02

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indicating that the R&D investment of the treatment group is much greater than that of the control group. From the perspective of the total number of patent applications, the mean value of the treatment group is 2.32 and the median is 2.40. Compared with 2.12 and 2.20 of the control group, the overall output level of the treatment group is also higher than that of the control group. Observing each detailed patent output index, we can still find this conclusion. Although some indicators of the control group are slightly higher compared to the treatment group at the maximum value, the values in each percentile are still significantly higher in the treatment group. Therefore, it still shows that the overall output of the treatment group is higher than that of the control group. This also shows to a certain extent that the level of innovation ability of the treatment group is relatively small, while the level of innovation ability of the control group may be uneven, with a large gap between each other. Preliminary inference is as follows: the companies that enjoy the weighted deduction policy for R&D expenses do perform better in terms of input and output, but is this outstanding performance the effect of policy incentives or the company itself has such characteristics? The use of PSM can reduce endogeneity problems and help us better identify policy effects. The details are shown in Table 4.

4.2. Hypothesis Testing. The common support hypothesis is to require a large degree of overlap between the control group and the treatment group to ensure that every individual in the treated group can find at least one similar individual in the control group. Figures 1 and 2 show the results before and after matching.

The scores of the prematching treatment group are concentrated in [0.1, 0.71], the propensity scores of the control group are concentrated in [0.02, 0.73], and the overlapping area of the two sides is [0.1, 0.71]. After applying PSM, the overlapping areas of the two sides are further expanded, with the two curves fitting more closely. It shows that the characteristics of the treatment group and the control group are very close, which indicates that PSM solves the problem of sample endogeneity better. It also provides a clearer reflection of the policy incentive effect.

4.3. The Average Incentive Effect of the Sample Population. The results show that, after eliminating individual differences, that is, after controlling for factors other than policy factors, the R&D investment and patent output of the treatment group are significantly higher than those of the control group at the level of 5%. It indicates that the weighted deduction policy for R&D expenses has an impact on the investment. The output has a significant role in promoting. Assume that H1 and H2 are verified.

From the perspective of output breakdown, after matching, the difference in ATT between the treatment group and the control group on invention patents and utility patents is significant at least at the level of 10%, indicating that the policy has an "additionality effect" on invention patents and utility patents, which generates additional research and development. Appearance patents do not show significance, indicating that the policy has not brought about the creation of additionality appearance patents. In general, the policy has strengthened the incentives for additionality input and additionality output. Or at least it shows that, under the effect of signal transmission, the policy has transmitted information on the quality of firm innovation to the outside, helped firms to obtain external recognition and financial support, and promoted the creation of additionality innovation input and output. The details are shown in Table 5.

4.4. Policy Incentive Effect under the Adjustment of Intermediary Factors

4.4.1. The Role of Marketization. The results show that, under the low degree of marketization, the policy exerts a corresponding incentive effect. This effect is confirmed under neighbor matching, radius matching, and core matching, indicating that the conclusion is stable. Specifically, (1) in terms of R&D investment, under low marketization, after R&D investment is matched, the ATT difference is still highly significant at the 1% level under neighbor matching, radius matching, and nuclear matching, which shows that the policy supplements the R&D investment of firms; (2) in terms of patent output, the ATT difference of patent output was reduced to a significance level of 5% after matching, which has still steadily proved the positive effect of the policy; after further exploring the patent output under segmentation, we can also find that the matched control group and treatment group still have high significance at the 5% level in utility patents and invention patents, while appearance patents have significant differences at least at the 10% level. Such findings have further confirmed the incentive effect of the policy, assuming that H3a and H3b are verified. See Table 6 for details.

4.4.2. The Role of Market Competition. The results show that the weighted deduction policy for R&D expenses exerts an incentive effect under high market competition. This incentive effect is consistent and significant under neighbor matching, radius matching, and nuclear matching, which proves that the conclusion is reliable. From the perspective of R&D investment, under high market competition, before and after matching, the ATT of the treatment group and that of the control group are both significant at the level of 1% or 5%, which shows that, under high market competition, companies that enjoy the policy have higher R&D investment. This indicator is still significant after eliminating individual differences, which proves the existence of policy incentives. From the perspective of patent output, under high market competition, after matching, the ATT value of the treatment group and that of the control group are significant at the 10% level, which shows that the policy has produced a positive effect; with a further observation of the detailed output indicators, after matching, the ATT value of the invention patent is significant under one-to-one matching, radius matching, and nuclear matching, while the ATT values of utility patents are all significant in four

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Table 4: Descriptive statistics of explained variables.

	Variable	Mean	Standard	p25	p50	p75	Min	Max
Control group	Investment	8.50	1.11	7.82	8.51	9.20	2.67	12.04
	Output	2.12	1.44	1.10	2.20	3.05	0.00	7.48
	Invest	1.46	1.24	0.00	1.39	2.30	0.00	6.40
	Utility	1.35	1.33	0.00	1.10	2.30	0.00	7.20
	Appearance	0.44	0.94	0.00	0.00	0.00	0.00	6.19
Treatment group	Investment	8.62	0.96	7.97	8.57	9.21	5.51	12.67
	Output	2.32	1.44	1.39	2.40	3.37	0.00	6.64
	Invest	1.61	1.24	0.69	1.61	2.49	0.00	5.94
	Utility	1.52	1.35	0.00	1.39	2.57	0.00	5.79
	Appearance	0.55	1.04	0.00	0.00	0.69	0.00	6.32
Total sample	Investment	8.55	1.05	7.89	8.54	9.21	2.67	12.67
	Output	2.20	1.44	1.10	2.30	3.18	0.00	7.48
	Invest	1.52	1.25	0.00	1.39	2.40	0.00	6.40
	Utility	1.42	1.34	0.00	1.39	2.40	0.00	7.20
	Appearance	0.49	0.98	0.00	0.00	0.69	0.00	6.32

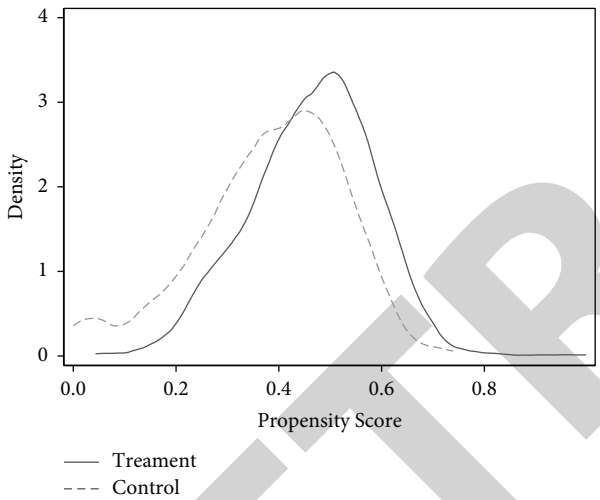

Figure 1: Before propensity score matching.

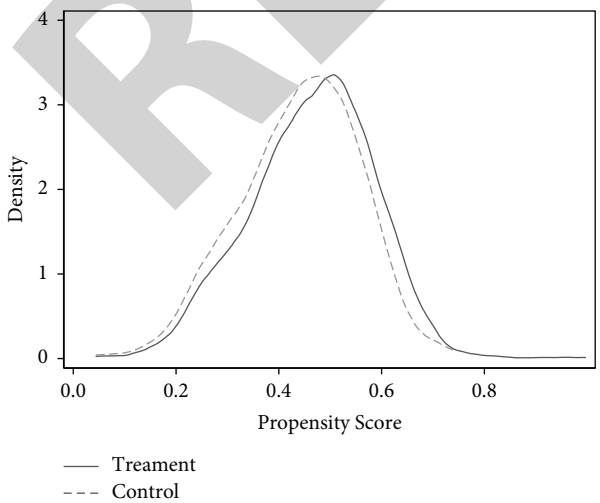

Figure 2: After propensity score matching.

matching methods, while the appearance patents are not significant before and after the matching in different matching methods. This has proved the incentive effect of policies on innovation output, and it has also shown that policies do not have an incentive effect on nontechnical innovation. Assuming that H4a and H4b are verified, see Table 7 for details.

4.4.3. The Role of Political Connections. The results show that politically connected companies are more likely to receive policy incentives. This incentive is significant in the four matching methods, which proves the credibility of the conclusions. Specifically, (1) at the level of R&D investment, the difference between the postmatching treatment group and the control group of politically connected companies still exists at a significance level of 1%, and the difference value ATT has increased to a certain extent, which shows that the policy has exerted a positive effect in the politically connected group; (2) at the level of patent output, politically connected firms, after matching, ATT shows a difference at a significance level of 5%, indicating that the policy has played an incentive role; (3) from the perspective of patent subdivision, it can be seen that the difference in ATT value after the matching of invention patents and utility patents still exists, while appearance patents become insignificant. This shows that the policy has a positive effect on the improvement of the quality of firm innovation. Assuming that H5a and H6a have been verified (see Table 8).

4.5. Robustness Test. We try to use spline matching to test the full sample. The robustness test results show that the weighted deduction policy for R&D expenses stimulates the increase in input and output. Specifically, (1) in terms of R&D investment, after eliminating the interference of non-policy-influencing factors, the difference between the treatment group and the control group is still highly significant at the level of 1%, which proves that the weighted deduction policy for R&D expenses has a positive effect on

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Table 5: The average treatment effect of the sample population.

	Variable	Match	Control group	Treatment group	ATT	S.E.	T-state
One-to-one matching	Output	Before	2.32	2.13	0.19	0.05	3.98***
		After	2.32	2.18	0.14	0.06	2.14**
	Investment	Before	8.62	8.50	0.12	0.03	3.64***
		After	8.62	8.51	0.11	0.05	2.42**
	Invest	Before	1.61	1.47	0.14	0.04	3.53***
		After	1.61	1.50	0.11	0.06	1.91*
	Utility	Before	1.52	1.36	0.16	0.04	3.62***
		After	1.52	1.40	0.12	0.06	1.99**
	Appearance	Before	0.55	0.45	0.10	0.03	3.12***
		After	0.55	0.48	0.06	0.04	1.46
Nearest neighbor matching	Output	Before	2.32	2.13	0.19	0.05	3.98***
		After	2.32	2.21	0.11	0.06	1.96**
	Investment	Before after	8.62	8.50	0.12	0.03	3.64***
		After	8.62	8.53	0.10	0.04	2.44**
	Invest	Before	1.61	1.47	0.14	0.04	3.53***
		After	1.61	1.53	0.09	0.05	1.79*
	Utility	Before	1.52	1.36	0.16	0.04	3.62***
		After	1.52	1.40	0.12	0.05	2.35**
	Appearance	Before	0.55	0.45	0.10	0.03	3.12***
		After	0.55	0.53	0.02	0.04	0.51
Radius matching	Output	Before	2.32	2.13	0.19	0.05	3.98***
		After	2.32	2.21	0.11	0.06	1.96**
	Investment	Before	8.62	8.50	0.12	0.03	3.64***
		After	8.62	8.53	0.10	0.04	2.44**
	Invest	Before	1.61	1.47	0.14	0.04	3.53***
		After	1.61	1.53	0.09	0.05	1.79*
	Utility	Before	1.52	1.36	0.16	0.04	3.62***
		After	1.52	1.40	0.12	0.05	2.35**
	Appearance	Before	0.55	0.45	0.10	0.03	3.12***
		After	0.55	0.53	0.02	0.04	0.51
Nuclear matching	Output	Before	2.32	2.13	0.19	0.05	3.98***
		After	2.32	2.19	0.13	0.05	2.56**
	Investment	Before	8.62	8.50	0.12	0.03	3.64***
		After	8.62	8.54	0.09	0.04	2.47**
	Invest	Before	1.61	1.47	0.14	0.04	3.53***
		After	1.61	1.52	0.09	0.04	2.2**
	Utility	Before	1.52	1.36	0.16	0.04	3.62***
		After	1.52	1.38	0.14	0.05	3.03***
	Appearance	Before	0.55	0.45	0.10	0.03	3.12***
		After	0.55	0.51	0.04	0.03	1.23

Table 6: Policy incentive effects under different degrees of marketization.

	Variable	Match	High marketization				Low marketization			
			Control	Treat	ATT	T	Control	Treat	ATT	T
One-to-one matching	Output	Before	2.34	2.23	0.11	1.69*	2.28	2.06	0.23	3.43***
		After	2.34	2.29	0.06	0.61	2.28	2.16	0.12	1.37
	Investment	Before	8.71	8.68	0.03	0.65	8.51	8.36	0.15	2.87***
		After	8.71	8.64	0.07	1.06	8.51	8.42	0.09	1.29
	Invest	Before	1.62	1.53	0.09	1.53	1.60	1.42	0.18	3.11***
		After	1.62	1.56	0.06	0.74	1.60	1.51	0.09	1.09
	Utility	Before	1.55	1.43	0.13	2.02**	1.47	1.31	0.16	2.6***
		After	1.55	1.41	0.14	1.58	1.47	1.35	0.12	1.43
	Appearance	Before	0.62	0.56	0.06	1.11	0.45	0.36	0.09	2.29***
		After	0.62	0.67	−0.06	−0.81	0.45	0.36	0.09	1.71

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Table 6: Continued.

	Variable	Match	High marketization				Low marketization			
			Control	Treat	ATT	T	Control	Treat	ATT	T
Nearest neighbor matching	Output	Before	2.34	2.23	0.11	1.69*	2.28	2.06	0.23	3.43***
		After	2.34	2.29	0.05	0.63	2.28	2.11	0.18	2.36**
	Investment	Before	8.71	8.68	0.03	0.65	8.51	8.36	0.15	2.87***
		After	8.71	8.63	0.08	1.51	8.51	8.37	0.14	2.58***
	Invest	Before	1.62	1.53	0.09	1.53	1.60	1.42	0.18	3.11***
		After	1.62	1.55	0.07	1.07	1.60	1.47	0.13	1.99**
	Utility	Before	1.55	1.43	0.13	2.02**	1.47	1.31	0.16	2.6***
		After	1.55	1.47	0.08	1.11	1.47	1.31	0.16	2.31**
	Appearance	Before	0.62	0.56	0.06	1.11	0.45	0.36	0.09	2.29**
		After	0.62	0.66	−0.04	−0.76	0.45	0.35	0.10	2.21**
Radius matching	Output	Before	2.34	2.23	0.11	1.69*	2.28	2.06	0.23	3.43***
		After	2.34	2.29	0.05	0.62	2.29	2.10	0.19	2.55**
	Investment	Before	8.71	8.68	0.03	0.65	8.51	8.36	0.15	2.87***
		After	8.71	8.63	0.08	1.50	8.51	8.36	0.15	2.7***
	Invest	Before	1.62	1.53	0.09	1.53	1.60	1.42	0.18	3.11***
		After	1.62	1.55	0.07	1.06	1.61	1.46	0.15	2.18**
	Utility	Before	1.55	1.43	0.13	2.02**	1.47	1.31	0.16	2.6***
		After	1.55	1.47	0.08	1.10	1.48	1.30	0.17	2.43**
	Appearance	Before	0.62	0.56	0.06	1.11	0.45	0.36	0.09	2.29**
		After	0.62	0.66	−0.04	−0.77	0.46	0.35	0.11	2.32**
Nuclear matching	Output	Before	2.34	2.23	0.11	1.69*	2.28	2.06	0.23	3.43***
		After	2.34	2.29	0.05	0.77	2.28	2.11	0.18	2.63***
	Investment	Before	8.71	8.68	0.03	0.65	8.51	8.36	0.15	2.87***
		After	8.71	8.65	0.06	1.16	8.51	8.38	0.13	2.62***
	Invest	Before	1.62	1.53	0.09	1.53	1.60	1.42	0.18	3.11***
		After	1.62	1.56	0.06	1.01	1.60	1.47	0.14	2.26**
	Utility	Before	1.55	1.43	0.13	2.02**	1.47	1.31	0.16	2.6***
		After	1.55	1.46	0.09	1.35	1.47	1.31	0.16	2.5**
	Appearance	Before	0.62	0.56	0.06	1.11	0.45	0.36	0.09	2.29**
		After	0.62	0.63	−0.01	−0.22	0.45	0.38	0.07	1.67*

Table 7: Policy incentive effects under different market competition levels.

	Variable	Match	High competition				Low competition			
			Control	Treat	ATT	T	Control	Treat	ATT	T
One-to-one matching	Output	Before	2.37	2.20	0.17	2.53**	2.26	2.06	0.19	2.95***
		After	2.37	2.23	0.14	1.54	2.26	2.21	0.04	0.48
	Investment	Before	8.58	8.46	0.12	2.59***	8.67	8.54	0.14	2.69***
		After	8.58	8.45	0.12	2.02**	8.67	8.67	0.00	0.05
	Invest	Before	1.65	1.52	0.13	2.32**	1.57	1.42	0.15	2.55**
		After	1.65	1.50	0.15	1.87*	1.57	1.56	0.01	0.06
	Utility	Before	1.50	1.29	0.21	3.4***	1.54	1.43	0.11	1.80
		After	1.50	1.35	0.15	1.77*	1.54	1.47	0.06	0.73
	Appearance	Before	0.70	0.67	0.03	0.63	0.38	0.24	0.14	3.96***
		After	0.70	0.71	−0.01	0.08	0.38	0.29	0.09	1.66*
Nearest neighbor matching	Output	Before	2.37	2.20	0.17	2.53**	2.26	2.06	0.19	2.95***
		After	2.37	2.22	0.15	1.92*	2.26	2.14	0.12	1.49
	Investment	Before	8.58	8.46	0.12	2.59***	8.67	8.54	0.14	2.69***
		After	8.58	8.46	0.12	2.3**	8.67	8.60	0.07	1.32
	Invest	Before	1.65	1.52	0.13	2.32**	1.57	1.42	0.15	2.55**
		After	1.65	1.53	0.12	1.83*	1.57	1.50	0.07	1.04
	Utility	Before	1.50	1.29	0.21	3.4***	1.54	1.43	0.11	1.8*
		After	1.50	1.30	0.20	2.75***	1.54	1.44	0.09	1.28
	Appearance	Before	0.70	0.67	0.03	0.63	0.38	0.24	0.14	3.96***
		After	0.70	0.70	0.00	0.07	0.38	0.29	0.09	2.12**

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Table 7: Continued.

	Variable	Match	High competition				Low competition			
			Control	Treat	ATT	T	Control	Treat	ATT	T
Radius matching	Output	Before	2.37	2.20	0.17	2.53**	2.26	2.06	0.19	2.95***
		After	2.37	2.22	0.15	1.93*	2.26	2.14	0.12	1.47
	Investment	Before	8.58	8.46	0.12	2.59***	8.67	8.54	0.14	2.69***
		After	8.58	8.46	0.12	2.31**	8.67	8.60	0.07	1.27
	Invest	Before	1.65	1.52	0.13	2.32**	1.57	1.42	0.15	2.55**
		After	1.65	1.53	0.12	1.83*	1.57	1.50	0.07	1.02
	Utility	Before	1.50	1.29	0.21	3.4***	1.54	1.43	0.11	1.8*
		After	1.50	1.30	0.20	2.75***	1.54	1.45	0.09	1.27
	Appearance	Before	0.70	0.67	0.03	0.63	0.38	0.24	0.14	3.96***
		After	0.70	0.70	0.00	0.07	0.38	0.29	0.09	2.12**
Nuclear matching	Output	Before	2.37	2.20	0.17	2.53**	2.26	2.06	0.19	2.95***
		After	2.37	2.24	0.13	1.84*	2.26	2.12	0.14	1.97**
	Investment	Before	8.58	8.46	0.12	2.59***	8.67	8.54	0.14	2.69***
		After	8.58	8.49	0.09	1.85*	8.67	8.59	0.09	1.63
	Invest	Before	1.65	1.52	0.13	2.32**	1.57	1.42	0.15	2.55**
		After	1.65	1.57	0.09	1.42	1.57	1.46	0.11	1.8*
	Utility	Before	1.50	1.29	0.21	3.4***	1.54	1.43	0.11	1.8*
		After	1.50	1.31	0.19	2.92***	1.54	1.47	0.07	1.11
	Appearance	Before	0.70	0.67	0.03	0.63	0.38	0.24	0.14	3.96***
		After	0.70	0.68	0.02	0.38	0.38	0.27	0.11	2.92**

Table 8: Policy incentive effects under different political connections.

			Politically connected				No political connection			
	Variable	Mat	Control	Treatment	ATT	T	Control	treatment	ATT	T
One-to-one matching	Output	Before	2.33	2.11	0.22	3.44***	2.31	2.16	0.15	2.14**
		After	2.33	2.11	0.21	2.36**	2.31	2.24	0.06	0.65
	Investment	Before	8.55	8.44	0.11	2.34**	8.71	8.57	0.14	2.78***
		After	8.55	8.33	0.21	3.41***	8.71	8.63	0.09	1.29
	Invest	Before	1.61	1.42	0.19	3.42***	1.61	1.52	0.09	1.50
		After	1.61	1.40	0.22	2.82***	1.61	1.60	0.01	0.10
	Utility	Before	1.55	1.34	0.21	3.56***	1.48	1.39	0.10	1.51
		After	1.55	1.37	0.17	2.06**	1.48	1.35	0.13	1.43
	Appearance	Before	0.59	0.48	0.11	2.31**	0.51	0.41	0.10	2.14
		After	0.59	0.48	0.10	1.54	0.51	0.50	0.01	0.14
Nearest neighbor matching	Output	Before	2.33	2.11	0.22	3.44***	2.31	2.16	0.15	2.14**
		After	2.33	2.13	0.20	2.59***	2.31	2.22	0.09	1.06
	Investment	Before	8.55	8.44	0.11	2.34**	8.71	8.57	0.14	2.78***
		After	8.55	8.42	0.13	2.35**	8.71	8.61	0.10	1.69*
	Invest	Before	1.61	1.42	0.19	3.42***	1.61	1.52	0.09	1.50
		After	1.61	1.40	0.21	3.21***	1.61	1.58	0.03	0.37
	Utility	Before	1.55	1.34	0.21	3.56***	1.48	1.39	0.10	1.51
		After	1.55	1.38	0.17	2.33*	1.48	1.37	0.12	1.46
	Appearance	Before	0.59	0.48	0.11	2.31*	0.51	0.41	0.10	2.14**
		After	0.59	0.51	0.08	1.36	0.51	0.49	0.02	0.34
Radius matching	Output	Before	2.33	2.11	0.22	3.44***	2.31	2.16	0.15	2.14**
		After	2.33	2.13	0.20	2.63***	2.31	2.22	0.09	1.09
	Investment	Before	8.55	8.44	0.11	2.34**	8.71	8.57	0.14	2.78***
		After	8.55	8.42	0.13	2.37**	8.71	8.60	0.11	1.81*
	Invest	Before	1.61	1.42	0.19	3.42***	1.61	1.52	0.09	1.50
		After	1.61	1.40	0.21	3.23***	1.61	1.58	0.03	0.45
	Utility	Before	1.55	1.34	0.21	3.56***	1.48	1.39	0.10	1.51
		After	1.55	1.38	0.17	2.37**	1.48	1.36	0.12	1.53
	Appearance	Before	0.59	0.48	0.11	2.31**	0.51	0.41	0.10	2.14**
		After	0.59	0.51	0.08	1.36	0.51	0.49	0.02	0.28

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Table 8: Continued.

			Politically connected				No political connection			
	Variable	Mat	Control	Treatment	ATT	T	Control	treatment	ATT	T
Nuclear matching	Output	Before	2.33	2.11	0.22	3.44***	2.31	2.16	0.15	2.14**
		After	2.33	2.16	0.17	2.45**	2.31	2.23	0.08	1.08
	Investment	Before	8.55	8.44	0.11	2.34**	8.71	8.57	0.14	2.78***
		After	8.55	8.46	0.09	1.79*	8.71	8.62	0.09	1.77*
	Invest	Before	1.61	1.42	0.19	3.42***	1.61	1.52	0.09	1.50
		After	1.61	1.45	0.16	2.83***	1.61	1.60	0.01	0.13
	Utility	Before	1.55	1.34	0.21	3.56***	1.48	1.39	0.10	1.51
		After	1.55	1.36	0.18	2.95***	1.48	1.39	0.09	1.32
	Appearance	Before	0.59	0.48	0.11	2.31**	0.51	0.41	0.10	2.14**
		After	0.59	0.52	0.07	1.39	0.51	0.48	0.03	0.54

Table 9: Robustness test results.

	Variable	Match	Control	Treatment	ATT	S.E.	T-State
Spline matching	Output	Before	2.32	2.12	0.19	0.05	4.29***
		After	2.32	2.17	0.14	0.05	2.99***
	Investment	Before	8.62	8.50	0.12	0.03	3.64***
		After	8.62	8.53	0.10	0.02	4.03***
	Invest	Before	1.61	1.46	0.14	0.04	3.79***
		After	1.61	1.51	0.11	0.04	2.54**
	Utility	Before	1.52	1.35	0.17	0.04	3.83***
		After	1.52	1.37	0.15	0.04	3.46***
	Appearance	Before	0.55	0.44	0.10	0.03	3.24***
		After	0.55	0.50	0.04	0.03	1.27

the increase of investment; (2) in terms of patent output, the difference exists between the matched treatment group and the control group; the ATT value is still significant at the 1% level, which proves that the weighted deduction policy for R&D expenses can promote the increase in output; (3) from the perspective of patent subdivision, before and after matching, there are significant differences between the treatment group and the control group in invention patents and utility patents, while the appearance patents have significant differences before matching, but the differences disappear after matching. This is consistent with the previous conclusion, indicating that the policy promotes the high-quality development of innovation. See Table 9 for details.

5. Research Conclusions, Contributions, and Suggestions

5.1. Research Conclusion. Based on the "additionality effect" analysis framework, we use the PSM method to evaluate the impacts of the weighted deduction policy for research and development (R&D) expenses on innovation additionality, from the moderation perspective of marketization, market competition, and political connections. The research has further verified the following: this policy can effectively stimulate the additionality of input and output, and it has a significant "additionality effect" on invention patents and utility patents, thus promoting high-quality innovation of firms. As moderation variables, low degree of marketization, high degree of market competition, and political connections positively regulate additionality effect of input and output brought by the weighted deduction policy for R&D expenses. Among them, the effect of low degree of marketization is contrary to the research findings of He Kang et al.

5.2. Research Contribution. Generally speaking, compared with the existing studies, we have at least the three following aspects of research contributions: (1) Combining the "additionality effect" analysis framework with the PSM method, we examined the real incentive effect of the weighted deduction policy for R&D expenses on the innovation of listed firms on the SME board and GEM and provided microempirical evidence based on Chinese practice. (2) The regulating mechanism of signal transmission is verified, which strongly supports the fact that the weighted deduction policy for R&D expenses can transmit signals of good development of firms to market in the background of information asymmetry, thereby helping firms to obtain innovation resources. In regions with low degree of marketization and high degree of market competition, the regulation effect of signal transmission is more significant, and political connections can transmit a signal of good political-business relationship, which will further strengthen the innovation and incentive effect of the policy. (3) The effect of the weighted deduction policy on firm innovation incentives is significant in multiple hypotheses, which strongly supports the policy's reform orientation.

5.3. Recommendations

(1) As far as they are concerned, state-owned firms have natural endowment advantages in terms of political-

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business relations in China. Other factors, such as whether there is high-tech enterprises' identification, are likely to be one of the important factors in signal transmission. It is also worthy to verify the heterogeneity of innovation effects.

(2) In terms of policy implementation, firms should make full use of policy window periods. Meanwhile, to avoid R&D manipulation, the government should effectively supervise the behavior of firms and intermediaries. Building a clean political-business relationship will help strengthen signal transmission and optimize policy effects.

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.

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Research Article

Research on Solving Path of Negative Effect of "Information Cocoon Room" in Emergency

Wei Liu and Wei Zhou

School of Public Administration and Law, Hunan Agricultural University, Changsha 410128, China

Correspondence should be addressed to Wei Zhou; zhouwei13517471489@stu.hunau.edu.cn

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The "information cocoon" can hinder the normal dissemination and flow of emergency information during emergencies. It is important to explore the factors of this effect and to resolve the negative effects of the information cocoon, so as to help the public to "break out of the cocoon" and help the government to better promote emergency information management. Based on information ecology theory and the S-O-R model, this study designed questionnaires using a Likert five-level scale and selected 388 publics from several smart city pilot areas in Changsha, Zhuzhou, Shaoshan, and Yueyang cities in Hunan Province. Field research was conducted based on four factors, information ontology, information technology, government regulation, and social network, and empirical analysis was conducted through structural equations. The study shows that information ontology, information technology, government regulation, and social networks have significant effects on the information cocoon effect by influencing the reinforcement of public information preferences. Among them, government regulation ($P = 0.34$) has the most significant effect on the reinforcement of public information preferences, followed by information ontology ($P = 0.32$) and social networks ($P = 0.31$), and information technology ($P = 0.29$) has the weakest effect. Combining the results of empirical analysis, we propose a four-dimensional path of "information-technology-regulation-value" to break the cocoon. By optimizing information ontology, using technology for good governance, promoting algorithmic fairness, and enhancing social stickiness, we help the public break through the shackles and negative effects of the information cocoon and promote the harmonious, stable, and healthy development of the emergency information field.

1. Introduction

In the digital era, information technology helps the government to disclose emergency warning information more quickly through government websites, emerging media, and mobile terminal programs and respond to social emergency information search demands. Emergency data, as an important factor of production, have widely penetrated into all aspects of emergency management [1]. Emergency information is the general name of information content and information resources released by official and unofficial channels in the process of emergency management of public emergencies [2]. The transmission of this information is of great significance to the public's behavior choice in all kinds of emergencies. At present, the personalized information push with algorithm technology as the core enables the public to freely obtain massive emergency information through different media, effectively reducing the time cost of obtaining information and meeting the high matching of individual needs and information. However, the information filtering mechanism based on algorithm technology caters to the public's browsing habits and interests and pushes homogenous content to users to create a relatively closed information space environment. As a result, the public's information vision becomes narrow, the information source is unbalanced, and the heterogeneous information is not accessible. The public is just like a silkworm chrysalis in a cocoon, thus forming the "information cocoon" effect [3]. In August 2021, the Cyberspace Administration of China (CAC) deployed a series of special actions called "Clear and Clear" to prohibit the push of emergencies, disasters, and accidents, as well as false information from

unknown sources or illegal production. Under an emergency situation, the information cocoon will lead to the public continuously strengthening the existing values and it is difficult to interact with the heterogeneous value groups. In the long run, it is easy to lead to the negative effects such as the intensification of group polarization and the weakening of social adhesion. In addition, the public is bound in the cocoon and one-sided understanding of emergencies, but also it is easy to cause panic, anxiety, and other negative emotions, which is not conducive to emergency information management and effective prevention of emergencies. Therefore, how to break through the shackles, eliminate the negative effect of the "information cocoon room" that may be generated by the public in emergencies, and create a comprehensive, objective, true, and accurate benign emergency information circulation space has become a new problem faced by the government's emergency information management in the era of digital China.

After the emergence of the concept of the information cocoon room, it has aroused extensive attention in academic circles. Many scholars combine their own research fields to study whether the information cocoon room really exists. Duan et al. [4] believe that it has become a common social phenomenon for users to be in the information ecological environment of an external cocoon and internal cocoon driven by information technology. Zhang [5] analyzed the social situation in China and believed that the public's access to information was constantly converging and narrowing, resulting in the information cocoon effect becoming a new social problem. Research on the influence of information cocoon has been the focus of many scholars. Rehm [6] believes that the information cocoon room can strengthen the effect of information dissemination and is easy to be used purposefully to spread public opinion information and information with emotional incitement. Zhou [7] believes that the information cocoon house poses a potential threat to social consensus building by reducing social stickiness, intensifying the sense of division, and widening the knowledge gap. Gong [8] puts forward that the cocoon house of information restricts the free flow of information and causes the squeeze and narrowing of the main space in the ideological field. The discussion on the causes of information cocoon can be roughly divided into three categories in the academic circle. The first category focuses on information technology, the second focuses on the public's own information choice, and the third focuses on the influence of the social information environment. Some scholars believe that algorithm technology is the key factor to produce the information cocoon effect [9], and the personalized recommendation mechanism will strengthen users' inherent bias and weaken their desire for broader information [10]. However, many scholars believe that there is no need to worry about information technology and individual information selection [11] is the main cause of its occurrence. Because the current information technology is not mature enough and the technology between the information providing platform is not interconnected, cannot completely trap users. Shen [12] analyzed the formation process of the information cocoon effect from the perspective of public psychological cognition. Wang [13] stressed that users' own information needs are the final determinant. From the perspective of user interaction, Yang and She [14] propose that the initiative of public participation in interaction is another influencing factor. In addition, many scholars agree that a highly artificial environment [15], social information environment [16], media information transmission [17], and other social environmental factors will affect the formation of the information cocoon house effect.

In summary, most scholars believe that information cocoons are real and have significant negative effects on social progress, so they study the causes of information cocoon effect from individual factors of information technology, individual information choice, and social environment but rarely combine the three factors in multiple discussions. At the same time, most studies on information cocoon are based on information in a broad sense and few scholars have studied emergency information in emergencies. Therefore, this paper combines the information ecology theory with the S-O-R model and analyzes the factors influencing the formation of public information cocoon effect in emergencies from multiple dimensions with the help of the structural equation model. Then, based on the empirical results, we propose suggestions to break the cocoon and eliminate the negative effect of the information cocoon, so as to contribute to the harmonious development of emergency information management in China.

The paper is structured as follows: Section 2 presents the theoretical basis of the article and the research hypotheses. Section 3 describes the data sources, the construction of the overall model, and the selection of specific variables. Section 4 presents the analysis of the empirical results. Section 5 presents the policy recommendations, with the findings of the above study as the suggested starting point.

2. Theoretical Analysis and Research Hypothesis

2.1. Theoretical Model

2.1.1. Information Ecology Theory. Information ecology theory is a new research theory formed by Horton [18], a famous scholar, who combines ecological theory with the views of information resource management. Its core idea emphasizes the harmonious symbiosis between "people, information, and environment." Based on this, Crawford [19] proposed the concept of an information ecosystem in 2000. All kinds of information service activities in emergencies form an emergency information ecosystem, which also emphasizes the harmonious coexistence of the "human-information-environment." The system has the functions of generating, transmitting, communicating, and sharing information and can provide all kinds of emergency information for the public in time. The "human" factor refers to the preference degree of individuals when choosing emergency information. The "information" factor is composed of information ontology and information technology. In the process of an emergency, various disaster information, disaster dynamics, emergency decision-making, and event

evaluation are disseminated to the society through various information transmission methods through official and unofficial channels. Starting from information ontology [20], information ontology is the general name of information type, information content, information quantity, and information quality. With the support of computer and communication technology, algorithmic recommendation technology is an intelligent technical tool that can collect user information data, generate user portraits, and filter and push information through recording plate, analysis plate, and distribution plate, so as to meet the public's information needs [21]. "Environmental" factors include the government's regulatory environment for emergency information dissemination and the public's social network environment. Government supervision is the environment formed by the government's supervision of the contents and channels of emergency information dissemination. The social network is an interpersonal communication circle formed by informal groups such as family members, friends, and colleagues that the public can contact in the process of an emergency before and after the event. Under the joint action of "information" and "environment," the public chooses information based on individual information preference.

2.1.2. S-O-R Model. The S-O-R (stimulus-germ-response) model was first proposed by A. Mehrabian and Aeroshell [22]. It is a classical framework for studying the relationship between Stimulus (S), Organism (O), and Response (R). The core idea of the model is that an individual's environment will stimulate his cognitive and emotional changes and ultimately lead to individual behavior responses. Nowadays, many scholars have introduced the S-O-R model into the research fields of user information behavior such as online health communities [23], mobile government apps [24], and the WeChat platform of university libraries [25]. Combined with the public information cocoon effect, the process of public information narrowing is the process of internal and external factors in stimulating the operation and the body's information preference ultimately leads to the formation of an information cocoon. Therefore, the S-O-R model has internal consistency with the formation of an information cocoon room in emergencies. Therefore, the research paradigm of the S-O-R model is used to comprehensively explore the effect of the public information cocoon room in emergencies.

2.1.3. Hypothetical Model. Based on the research paradigm of information ecology theory and the S-O-R model, this study constructed a research model for the formation factors of the "information cocoon house" effect in emergencies (Figure 1). In the context of emergencies, the public is stimulated by the four factors of information ontology, information technology, government regulation, and social network due to the drastic changes in the environment and their preference for information keeps deepening, which leads to the development of the "information cocoon" effect in the acquisition of actual information by the public.

2.2. Research Hypothesis

2.2.1. Influence of Information Ontology on the Reinforcement of Public Information Preference. Information ontology is the information provided by official and unofficial channels that can be received by the public in emergency events, including information type, information content, information form, and information quality. Zhou [7] pointed out that different groups have different preferences for different types of information. In addition, with the popularity of short video apps, Wang and Zhang [26] found through their research that dynamic audio and video books can better stimulate the public's interest in reading. Therefore, Wang et al. [27] concluded that in the process of receiving and understanding information, the public is affected by the type, content, presentation form, and quality of information and information preference is generated and strengthened over time. Based on this, the following hypotheses are proposed:

> H1: information ontology has a significant impact on the reinforcement of public information preference.

2.2.2. Influence of Information Technology on the Strengthening of Public Information Preference. Algorithmic recommendation technology is a kind of digital information technology that generates a recommendation list based on user interest and realizes efficient matching between user interest and information recommendation content [28]. Zhang and Zhao [29] believe that intelligent algorithms make interest preference labels for the public and recommend homogenous and single reading content. Shen et al. [30] further pointed out that the intelligent recommendation algorithm would cause the public to be trapped in the full picture of the emergency, which further catalyzed the reinforcement of preference. Based on this, the following hypotheses are proposed:

> H2: information technology has a significant impact on the reinforcement of public information preference.

2.2.3. Influence of Government Regulation on the Strengthening of Public Information Preference. Under the background of emergencies, the government supervises the social emergency information environment by using the information technology usage norms, information dissemination norms, laws and regulations in the field of network security, and accountability systems [31]. Li and Hao [32] pointed out that information dissemination must have a public pressure mechanism, rather than relying on self-regulation and restraint of media platforms such as we-media, Weibo, and WeChat. Hen and Wang [33] believe that there are still loopholes in government supervision, which hinder the transmission of the correct information and easily lead to the public's preference for false and public opinion information. Based on this, the following hypotheses are proposed:

> H3: regulatory environment has a significant impact on the reinforcement of public information preference.

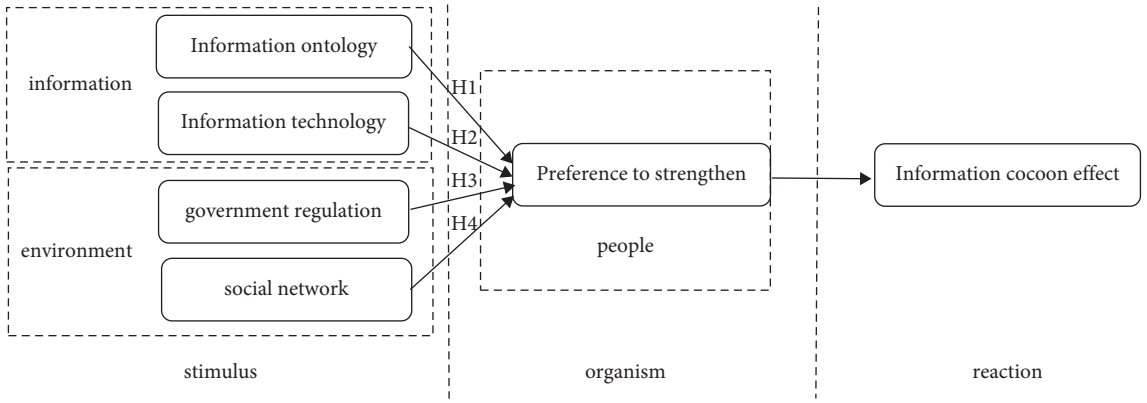

Figure 1: Research model of the formation factors of the "information cocoon room" effect in emergencies.

2.2.4. Influence of Social Network on the Reinforcement of Public Information Preference. The social network is composed of relatives, friends, classmates, and other social groups. Zhu et al. [34] proposed that conformity psychology and group identity would have a direct impact on individual information reading tendency in the process of public information browsing. Zhang [35] also believes that under the subtle influence of parents, friends, relatives, and other social groups, the public's preference for emergency information is constantly strengthened. Based on this, the following hypotheses are proposed:

> H4: social network has a significant impact on the reinforcement of public information preference.

2.2.5. Effect of Strengthening Public Information Preference on the Formation of Emergency Information Cocoon Effect. Preference reinforcement refers to the deepening of the public's emotional tendency and attitude preference when browsing emergency information. Ren et al. [17] believe that information preference causes the public to have stereotyped thinking on information selection. Li et al. [36] showed that the continuous strengthening of information preference would affect the public's attitude and concept of viewing the overall picture of an event. In this process, the public would continuously accept homogenized information and eventually form the information cocoon effect. In emergencies, many information disseminators take advantage of this effect to spread false, fake, junk marketing, emotional incitement, and other bad information, bringing wrong value orientation to the public and causing negative social impact. Based on this, the following hypotheses are proposed:

> H5: the strengthening of public information preference has a significant impact on the formation of the cocoon effect of emergency information.

3. Data Description, Model Setting, and Variable Selection

3.1. Data Sources. The survey questionnaire of this study is generated after adjustment according to the measurement items in the information ecology theory and S-O-R model research literature combined with the specific purpose. The questionnaire is divided into two parts: demographic variables such as gender, age, and education background constitute the first part of the questionnaire, and factors influencing the formation of public information cocoon effect in emergencies constitute the second part of the questionnaire. In order to ensure the scientific, rationality, and standardization of the survey questionnaire, the authors first issued 30 questionnaires for presurvey and sent them to experts in the field for evaluation and modified them according to the presurvey and experts' feedback. According to the list of pilot smart cities announced by the National Ministry of Housing and Urban-Rural Development, field research was conducted in the Hunan Province in February and March 2021. Based on the principle of stratified sampling, Changsha City (Meixi Lake International Service Area, Daxi Pilot District, Changsha County), Zhuzhou City (Yunlong Demonstration Zone), Shaoshan City (Shaoshan Township), Yueyang City (Yueyanglou District), Chenzhou City (Yongxing County, Jiahe County, Yizhang County), etc., were mainly sampled. According to the principle of incidental sampling, 450 questionnaires were sent out and 388 valid questionnaires were sent out, with an effective rate of 86.2%.

3.2. Sample Characteristics. The characteristics of valid data collected by the questionnaire show that the number of females is slightly more than that of males, and most of the interviewees are from the young population aged 19–40. The number of respondents with a bachelor's degree or above was the largest, accounting for 34.8%; according to the law of the People's Republic of China on occupational classification ceremony, based on practice, this study will investigate the object is divided into administrative institutions and enterprises management personnel, professional and technical personnel, business services personnel, and other agricultural industry personnel, including most of the respondents from professional and technical personnel, business services personnel, and other professional personnel; other professional accounted for the highest value, 32.7%; 23.2% of respondents have been paying attention to emergency information for more than 8 years. Respondents used the

emergency information platform for 1–2 hours on average every day. Specific sample characteristics are shown in Table 1.

3.3. Model Selection. The structural equation model is the best method to test the empirical data collected by the survey [37]. The structural equation model is a multivariate statistical approach that can analyze both the effect of individual variables on the explanatory variables and the interrelationships between variables. This paper aims to analyze the influence of information ontology, information technology, government regulation, and social network on the reinforcement of public information preference and the influence of the reinforcement of public information preference on the formation of the information cocoon effect. Therefore, the structural equation model is used to analyze the formation process of the information cocoon effect under the influence of multiple variables. The general structural equation includes two parts: the measurement model and structural equation, which can be expressed by the following three basic equations:

$$\eta = \beta\eta + \Gamma\xi + \zeta, \tag{1}$$

$$y = \Lambda y\eta + \varepsilon, \tag{2}$$

$$x = \Lambda x\xi + \delta. \tag{3}$$

Among them, the endogenous observation variable is Y, the exogenous observation variable is X, the endogenous potential variable is η, and the exogenous potential variable is ξ. In this study, information ontology, information technology, government regulation, and social networks are ξ and preference reinforcement and information cocoon effect are η. η and ξ are linked by linear equations of the molar and γ matrix and error vector ζ to form equation (1), the structural equation. Equations (2) and (3) are measurement models; namely, six latent variables of information ontology, information technology, government regulation, social network, preference reinforcement, and information cocoon effect are described by different observation variables. The measurement variables Y and X are related to the corresponding potential variables η and ξ, respectively, through the factor loads $\lambda\ y$ and $\lambda\ \chi$, while ε and δ are the measurement errors.

3.4. Variable Setting and Description. All the observed variables in this study were based on the existing literature and social reality, and all the answers were given by Likert five-level scale. Specifically, there are five levels: totally disagree, disagree, indifferent, agree, and strongly agree. A specific variable description is shown in Table 2.

4. Empirical Results and Analysis

4.1. Model Evaluation. In this paper, the factors influencing the formation of the public information cocoon house effect were determined through a literature review and the analysis framework was constructed by using information ecology theory and the S-O-R model, and then, the hypothesis testing and parameter estimation were carried out by using Amos24.0 software construction theory. Details are given as follows.

4.1.1. Reliability and Validity Test. Reliability refers to the reliability of measurement data. Cronbach's Alpha and combined reliability were used to test the reliability of the survey questionnaire in this paper. Cronbach's alpha greater than 0.6 indicates that the data reliability passed the test. As shown in Table 3, the alpha values of all variables are greater than 0.8 and the internal consistency of the sample data is good throughout the test.

It can be seen from Table 4 that the combined reliability (CR) of all variables is between 0.818 and 0.885, all greater than 0.7; that is, the sample data have passed the combined reliability test. Validity refers to the validity of measured data. This paper tests the validity from two aspects: convergence validity and discriminant validity. As shown in Table 4, the standardized load is between 0.703 and 0.860, both greater than 0.6. AVE values range from 0.530 to 0.658, all of which are greater than 0.5; that is, the sample data pass the convergence validity test.

It can be seen from Table 5 that the AVE square root values of all variables are greater than the correlation values of other variables; that is, the sample data pass the discriminant validity test.

4.1.2. Fitting Degree Test and Hypothesis Test. A fitting test is used to evaluate the degree of matching between model and data. As the multivariate normal value of the data in this study is greater than 5, it does not conform to the multivariate normal distribution. Therefore, Bollen–Stine Bootstrap was used to carry out the correction operation to improve the accuracy of sample estimation and prevent chi-square expansion and mismatch [38, 39]. Amos24.0 software was used for empirical calculation, and the fitting test results of the hypothesis model were obtained. As shown in Table 6, CMIN/DF is 1.42, RMSEA is 0.03, GFI is 0.94, NFI is 0.94, CFI is 0.98, and NFI is 0.94. All the indicators meet the fit criteria and the fit indices pass the test.

It can be seen from Table 7 that, in emergencies, information ontology has a significant positive impact on the reinforcement of public information preference. The standardized path coefficient is 0.317, and hypothesis 1 passes the test. Information technology has a significant positive effect on the reinforcement of public information preference. The standardized path coefficient is 0.290, and hypothesis 2 passes the test. Government regulation has a significant positive effect on the reinforcement of public information preference, the standardized path coefficient is 0.342, and hypothesis 3 passes the test; social network has a significant positive effect on the reinforcement of public information preference, and the standardized path coefficient is 0.313. Hypothesis 4 passes the test. The reinforcement of public information preference has a significant positive effect on the information cocoon effect, and the standardized path

Table 1: Description of sample characteristics.

Statistics		Frequency	Proportion (%)
Gender	Male	190	49
	Female	198	51
Age	Under the age of 18	39	10
	19–25	97	25
	26–40	151	39
	41–55	81	21
	More than 55 years old	20	5
Education level	Primary and below	4	1
	Junior high school	32	8.2
	High school or technical secondary school	107	27.6
	College	110	28.4
	Bachelor degree or above	135	34.8
Professional	Administrative personnel in enterprises and institutions	55	14.2
	Professional and technical personnel	86	22.2
	Business service personnel	75	19.3
	Agricultural personnel	45	11.6
	Others	127	32.7
Pay attention to emergency information time	2 years or less	34	8.8
	3–4 years	53	13.7
	5-6 years	98	25.2
	7–8 years	113	29.1
	More than 8 years	90	23.2
Average time spent using the platform per day	1 hour or less	132	34
	1 to 2 hours	154	39.7
	2 to 3 hours	61	15.7
	3 to 4 hours	27	7
	More than 5 hours	14	3.6

coefficient is 0.602. Hypothesis 5 passes the test. Accordingly, the structural equation research model with path coefficient as shown in Figure 2 is generated.

4.2. Result Analysis. Under the framework of "human-information-environment" analysis emphasized by information ecology theory, combined with the S-O-R model, the structural equation model is used to study the influence of information ontology, information technology, government regulation, and social network on the reinforcement of public information preference and the influence of the reinforcement of public information preference on the information cocoon effect. The main results are analyzed as follows.

4.2.1. Influence of Information Ontology on the Reinforcement of Public Information Preference. Information ontology has a significant positive influence on the reinforcement of public information preference, with a path coefficient of 0.317 and a P value less than 0.001. This shows that information data in the era of big data increase exponentially, and information itself will seriously affect the public's preference. First, there is a lack of effective integration of different types of emergency information. The public prefers to know information closely related to themselves and lacks understanding and prevention of other types of emergencies. Second, in terms of safety knowledge, emergency prevention knowledge, rescue knowledge, and other information content, when there is no emergency, the public is not within the scope of daily information browsing selection, very easy to be ignored. Thirdly, in emergency situations, the public prefers to learn about events in the form of video information, picture information, and sound information within a limited time. Fourthly, the timeliness, authenticity, and comprehensiveness of information cannot be guaranteed, resulting in the fragmentation of public access to information and individuals being covered in limited information.

4.2.2. Influence of Information Technology on the Strengthening of Public Information Preference. Information technology has a significant positive effect on the reinforcement of public information preference, with a path coefficient of 0.290 and a P value less than 0.001. In order to achieve the purpose of increasing the click rate, information disseminators will make labels for users by using intelligent algorithms based on the public's forwarding, browsing, collecting, and other behaviors during the previous emergency situation. Finally, a personalized push is used to transmit information to the public, so that the information delivery can better meet the public's information preference. The application of algorithm technology makes the information pushed regular and directional, which reduces the chance for the public to come across information outside their interest scope and urges users to continuously strengthen the information preference they have formed. As

Table 2: Variable definition and literature sources.

Latent variables	Item	Observation variable	Source
Information ontology	IO1	I pay different attention to four types of emergencies: natural disaster information, accident disaster information, public health event information and social security event.	Davis F D, 1989; Venkatesh V et al., 2000
	IO2	I pay different attention to different information contents such as basic information of emergencies, common sense of safety prevention and government safeguard measures.	
	IO3	The way information is presented (video, audio, graphic, text, etc.) affects how I pay attention to information.	
	IO4	When an emergency does not occur, the timeliness and comprehensiveness of information will affect my attention to information.	
Information technology	IT1	I will use the software search function to directly retrieve the emergency information of interest.	Yu Guoming, Canren, 2019; zhang Hai, 2020; Ajzen I, 2002
	IT2	I use filters to filter out content that I'm not interested in.	
	IT3	I often see messages pushed by Weibo, WeChat and Douyin.	
	IT4	Most of the information pushed by Weibo, WeChat, Douyin and other software is what I am interested in.	
Government Regulation	GR1	I do not think the laws governing emergency information are perfect enough.	Zhou T, 2018
	GR2	I do not think government regulation of emergency information distributors is in place.	
	GR3	I think there are still some deficiencies in the regulation of algorithmic recommendation technology.	
	GR4	I think the emergency information regulatory environment needs to be improved and perfected.	
Social networking	SN1	I will pay attention to the emergency information recommended by my relatives and friends.	Yang Mengqing et al., 2017; Zhang Changliang, 2019
	SN2	I will share and exchange emergency information with my relatives and friends.	
	SN3	My mood is easily influenced by the people around me.	
	SN4	My preference for emergency information tends to be influenced by the people around me.	
Preference strengthen	PS1	I Have a strong emotional bias toward different emergency messages.	Ajzen I, 2002
	PS2	I Have a distinct preference for different emergency messages.	
	PS3	I know exactly what my preference is for emergency information.	
Information Cocoon effect	ICE1	I Often read information that interests me.	Zhang Hai, 2020; Duan Hui et al., 2020;
	ICE2	It's hard for me to accept information that I'm not interested in and have different values.	
	ICE3	My information source channel, information type is single.	
	ICE4	I do not want to communicate with people who have different values.	

Table 3: Cronbach's alpha test of measurement contents.

The variable name	Information ontology	Information technology	The government regulation	The social network	Preference to strengthen	Information cocoon effect	The overall
Cronbach's alpha	0.852	0.853	0.838	0.818	0.843	0.885	0.939

a result, the public's understanding of the whole face of an emergency is blocked, heterogeneous information input is lacking, and other valuable content is not timely, fully, and effectively utilized. The negative effect of the information cocoon will become more and more significant.

4.2.3. Influence of Government Regulation on the Strengthening of Public Information Preference. Government regulation has a significant positive effect on the reinforcement of public information preference, with a path coefficient of 0.342 and a P value less than 0.001. This indicates that whether the information environment formed under government supervision is good or not will affect the strengthening of public preference for information. There are some loopholes in the government's governance of online public opinion, legislation of network security information, and formulation of emergency information dissemination standards, which result in the inability of social supervision to be carried out effectively. Driven by interests, information disseminators tend to use the public's psychology of rationality, novelty, and conformity to distort

Table 4: Test of combination reliability and convergence validity of measurement contents.

The variable name	Measurement	Nonstandardized load	SE	CR	*P*	Standardized load	CR	AVE
Information ontology	IO1	1.000				0.725	0.853	0.592
	IO2	1.077	0.079	13.636	***	0.762		
	IO3	1.135	0.078	14.511	***	0.828		
	IO4	1.012	0.074	13.592	***	0.759		
Information technology	IT1	1.000				0.710	0.855	0.597
	IT2	0.973	0.075	13.026	***	0.736		
	IT3	1.035	0.073	14.208	***	0.819		
	IT4	1.089	0.077	14.198	***	0.818		
Government regulation	GR1	1.000				0.773	0.838	0.564
	GR2	1.074	0.077	13.924	***	0.760		
	GR3	1.043	0.076	13.751	***	0.749		
	GR4	0.976	0.074	13.279	***	0.721		
Social network	SN1	1.000				0.756	0.818	0.530
	SN2	0.965	0.077	12.488	***	0.718		
	SN3	0.919	0.075	12.277	***	0.703		
	SN4	1.083	0.085	12.673	***	0.732		
Preference to strengthen	IP1	1.000				0.777	0.844	0.644
	IP2	1.056	0.070	15.023	***	0.860		
	IP3	0.865	0.060	14.522	***	0.767		
Information cocoon effect	ICE1	1.000				0.819	0.885	0.658
	ICE2	0.976	0.052	18.643	***	0.858		
	ICE3	0.867	0.052	16.701	***	0.781		
	ICE4	0.944	0.056	16.827	***	0.785		

Table 5: Discriminant validity test of measurement contents.

	Preference to strengthen	Information cocoon effect	Social network	Information technology	Government regulation	Information ontology
Preference to strengthen	**0.802**					
Information cocoon effect	0.621	**0.811**				
Social network	0.620	0.593	**0.728**			
Information technology	0.622	0.562	0.590	**0.773**		
Government regulation	0.631	0.568	0.585	0.643	**0.751**	
Information ontology	0.640	0.654	0.715	0.714	0.649	**0.769**

Table 6: Test of fit degree of the research model.

Fitting index	CMIN/DF	RMSEA	GFI	NFI	CFI	NFI
Adapter standard	<3	<0.05	>0.90	>0.90	>0.90	>0.90
This model values	1.42	0.03	0.94	0.94	0.98	0.94

Table 7: Hypothesis testing and path coefficients.

Path to the relationship between	Normalized path coefficient	Significant	Hypothesis testing
Information ontology ⟶ preference to strengthen	0.317	***	H1 (support)
Information technology⟶preference to strengthen	0.290	***	H2 (support)
Government regulation ⟶ preference to strengthen	0.342	***	H3 (support)
Social network ⟶ preference to strengthen	0.313	***	H4 (support)
Preference to strengthen ⟶ information cocoon effect	0.602	***	H5 (support)

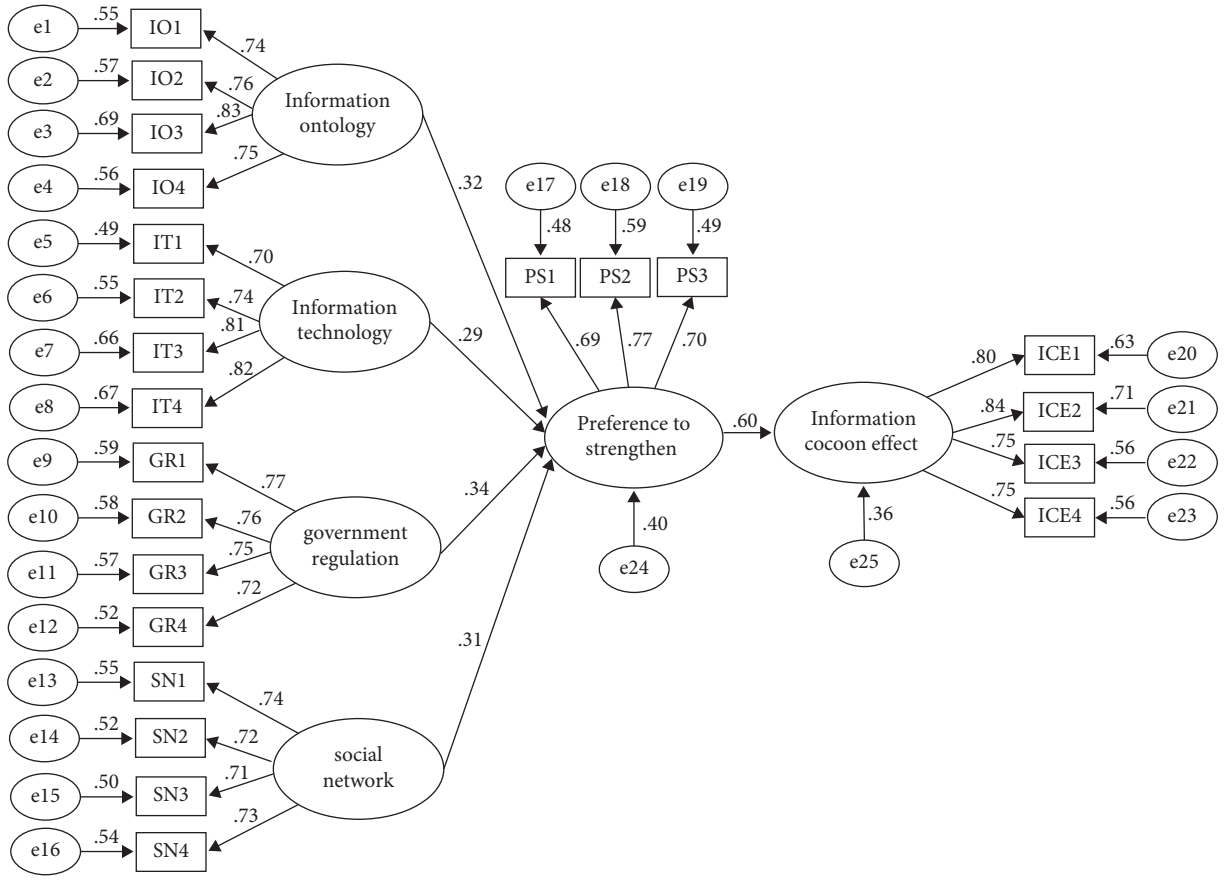

Figure 2: Structural equation model.

the truth of emergencies or use difficult words to stir up emotions, so as to distort their mainstream values, weaken the sense of trust in the government's emergency handling, and cause negative social energy. For example, many studies have found that the public's response to emergencies is passive and helpless. Under abnormal circumstances, the public tends to blame the government for the defects of emergency work, believing that the government's response is slow, the protection is insufficient, and the information is not transparent [40].

4.2.4. Influence of Social Network on the Reinforcement of Public Information Preference. The social network has a significant positive influence on the reinforcement of public information preference, with a path coefficient of 0.313 and a P value less than 0.001. It shows that in the complex and changeable social network environment, the public will be influenced by the community of family, friends, colleagues, and classmates. Due to the sudden events, work and life, politics and economy, social culture, and other drastic changes that break the original balance, the public will tend to find groups who live together, have similar interests, and have timely communication for information exchange and interaction. When seeing emergency reports, disaster data, factual information, and images shared by parents, friends, and relatives, the public can easily reach psychological identity with others, leading to imitation and following in behavior. This effect is highlighted by the fact that, in the face of emergency information, if the information preference of the surrounding community is inconsistent with their own, the public is likely to change their attitude to conform to the preference of the community.

4.2.5. Influence of Enhanced Public Information Preferences on the Formation of Information Cocoon Effect. The reinforcement of public information preference has a significant positive influence on the formation of the emergency information cocoon effect, the path coefficient is 0.602, and P value is less than 0.001. Preference reinforcement is the direct factor leading to the information cocoon effect. Under algorithm recommendation, individuals tend to select emergency information according to their own emotions and attitudes. In the outbreak period of an emergency, the public will take the initiative to transfer information attention to the event, so that the understanding of emergency information will be more profound. However, in the fading period of the event, the public will pay less attention to the event, and the follow-up treatment of the emergency may be relatively unknown. Therefore, when the public chooses information according to their preferences and tendencies, they will confine themselves in the "cocoon house" constructed, resulting in negative effects. First, an "information

cocoon" tends to make the public believe in some distorted and false information, lose individual criticism and negation, and breed public opinion. Second, in a closed information environment, the public lacks an overall understanding of emergencies and is prone to blindly optimistic psychology or even to relax vigilance, which is not conducive to the timely disposal of emergencies. Third, living in the "information cocoon," the public is not willing to accept heterogeneous information and may have panic, anxiety, depression, and other unhealthy psychological emotions under self-suggestion.

5. Conclusions and Policy Implications

Through questionnaire survey and empirical analysis, from the perspective of organism change-response, the formation of the information cocoon effect is the result of the strengthening of public information preference. Therefore, to get rid of the shackles of the cocoon room, it is necessary to pay attention to the strengthening of public information preference. From the perspective of stimulus-organism change-response, information ontology, information technology, government regulation, and social network all make the public strengthen information preference in the process of obtaining emergency information and then produce the information cocoon effect. Therefore, in order to break the cocoon effect of public information in emergency events, we should reduce the factors leading to the strengthening of public information preference. Based on this, a four-dimensional cocoon-breaking path of "information-technology-regulation-value" is proposed to provide a reference for government emergency information management.

5.1. Optimizing Information Ontology to Improve Public Interest in Reading. From the information type, information content, information form, and information quality, we optimize information ontology and stimulate reading interest, which is conducive to the public to accept more emergency content. First, information processing uses digital connections to aggregate different types of information. We form "public forum," give the public choicer angle, and increase the chance of an encounter with heterogeneous information. Second, we increase the propaganda of emergency science popularization of information content and normalize science popularization. Through knowledge lectures, education and popular science, online q&A, and other ways, we popularize common-sense safety prevention knowledge to the public in easy-to-understand language, so as to ensure that more people can receive effective popular science information. Third, diversified forms of information are used to present the professional knowledge involved in emergencies in a more intuitive and vivid form to reduce the public's reading fatigue. At the same time, color, background, pattern, and other materials can be used to improve the ability of information display and improve the public's interest in reading. Fourth, we ensure the timeliness, authenticity, and comprehensiveness of emergency information and maintain a good quality of information. In the face of sudden crisis events, we should pay attention to the timeliness of information, shorten the time interval of collection, analysis, processing, and dissemination as far as possible, and collect disaster information in time. Based on the results of information collection for objective analysis, we strive to restore the truth of the emergency facts in a comprehensive, scientific, and impartial manner to ensure that there is no deficiency in information transmission.

5.2. Using Good Governance of Technology to Break the Barrier of Public Information. With the application of big data, Internet of things, cloud computing, and other technologies in the field of emergency response, emergency management has entered the era of intelligent emergency response. It optimizes digital algorithm technology and helps break down information barriers. In November 2021, the China Federation of Network Social Organizations initiated the Convention on Self-Regulation of Internet Information Service Algorithm Applications to strengthen the self-regulation of the Internet information service industry. In order to better achieve algorithmic self-regulation, algorithm analysis can be improved, an all-round, all-process, and scenario-based user preference system can be built, and distribution strategies can be further improved to combine targeted pushing and mandatory pushing. While targeting information pushing according to public interest, mandatory pushing of public opinion disinformation, basic common sense self-help information, government emergency notices, and other news, by promoting design research and development innovation and continuous algorithm research and development, that information related to emergencies can be disseminated more comprehensively, and better services can be provided for effective prevention of emergencies.

5.3. Promoting the Fairness of Algorithms and Promoting the Disclosure of Public Information. It is an effective way to build a complete regulatory environment in that the government leads supervision and all sectors of society supervise together. First, the government should strengthen the supervision of algorithmic technology. By establishing a comprehensive governance mechanism for algorithm security, from the standpoint that algorithm technology serves social governance, we can separate emergency information from daily entertainment information and prevent the algorithm from impeding the popularization of emergency information. Second, the government should strengthen supervision over information publishers. At the present stage, many "We media" have the problem of the forced push of traffic and entertainment news. Relevant regulatory departments can intervene and urge them to make rectification, guide "We media" to build emergency service columns, top the hot spots of emergency-related information, and optimize online information push services. Third, improve standards, procedures, and regulations for information dissemination. In August 2021, the Regulations on The

Management of Algorithm Recommendation for Internet Information Services (Draft) issued by CAC mentioned that "algorithm recommendation service providers should provide users with options that are not specific to their personal characteristics," which is an important constraint on information dissemination in China. Through the rule of law, the algorithm logic that caters to preferences and solidifies prejudices should be eliminated and individuals or groups that maliciously obstruct the transmission of urgent information and scientific information should be effectively dealt with. Fourth, the government should strengthen cooperation with social organizations. We deeply dig and develop all kinds of mainstream authoritative information service platforms and expand the public's horizon of understanding emergencies through all-round and three-dimensional information transmission. We must establish a "joint contribution, sharing, and governance" emergency information dissemination supervision system.

5.4. Strengthening Social Stickiness and Maintaining Public Value Neutrality. The public will be indirectly influenced by social networks when making judgments and evaluations on emergencies. First, increase group interaction and enhance social stickiness. The public should be encouraged to actively establish communication links with other social groups and perceive emergencies from multiple perspectives and channels. The public should be encouraged to cultivate social cooperation and collective spirit, enhance the perception of public values and enhance social cohesion. Second, improve information literacy and improve information acceptance and tolerance. In the face of numerous emergency information, the public should improve rational thinking, adjust the degree of preference, and receive more comprehensive emergency information. Through rational use of digital media, various emergency information can be consciously "mixed" to enhance the collision of information views and avoid the negative effect of the "information cocoon house." Third, be as value-neutral as possible in the social networking environment. For public emergencies, which are related to public interests, while obtaining emergency information from the external environment, emotional rationality should be strengthened, value neutrality should be maintained, and opportunities for communication and association with the society should be enhanced.

Due to the limitations of subjective and objective factors, this paper only explores the path of breaking the negative effect of the "information cocoon" in emergencies, which is suitable for the topic of the article. There are still some limitations in the study, and further improvement and refinement are needed to address the shortcomings and defects.

Data Availability

The experimental 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 present study.

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Research Article

Evolutionary Game and Simulation Research of Blockchain-Based Co-Governance of Emergency Supply Allocation

Huawei Zhao [1,2] **and Lili Ma** [1]

[1]*Department of Economics and Management, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, China*
[2]*Shandong Chanyan Fintech Institute Co. LTD, Jinan 250100, China*

Correspondence should be addressed to Lili Ma; 10431200786@stu.qlu.edu.cn

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Recently, with the spread of COVID-19 pandemic, emergency supply allocation system is drawing more and more social attention. Emergency supply allocation system is an important part of emergency governance system. It reflects social organizations' credibility, public safety, and the modernization level of social governance. However, emergency supply allocation system still has some problems, such as information asymmetry, different desires of participants, unreasonable allocation, and so on. At present, it is widely accepted that the advantage of blockchain in co-governance could be of great help in solving above problems. And in order to distinguish the effect of blockchain to the emergency supply allocation, the paper builds a tripartite evolutionary game model among the government, social organizations, and the public to analyse the impact of blockchain platform on emergency supply allocation. The simulation analysis shows the following: (1) The strategy choices of the government have a crucial impact on the evolution and stability of social organizations' strategies. It needs a long-term process to guide social organizations practicing active allocation, and the government should accelerate to build the blockchain platform to promote this process. (2) With the help of blockchain platform, the increment of penalty intensity of the government is conductive to increasing the probabilities that social organizations practice active allocation and the government practices strict supervision. (3) Blockchain platform has a significant impact on social organizations' choice for active allocation in many aspects, such as the positive and negative effects of social organizations, effect's increasing multiple, and the cost of the public informing. In the end, some suggestions are presented to improve the co-governance of emergency supply allocation.

1. Introduction

Emergency supply allocation is a significant part of emergency management system [1]. However, the emergency supply allocation still has problems at present; for example, in the early control of COVID-19, the improper allocation of supplies due to poor data collection and sharing led to serious crisis of confidence; patients were unable to obtain essential emergency supplies due to poor coordination among different departments [2]. The assessment of the status of emergency management collaboration by the United Nations and Economic and Social Commission for Asia and the Pacific indicated that it is necessary to improve the level of collaboration at all levels [3]. It can be seen that, in the emergency supply allocation, scientific allocation is the key, and the collaborative participation among the government, social organizations, and the public is the trend. Therefore, to improve emergency supply allocation, it is necessary to research the promotion effect of information technology and decision strategies of participants co-governance on emergency allocation.

With the rapid evolution of the new round technology revolution, technological innovation plays an important role in promoting the optimization of social governance mechanisms and upgrading of social governance model, and at the same time, technological innovation is becoming an important driving force for the innovation of emergency management. In this background, with the development of

blockchain, many studies showed that blockchain had the features of collaborative consensus, traceability, and immutability of information [4–8], and it played an important role in the innovation of emergency management. Recently, researchers begun to study the improvement of emergency management with the help of blockchain. Yao and Xue [9] summarized the applications of blockchain in emergency management and found that the blockchain had great application values in the realms of emergency information transmission, emergency prevention and control early warning, and emergency charitable donation. Hu et al. [10] used blockchain to construct emergency information system and realized the storage integrity, distributed sharing, and information's traceability. Wang [1] designed a blockchain platform architecture, organizational structure, and operation mode for social donations of emergency supplies, aiming to solve the problem of information asymmetry. Deng et al. [11] made use of blockchain to build an emergency logistics system and realized traceability and anticounterfeiting of emergency supplies, automatic matching of supply and demand, and whole-process monitoring of distribution. Wu et al. [12] also demonstrated the application prospect of blockchain in promoting emergency logistics to achieve efficient guarantee, trust governance, and intelligent operation from the perspective of epidemic material security's prevention and control by combining theory analysis with application cases. In addition, some institutes and companies constructed information exchange platforms for emergency supplies and emergency donation based on blockchain. For example, BitGive, BitNation, Start Network, and other international organizations established relevant blockchain platforms to manage funds and supplies from social donations after emergencies [13]. These platforms have played a key role in the information collection on supply and demand of emergency supplies and reliable traceability of supplies [9]. From above, it can be seen that people have gradually noticed the importance of blockchain to emergency management.

In emergency management, different requirements of participants will influence the choice of their strategies, and the dynamic adjustment of strategies is suitable to be studied by evolutionary game theory [14]. Therefore, many researchers used evolutionary game method to study emergency management recently. As a whole, the game study of emergency management mainly includes cross-regional governance, emergency reserve mechanism, information exchange, and dissemination mechanism. Xiao et al. [15] used the analysis framework of regional evolutionary game to study the cross-regional governance of emergencies and found that when the regional spill-over effect and governance cost are small or the economic and social losses caused by emergencies are large, all regions will choose co-governance. Pi [16] discussed the mechanism construction of the national medical emergency supply reserve system with the combination of government and enterprise based on evolutionary game and proposed to give full play to the role of financial incentives in guiding enterprises to participate. Xu et al. [17] took SARS as a background and analysed the mechanisms of information communication by using evolutionary game theory. They found that the measures taken by the government to disclose information are conducive to restraining the spreading trend of emergencies. Deng et al. [18] further constructed a tripartite evolutionary game model among producers, transmitters, and decomposers of information and analysed the stability strategy. They found that information quality and punishment intensity of information producers are key factors affecting the dissemination of online public opinion information under emergencies. Xu et al. [19] constructed and analysed the tripartite evolutionary game model among the government, enterprises, and the public to deal with emergencies. Through model construction and simulation analysis, they found that the government can promote tripartite cooperation to fight the emergency by strengthening supervision, formulating reasonable reward and punishment mechanisms, and encouraging public participation.

From the above literature review, it can be seen that blockchain can promote the innovation of emergency management, and evolutionary game theory is an important grasp to analyse the strategies of participants in co-governance of emergence, and more and more researchers proposed solutions from the above aspects, respectively. However, there is little research developed by using evolutionary game theory to analyse emergency management based on blockchain, especially in the scenario of emergency supply allocation.

Therefore, based on the assumption of bounded rationality, this paper develops evolutionary game research on the co-governance of emergency supply allocation based on blockchain. The main contributions of this paper are as follows: (1) This paper introduces tripartite participants, namely, the government, social organizations, and the public into evolutionary game, which is different from the relevant literates [14, 20]. (2) Analysing the advantage and mechanism of blockchain promoting emergency supply allocation. (3) Analysing the stability of tripartite evolutionary game and researching the impact of blockchain on emergency supply allocation. (4) Using simulation to verify the validity of evolutionary game analysis and giving the suggestions to promote the co-governance of emergency supply allocation.

2. Mechanism of Blockchain to Emergency Supply Allocation

Emergency supply allocation has the following requirements: First, the complexity of the emergency events brings about the requirement of decentralize governance. Second, multipart participation of emergency supply allocation brings about the requirement of information sharing and multiparticipant collaboration. And finally, the motivating multiparticipant taking part in emergency supply allocation brings about the requirement of traceability.

Fortunately, with the development of blockchain technology, many studies showed that the openness, distributed storage, traceability, and other features of blockchain could meet the above requirements, promoting the modernization of emergency supply allocation system and capability. First,

the blockchain platform is open to all authorized participants and they can store and read all kinds of information about emergency supply allocation, which can meet the requirement of decentralize governance and improve the public's trust in social organizations. Second, blockchain adopts distributed accounting method to realize real-time sharing data between multiple subjects, which meets the need of emergency supply allocation information sharing and multiparticipant collaboration. Third, the timestamp technology of blockchain achieves data tamper-proofing and traceability. It provides support for the government and the public to monitor the source and destination of emergency supplies and to hold those who are involved responsible, which meets the requirement of information traceability [21]. The mechanism of blockchain to emergency supply allocation is shown in Figure 1.

3. Game Analysis of Emergency Supply Allocation Based on Blockchain

3.1. Basic Assumptions of Game Model. This paper focuses on the strategic interaction among the government, social organizations, and the public during the emergency supply allocation, by modelling a tripartite evolutionary game. The three subjects follow the basic assumptions of bounded rationality and information asymmetry. Their choices will be influenced by other participants, and they will purse maximum profits by adjusting their strategies. Therefore, the following hypothesis are proposed.

Hypothesis 1. Strategic Space of Participants. As the supervisor, the government tends to invest a lot of human and material resources to construct information platform based on blockchain and implement strict supervision on social organizations. However, the construction of information platform and strict supervision will greatly increase the government's expenditure, and based on the consideration of short-term interests and responsibility avoidance, the government maybe practice relaxing supervision on social organizations. Therefore, the strategy space of the government is (strict supervision, relaxing supervision).

As the bridge connecting the supply and requisitioning parts of emergency supply allocation, social organizations tend to actively allocate emergency supplies to establish a good social image. However, for the reasons of poor professional ability, the higher cost of allocation or the lighter penalties, social organizations maybe passively allocate emergency supplies or practice jobbery to pursue the higher profits. Therefore, the strategy space of the social organizations is (active allocation, passive allocation).

Facing the passive allocation of social organizations, on one hand, the public may choose to inform against social organizations to protect their own benefits; on the other hand, the public may choose tolerance for the reasons of high cost of informing. Therefore, the strategy space of the public is (informing, tolerance).

Hypothesis 2. The Probability Parameters of the Participants' Strategies. The probability of social organizations' active allocation is $x\,(0 \le x \le 1)$, and the passive allocation is $1 - x$; the probability of the public's informing is $y\,(0 \le y \le 1)$, and the tolerance is $1 - y$; the probability of the government's strict supervision is $z\,(0 \le z \le 1)$, and the relaxing supervision is $1 - z$. In addition, x, y, z are all functions of time t.

Hypothesis 3. The Parameters of the Government. For the government, the cost of strict supervision is defined by C_y, which includes the expenses of constructing and maintaining blockchain platform and the expenses of daily supervision. Once the government receives information against passive allocation of social organizations and verifies it, the government will fine social organizations with F_a and award the informant with F_e. And in the situation of strict supervision, the government will achieve positive effect R_g.

To the government, the cost of relaxing supervision is defined by 0. And the negative effect caused by relaxing supervision is defined by N_g, which includes poor emergency management, damage of the public safety, and loss of credibility. In addition, the government will cost C_n to coordinate the emergency supplies and maintain social stability, in the condition that the social organizations practice passive allocation.

Hypothesis 4. The Parameters of Social Organizations. The profit of social organizations' normal operation is Y_a. The cost of social organizations' active allocation is C_a; the positive effect caused by active allocation is R_n. The cost of social organizations' passive allocation is C_p, and $C_a > C_p > 0$. If social organizations passively allocate emergency supplies or practice jobbery, they will achieve extra profits Y_p, which will cause negative effect N_n. In addition, when the government uses blockchain platform to strengthen supervision, N_n and R_n will both increase for the reason of the great enhancement of information transparency, and the coefficient of increment is defined by λ $(\lambda \ge 1)$.

Hypothesis 5. The Parameters of the Public. If social organizations actively allocate emergency supplies, the public will receive emergency supplies timely, and the positive effect is defined by R_p. If the public informs against social organizations maliciously, the government will fine the public with R_n under the strict supervision.

On the contrary, if the social organizations passively allocate emergency supplies, the public will not receive emergency supplies in time, and the negative effect is defined by N_p. The cost of the public informing against social organizations is defined by C_r. And if social organizations correct the behaviour of passive allocation, the public will achieve additional effect U_p. In addition, in the situation of strict supervision, the government will award the informants with F_e.

3.2. The Payoff Matrix. Based on above assumptions, the payoff matrix including various strategies of the

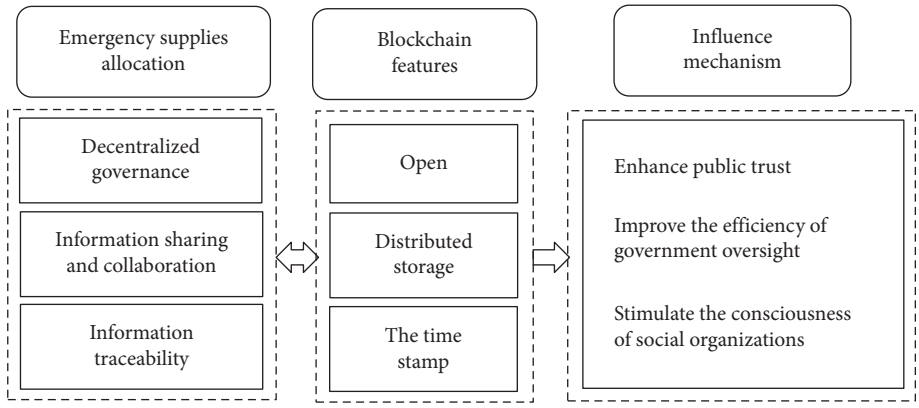

Figure 1: Mechanism of blockchain to emergency supply allocation.

government, social organizations, and the public is constructed, as shown in Table 1.

4. Game Model Solving and Evolutionary Stability Analysis

4.1. Stability Analysis of Tripartite Subjects

4.1.1. Stability Analysis of Social Organizations. Define the expected profits of social organizations in "active allocation" and "passive allocation" by U_{11} and U_{12}, respectively, and the average profit is U_1; then,

$$\begin{cases} U_{11} = yz\left(Y_a - C_a + \lambda R_n\right) + y(1-z)\left(Y_a - C_a + R_n\right) \\ \quad +z(1-y)\left(Y_a - C_a + \lambda R_n\right) + (1-y)(1-z)\left(Y_a - C_a + R_n\right) \\ U_{12} = yz\left(Y_a + Y_p - C_p - F_a - \lambda N_n\right) + y(1-z)\left(Y_a + Y_p - C_p - N_n\right) \\ \quad +z(1-y)\left(Y_a + Y_p - C_p - F_a - \lambda N_n\right) + (1-y)(1-z)\left(Y_a + Y_p - C_p - N_n\right) \\ U_1 = xU_{11} + (1-x)U_{12} \end{cases}. \tag{1}$$

Therefore, the replication dynamic equation and its first derivative of social organizations strategy selection are

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x\left(U_{11} - U_1\right) = x(1-x)\left(U_{11} - U_{12}\right) \\ &= x(1-x)\left[z\left(\lambda R_n - R_n + \lambda N_n - N_n + F_a\right) + R_n + C_p - C_a - Y_p + N_n\right], \\ F'(x) &= \frac{dF(x)}{dx} = (1-2x)\left[z\left(\lambda R_n - R_n + \lambda N_n - N_n + F_a\right) + C_p - C_a + R_n + N_n - Y_p\right]. \end{aligned} \tag{2}$$

According to the stability theorem of differential equations, if the probability that social organizations choose active allocation is in a stable state, it must meet the conditions that $F(x) = 0$ and $F'(x) < 0$. And letting $F(x) = 0$, we can get $x = 0$, $x = 1$, $z = C_a - C_p - R_n - N_n + Y_p/(\lambda - 1)(R_n + N_n) + F_a = z^*$. When $z = z^*$, we can get $F(x) \equiv 0$, any value of x is the evolutionary stable strategy of social organizations, and the strategy of social organizations does not change over time. When $z \neq z^*$, there will be two situations:

Table 1: The payoff matrix.

Social organizations	The public	Government	
		Strict supervision (z)	Relaxing supervision ($1-z$)
Active allocation (x)	Informing (y)	$\begin{bmatrix} Y_a - C_a + \lambda R_n \\ -F_e - C_r \\ R_g + F_e - C_y \end{bmatrix}$	$\begin{bmatrix} Y_a - C_a + R_n \\ -C_r \\ R_g \end{bmatrix}$
	Tolerance ($1-y$)	$\begin{bmatrix} Y_a - C_a + \lambda R_n \\ R_p \\ R_g - C_y \end{bmatrix}$	$\begin{bmatrix} Y_a - C_a + R_n \\ R_p \\ R_g \end{bmatrix}$
Passive allocation ($1-x$)	Informing (y)	$\begin{bmatrix} Y_a + Y_p - C_p - F_a - \lambda N_n \\ U_p + F_e - C_r - N_p \\ R_g + F_a - F_e - C_y - C_n \end{bmatrix}$	$\begin{bmatrix} Y_a + Y_p - C_p - N_n \\ -C_r - N_p \\ -C_n - N_g \end{bmatrix}$
	Tolerance ($1-y$)	$\begin{bmatrix} Y_a + Y_p - C_p - F_a - \lambda N_n \\ U_p - N_p \\ R_g + F_a - C_y - C_n \end{bmatrix}$	$\begin{bmatrix} Y_a + Y_p - C_p - N_n \\ -N_p \\ -C_n - N_g \end{bmatrix}$

(1) When $z > z^*$, we can get $F^{'}(0) > 0$, $F^{'}(1) < 0$. Thus, $x = 1$ is the steady state.

(2) When $z < z^*$, we can get $F^{'}(0) < 0$, $F^{'}(1) > 0$. Thus, $x = 0$ is the steady state. Figure 2 shows the phase diagram of social organizations' strategy evolution.

Proposition 1. *The probability that social organizations choose the strategy of "active allocation" is positively related to positive and negative effects, the effect's increasing multiple and the government penalty intensity, and is negatively related to the cost saved by negative allocation and extra profits.*

Proof. It can be seen from Figure 2 that the probabilities of social organizations adopting the strategies of "active allocation" and "negative allocation" are the volumes of A_1 and A_2, respectively, calculated as

$$V_{A_1} = 1 - \frac{\left(C_a - C_p\right) - \left(R_n + N_n\right) + Y_p}{(\lambda - 1)\left(R_n + N_n\right) + F_a}, \qquad V_{A_2} = 1 - V_{A_1} \tag{3}$$

According to the expression of V_{A_1} when social organizations choose "active allocation," the first-order partial derivative of each element can be obtained: $\partial V_{A_1}/\partial(R_n + N_n) > 0$, $\partial V_{A_1}/\partial\lambda > 0$, $\partial V_{A_1}/\partial F_a > 0$, $\partial V_{A_1}/(C_a - C_p) < 0$, $\partial V_{A_1}/Y_p < 0$. Therefore, increasing positive and negative effects, the effect's increasing multiple and the government penalty intensity, or decreasing the cost saved by negative allocation and extra profits can all increase the probability of social organizations choosing "active allocation." □

Proposition 2. *In the process of evolution, the probability that social organizations choose the strategy of "active allocation" is positively related to the probability that the government chooses "strict supervision."*

Proof. According to the stability analysis of social organizations, when $z < z^*$, we can get $F'(0) < 0$; thus, $x = 0$ is the steady state; otherwise, $x = 1$ is the steady state.

Therefore, with the increase of z, the probability that social organizations choose the strategy of "active allocation" will be increased from $x = 0$ to $x = 1$. It can be seen that through constructing the blockchain platform by the government to strengthen supervision, social organizations can effectively allocate emergency supplies. □

4.1.2. Stability Analysis of the Public. Suppose the expected profits of the public in "informing" and "tolerance" are U_{21} and U_{22}, respectively, and the average profit is U_2; then,

$$\begin{cases} U_{21} = xz\left(-F_e - C_r\right) + x(1-z)\left(-C_r\right) + (1-x)z\left(U_p + F_e - C_r - N_p\right) \\ \qquad +(1-x)(1-z)\left(-C_r - N_p\right) \\ U_{22} = xzR_p + x(1-z)R_p + (1-x)z\left(U_p - N_p\right) + (1-x)(1-z)\left(-N_p\right) \\ U_2 = yU_{21} + (1-y)U_{22} \end{cases} \tag{4}$$

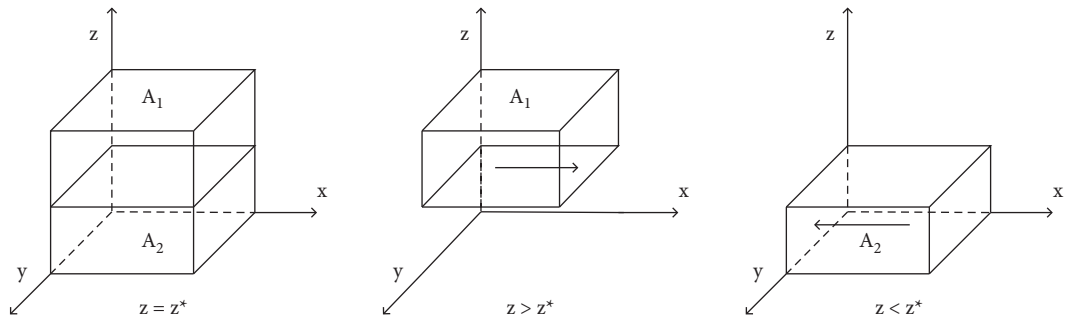

Figure 2: Phase diagram of social organizations' strategy evolution.

Therefore, the replication dynamic equation and its first derivative of the public strategy selection are

$$F(y) = \frac{dy}{dt} = y(U_{21} - U_2) = y(1-y)(U_{21} - U_{22})$$

$$= y(1-y)\left(-2xzF_e - xR_p + zF_e - C_r\right),$$

$$F'(y) = \frac{dF(y)}{dy} = (1-2y)\left(-2xzF_e - xR_p + zF_e - C_r\right). \tag{5}$$

According to the stability theorem of differential equations, if the probability that the public chooses to inform is stable, it must meet the conditions that $F(y) = 0$ and $F'(y) < 0$. Let $F(y) = 0$, we can get $y = 0$, $y = 1$, $x = zF_e - C_r/2zF_e + R_p = x^*$. When $x = x^*$, we can get $F(y) \equiv 0$; any value of y is the evolutionary stable strategy of the public, and the strategy of the public does not change over time. When $x \neq x^*$, there will be two situations:

(1) When $x > x^*$, we can get $F^{'}(0) < 0$, $F^{'}(1) > 0$. Thus, $y = 0$ is the steady state.

(2) When $x < x^*$, we can get $F^{'}(0) > 0$, $F^{'}(1) < 0$. Thus, $y = 1$ is the steady state. Figure 3 shows the phase diagram of the public's strategy evolution.

Proposition 3. *The probability that the public chooses the "informing" strategy is positively related to the informants' award, and it is negatively related to the cost of the public informing and the positive effect brought to the public by social organizations' active allocation supplies.*

Proof. Figure 3 shows that the probabilities that the public adopts the strategies of "informing" and "tolerance" are the volumes of B_1 and B_2, respectively, calculated as

$$V_{B_1} = \int_0^1 \int_{C_r/F_e}^1 \frac{zF_e - C_r}{2zF_e + R_p} dz dy = \frac{F_e - C_r}{2F_e} - \frac{2C_r + R_p}{4F_e} \ln\left(\frac{2F_e + R_p}{2C_r + R_p}\right)$$

$$V_{B_2} = 1 - V_{B_1} = \frac{F_e + C_r}{2F_e} + \frac{2C_r + R_p}{4F_e} \ln\left(\frac{2F_e + R_p}{2C_r + R_p}\right). \tag{6}$$

According to the expression of V_{B_1}, when the public adopts the strategy of "informing," the first-order partial derivative of each element can be obtained: $\partial V_{B_1}/\partial F_e > 0$, $\partial V_{B_1}/\partial C_r < 0$, $\partial V_{B_1}/\partial R_p < 0$. Therefore, increasing the informants' award or decreasing the cost of the public informing can all increase the probability of the public choosing "informing." In addition, when the positive effect brought to the public by social organizations' active allocation supplies exceeds a certain limit, the public's psychological endurance will be greatly improved. Thus, when the negative effect brought by social organizations' passive allocation supplies is far below the acceptance boundary [22], the probability of public informing will be reduced accordingly. □

Proposition 4. *In the process of evolution, the probability that the public chooses the strategy of "informing" is positively related to the probability that the government chooses "strict supervision." However, it is negatively related to the probability that social organizations choose "active allocation."*

Proof. According to the stability analysis of the public, when $x > x^*$ and $z < xR_p + C_r/(1-2x)F_e$, we can get $F'(0) < 0$; thus, $y = 0$ is the steady state; otherwise, $y = 1$ is the steady state. Thus, as x decreases or z increases, the probability of public informing will be increased from $y = 0$ to $y = 1$.

Therefore, in order to improve the enthusiasm of the public to participate in emergency supply allocation management, the government should strengthen supervision and create an open and transparent environment for the public to safeguard their rights with the help of emergency supply allocation information exchanging platform based on blockchain. In addition, as social organizations become more conscious of active allocation under strict supervision, the public can gain the highest benefits by choosing tolerance. □

4.1.3. Stability Analysis of the Government. Similarly, suppose the expected profits of the government choosing "strict supervision" and "relaxing supervision" are U_{31} and U_{32}, respectively, and the average profit is U_3; then,

$$\begin{cases} U_{31} = xy\left(R_g + F_e - C_y\right) + x(1-y)\left(R_g - C_y\right) \\ \qquad +(1-x)y\left(R_g + F_a - F_e - C_y - C_n\right) + (1-x)(1-y)\left(R_g + F_a - C_y - C_n\right) \\ U_{32} = xyR_g + x(1-y)R_g + (1-x)y\left(-C_n - N_g\right) \\ \qquad +(1-x)(1-y)\left(-C_n - N_g\right) \\ U_3 = zU_{31} + (1-z)U_{32} \end{cases}. \tag{7}$$

Therefore, the replication dynamic equation and its first derivative of the government strategy selection are

$$\begin{aligned} F(z) &= \frac{\mathrm{d}z}{\mathrm{d}t} = z\left(U_{31} - U_3\right) = z(1-z)\left(U_{31} - U_{32}\right) \\ &= z(1-z)\left[2xyF_e + (1-x)\left(R_g + N_g + F_a\right) - yF_e - C_y\right] \\ F'(z) &= \frac{\mathrm{d}F(z)}{\mathrm{d}z} = (1-2z)\left[2xyF_e + (1-x)\left(R_g + N_g + F_a\right) - yF_e - C_y\right]. \end{aligned} \tag{8}$$

According to the stability theorem of differential equations, if the probability that the government chooses strict supervision is in a stable state, it must meet the conditions that $F(z) = 0$ and $F'(z) < 0$. Letting $F(z) = 0$, we can get $z = 0$, $z = 1$, $y = (1-x)(R_g + N_g + F_a) - C_y/(1-2x)F_e = y^*$. When $y = y^*$, $F(z) \equiv 0$, any value of z is the evolutionary stable strategy of the government, and the strategy of the government does not change over time. When $y \neq y^*$, there will be two situations:

(1) When $y > y^*$, we can get $F^{'}(0) < 0$, $F^{'}(1) > 0$. Thus, $z = 0$ is the steady state.

(2) When $y < y^*$, we can get $F^{'}(0) > 0$, $F^{'}(1) < 0$. Thus, $z = 1$ is the steady state. Figure 4 shows the phase diagram of the government's strategy evolution.

Proposition 5. *The probability that the government chooses the "strict supervision" strategy is positively related to the fines imposed on social organizations and the positive and negative effects of the government and it is negatively related to the award for informants.*

Proof. Figure 4 shows that the probabilities that the government adopts the strategies of "strict supervision" and "relaxing supervision" are the volumes of C_1 and C_2, respectively, calculated as

$$\begin{aligned} V_{C_1} &= \int_0^1 \int_0^1 \frac{(1-x)\left(R_g + N_g + F_a\right) - C_y}{(1-2x)F_e}\,\mathrm{d}x\mathrm{d}z = \frac{R_g + N_g + F_a}{2F_e} \\ V_{C_2} &= 1 - V_{C_1} = \frac{2F_e - R_g - N_g - F_a}{2F_e} \end{aligned}. \tag{9}$$

According to the expression of V_{C_1}, when the government adopts the strategy of "strict supervision," the first-order partial derivative of each element can be obtained: $\partial V_{C_1}/\partial F_a > 0$, $\partial V_{C_1}/\partial(R_g + N_g) > 0$, $\partial V_{C_1}/\partial F_e < 0$. Therefore, increasing the fines imposed on social organizations and the positive and negative effects of the government or decreasing the rewards for informants can all prompt the government to practice strict supervision. □

Proposition 6. *In the evolution process, the probability that the government chooses the strategy of "strict supervision" is negatively related to the probability that the social organizations choose "active allocation" and the probability that the public chooses "informing."*

Proof. The proving process is the same as Proposition 4.

Therefore, when the probability that the social organizations choose "active allocation" and the probability that the public chooses "informing" is high, the government will reduce the probability of strict supervision, which is easy to lead to the lack of supervision. □

4.2. Stability Analysis of Tripartite Evolutionary Game System. In order to carry out the analysis of the evolutionary stable strategies under the mutual interaction among social organizations, the public, and the government, we first build a tripartite dynamic replication system for emergency supply allocation according to equations (2), (6), and (10).

$$\begin{cases} F(x) = x(1-x)\left[z\left(\lambda R_n - R_n + \lambda N_n - N_n + F_a\right) + C_p - C_a + R_n + N_n - Y_p\right] \\ F(y) = y(1-y)\left(-2xzF_e - xR_p + zF_e - C_r\right) \\ F(z) = z(1-z)\left[2xyF_e + (1-x)\left(R_g + N_g + F_a\right) - yF_e - C_y\right] \end{cases}. \tag{10}$$

Letting $F(x) = F(y) = F(z) = 0$, we can get 8 equilibrium points of the dynamic system: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,0,1)$, $E_4(0,1,1)$, $E_5(0,1,0)$, $E_6(1,1,0)$, $E_7(1,0,1)$, and $E_8(1,1,1)$. According to the replication dynamic equation in the tripartite game, a Jacobian matrix can be obtained:

$$J = \begin{bmatrix} \dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y} & \dfrac{\partial F(x)}{\partial z} \\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y} & \dfrac{\partial F(y)}{\partial z} \\ \dfrac{\partial F(z)}{\partial x} & \dfrac{\partial F(z)}{\partial y} & \dfrac{\partial F(z)}{\partial z} \end{bmatrix}. \tag{11}$$

To be specific, each element in the Jacobian matrix J is expressed as follows:

$$\begin{cases} \dfrac{\partial F(x)}{\partial x} = (1-2x)\left[z\left(\lambda R_n - R_n + \lambda N_n - N_n + F_a\right) + R_n + N_n - C_a - Y_p + C_p\right] \\ \dfrac{\partial F(x)}{\partial y} = 0 \\ \dfrac{\partial F(x)}{\partial z} = x(1-x)\left[(\lambda - 1)\left(R_n + N_n\right) + F_a\right] \\ \dfrac{\partial F(y)}{\partial x} = y(1-y)\left(-2zF_e - R_p\right) \\ \dfrac{\partial F(y)}{\partial y} = (1-2y)\left(-2xzF_e - xR_p + zF_e - C_r\right) \\ \dfrac{\partial F(y)}{\partial z} = y(1-y)\left(-2xF_e + F_e\right) \\ \dfrac{\partial F(z)}{\partial x} = z(1-z)\left(2yF_e - F_a - R_g - N_g\right) \\ \dfrac{\partial F(z)}{\partial y} = z(1-z)\left(2xF_e - F_e\right) \\ \dfrac{\partial F(z)}{\partial z} = (1-2z)\left[2xyF_e + (1-x)\left(F_a + R_g + N_g\right) - yF_e - C_y\right] \end{cases} \tag{12}$$

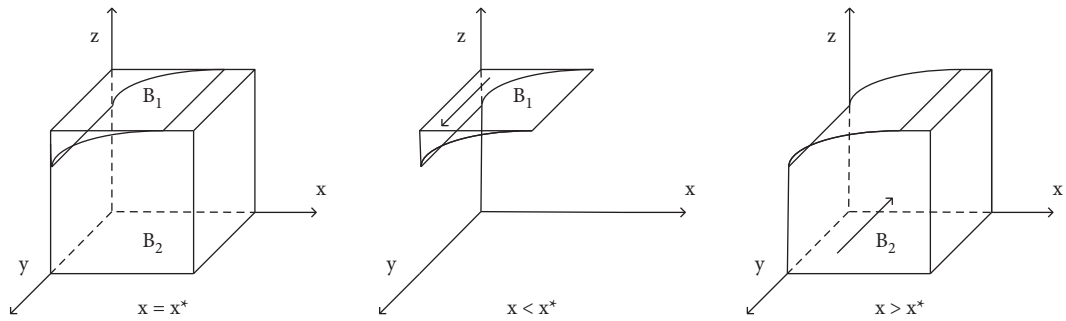

Figure 3: Phase diagram of the public's strategy evolution.

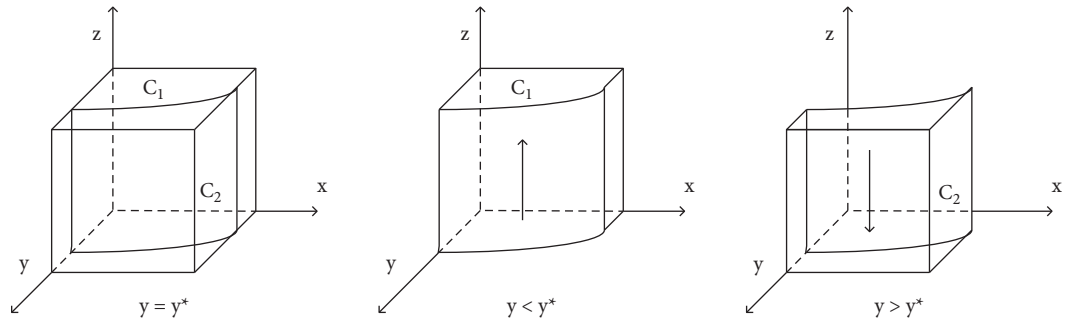

Figure 4: Phase diagram of the government's strategy evolution.

Inputting $E_1 \sim E_8$ into Jacobian matrix J, we can get the eigenvalues corresponding to each equilibrium point, as shown in Table 2.

According to the point of Friedman [23], when the eigenvalues of Jacobian matrix J are all negative, the equilibrium point is the asymptotic stable point of the system. It can be seen from Table 2 that the equilibrium points E_5, E_6, E_7, and E_8 all have positive eigenvalues, so they cannot be evolutionary stability strategies. Equilibrium points $E_1 \sim E_4$ are evolutionary stability strategies if the stability conditions in Table 3 are satisfied.

Scenario 1. When $C_a - C_p + Y_p > R_n + N_n$ and $C_y - F_a > R_g + N_g$, that is, when the extra profits obtained from social organizations' passive allocation are higher than the sum of positive and negative effects under relaxing supervision, as well as when the extra cost of the government' supervision (i.e., the cost of the government's strict supervision minus the fines the government carries on to social organizations) is higher than the sum of positive and negative effects, as shown in Table 3, there is only one stable point $E_1(0, 0, 0)$ in the dynamic replication system.

This means that it is expensive for the government to construct the blockchain platform for strict supervision, and for the sake of maximizing the benefits, the government will choose relaxing supervision. In this case, the lack of the government supervision will make it difficult for the blockchain to play a role, which will cause the problems of information asymmetry and information isolated island [22] and further cause social organizations to allocate passively in order to achieve extra profits. In addition, without the blockchain platform, the cost for the public to collect information and inform against the passive allocation of social organizations will greatly increase, and it will be more difficult to protect their rights. Therefore, the public tends to be tolerant.

Scenario 2. When $C_a - C_p + Y_p < R_n + N_n$, that is, when the extra profits of social organizations' passive allocation of supplies are less than the sum of positive and negative effects under relaxing supervision, as shown in Table 3, there is only one stable point $E_2(1, 0, 0)$ in the dynamic replication system. This equilibrium means that when social organizations obtain little benefit in passive allocation, they do not want to take risks to practice passive allocation. And at the same time, the government do not want to construct blockchain platform to optimize emergency supply allocation for the sake of the cost. In this case, the government's strategy is relaxing supervision, and the public's strategy is tolerance.

Scenario 3. When $C_a - C_p + Y_p > \lambda(R_n + N_n) + F_a$, that is, when the extra profits obtained from social organizations' passive allocation are higher than the sum of positive and negative effects under strict supervision, as shown in Table 3, the stable point may be $E_3(0, 0, 1)$ or $E_4(0, 1, 1)$, which means that no matter how the government and the public make strategy choices, social organizations will still choose passive allocation in order to seek high profits. On this basis, only when $C_r < F_e$ and $C_y - F_a < R_g + N_g - F_e$, that is, only when the cost of the public's informing is lower than the reward for informing, and the extra cost of strict supervision by the government is low, there will be only one stable point $E_4(0, 1, 1)$ in the dynamic replication system, which means

Table 2: The eigenvalues corresponding to each equilibrium point.

Equilibrium point	Eigenvalues		
	λ_1	λ_2	λ_3
$E_1(0,0,0)$	$-(C_a - C_p + Y_p) + (R_n + N_n)$	$-C_r$	$-(C_y - F_a) + (R_g + N_g)$
$E_2(1,0,0)$	$(C_a - C_p + Y_p) - (R_n + N_n)$	$-C_r - R_p$	$-C_y$
$E_3(0,0,1)$	$-(C_a - C_p + Y_p) + [\lambda(R_n + N_n) + F_a]$	$F_e - C_r$	$(C_y - F_a) - (R_g + N_g)$
$E_4(0,1,1)$	$-(C_a - C_p + Y_p) + [\lambda(R_n + N_n) + F_a]$	$C_r - F_e$	$(C_y - F_a) - (R_g + N_g - F_e)$
$E_5(0,1,0)$	$-(C_a - C_p + Y_p) + (R_n + N_n)$	C_r (+)	$-(C_y - F_a) + (R_g + N_g - F_e)$
$E_6(1,1,0)$	$(C_a - C_p + Y_p) - (R_n + N_n)$	$R_p + C_r$ (+)	$F_e - C_y$
$E_7(1,0,1)$	$(C_a - C_p + Y_p) - [\lambda(R_n + N_n) + F_a]$	$-C_r - R_p - F_e$	C_y (+)
$E_8(1,1,1)$	$(C_a - C_p + Y_p) - [\lambda(R_n + N_n) + F_a]$	$C_r + R_p + F_e$ (+)	$C_y - F_e$

Table 3: The condition of equilibrium point' stability.

Equilibrium point	Condition
$E_1(0,0,0)$	$C_a - C_p + Y_p > R_n + N_n$, $C_y - F_a > R_g + N_g$
$E_2(1,0,0)$	$C_a - C_p + Y_p < R_n + N_n$
$E_3(0,0,1)$	$C_a - C_p + Y_p > \lambda(R_n + N_n) + F_a$, $C_r > F_e$, $C_y - F_a < R_g + N_g$
$E_4(0,1,1)$	$C_a - C_p + Y_p > \lambda(R_n + N_n) + F_a$, $C_r < F_e$, $C_y - F_a < R_g + N_g - F_e$

the government and the public will stabilize their strategy choices on strict supervision and informing against social organizations respectively. In this case, even if government practices strict supervision with the help of blockchain platform and punishes social organizations for their passive allocation, social organizations still choose passive allocation in order to seek high profits.

In summary, the co-governance of emergency supply allocation can be divided into three stages: the ineffective stage, the intermediate stage, and the useless stage. The ineffective stage corresponds to Scenario 3, and in this case, no matter whether the government practices strict supervision with the help of blockchain platform, social organizations will choose passive allocation as the optimum strategy, and the emergency supply allocation management system is extremely deteriorating. The useless stage corresponds to Scenario 2, and in this case, social organizations will practice active allocation, and the government's blockchain platform will be useless. The emergency supply allocation management system is in a complete stage. The intermediate stage is the transition from the ineffective stage to the useless stage. At this stage, there are few evolutionary stable points in the system, and the strategies of social organizations are constantly adjusted according to the strategies of the public and the government. Therefore, it is necessary to build the blockchain platform to promote the optimization and adjustment of relevant parameters and realize the co-governance of emergency supply allocation from ineffective stage to useless stage [24].

5. Simulation Analysis

In order to observe the stable equilibrium strategies of tripartite participants and their sensitivity to parameters in evolutionary game, and verify the validity of the stability analysis, we use MATLAB R2021a to simulate the game. Define $R_n = 4$, $N_n = 4$, $C_p = 3$, $C_a = 6$, $Y_p = 4$, $F_e = 1$, $R_p = 4$, $C_r = 2$, $R_g = 2$, $N_g = 4$, $C_y = 13$, and $\lambda = 1.5$, which satisfies the condition of Scenario 2. Suppose the probabilities of initial game strategy choices of tripartite participants are all 0.5, and on this basis, in the following we discuss the impact of initial strategy choice, the government penalty intensity, social organizations' positive and negative effects, the effect's increasing multiple, and the changes of public' informing cost on evolutionary process and results.

5.1. The Impact of Initial Strategy Choice on the Stability of Game Strategy. According to replication dynamic equations, it can be seen that the evolutionary stable state of a single game participant will be affected by the initial strategy choices of other subjects. Based on this premise, this paper verifies the results of strategies evolution by adjusting the initial values. When examining the sensitivity of each game participant to the initial strategy choice, the initial values of other game subjects are set as 0.5. Respectively suppose the initial state of the social organizations is $x(0) = 0.2, 0.5, 0.7$, the initial state of the public is $y(0) = 0.2, 0.5, 0.7$, and the initial state of the government is $z(0) = 0.2, 0.5, 0.7$, and the other parameters keep unchanged. Then, the simulation results can be shown by Figures 5 to 7.

As shown in these figures, no matter what the initial strategy choice of tripartite participants is, with the probability of social organizations choosing active allocation strategies tends to 1, the public and the government will adopt the strategies of tolerance and relaxing supervision, respectively, which means that (1, 0, 0) is the evolutionary stability point.

As shown in Figure 5, with the increase of x, y and z will quickly converge to 0, which further verifies Propositions 4 and 6. This is because the increased awareness of social organizations in allocating emergency supplies has accelerated the process of emergencies prevention and control, and both the government and the public can obtain positive effects without paying extra costs for supervision. Therefore, the government tends to relaxing supervision and the public tends to tolerance.

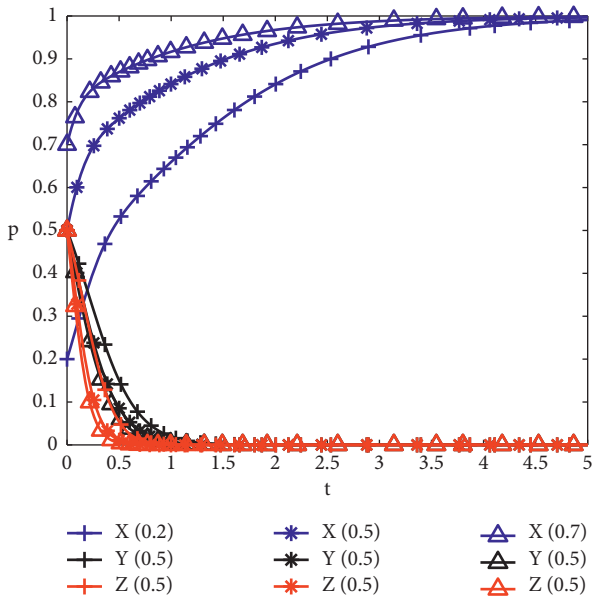

Figure 5: The evolution result of the change of social organizations' initial strategies.

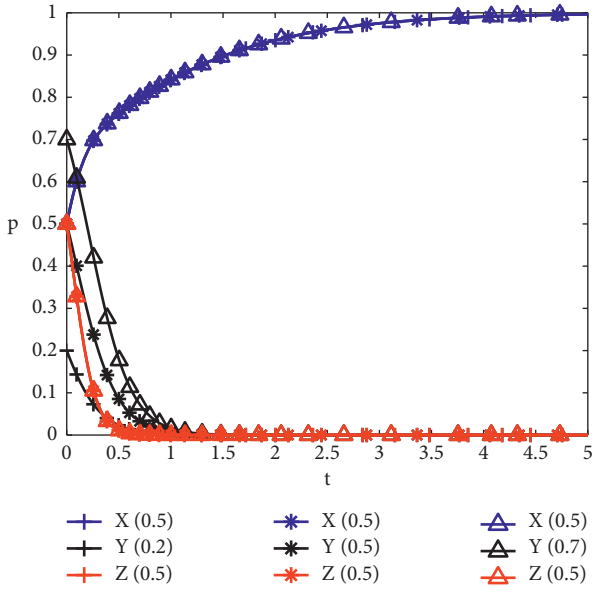

Figure 6: The evolution result of the change of public's initial strategies.

As shown in Figure 7, with the increase of z, the speeds of x converging to 1 are accelerated, which further verifies Proposition 2. When the government practices strict supervision with the help of blockchain platform, the information of social organizations' allocating emergency supplies will be recorded in the blockchain and be open to all of authorized participants; in this condition, the profits of passive allocation gradually cannot compensate the loss of fine by the government, the loss of social reputation, and so on, which promotes social organizations' active allocation.

From Figure 5 to Figure 7, it can be seen that no matter what the initial strategy choice is, the speed of x converging

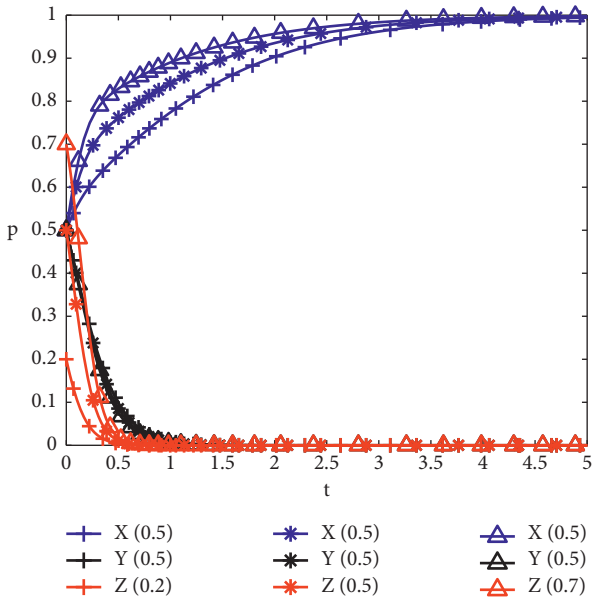

Figure 7: The evolution result of the change of government's initial strategies.

to 1 is less than the speed of y and z converging to 0. It means that guiding social organizations to practice active allocation needs a long-term process. The process requires the government actively to construct blockchain platform of emergency supplies allocation and build the reward and punishment mechanism to mobilize the participating enthusiasm of social organizations.

5.2. The Impact of Government Penalty Intensity on the Stability of Game Strategy. To analyse the impact of government penalties on the evolutionary game, we keep the remaining parameters unchanged, and set the values of F_a as follows: $F_a = 0$; $F_a = 4$; and $F_a = 8$. The simulation result is shown in Figure 8.

The figure indicates that in the evolution process, with the increment of the penalty imposed by the government on the passive allocation of social organizations, the probability of social organizations actively performing their duties increases, and at the same time the speed that the government evolves to strict supervision accelerates, which further verifies Propositions 1 and 5. In the condition of strict supervision, the government will supervise social organizations at a lower cost with the help of blockchain platform. And when the government's profits from penalties exceed the cost of strict supervision, the probability that the government enhances supervision by improving blockchain platform will increase, which will promote social organizations' active allocation.

5.3. The Impact of Social Organizations' Positive and Negative Effects on the Stability of Game Strategy. To analyse the impact of social organizations' positive and negative effects on the strategy stability, we keep the remaining parameters unchanged, and set the values of R_n and N_n as follows:

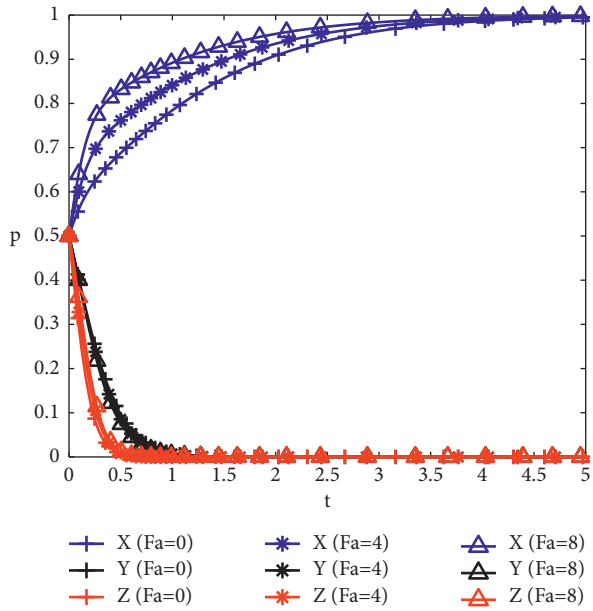

Figure 8: Evolution path under different penalties.

$R_n = 0$, $N_n = 0$; $R_n = 5$, $N_n = 5$; and $R_n = 10$, $N_n = 10$. The simulation result is shown in Figure 9.

Figure 9 indicates that in the process of evolution, with the increase of the positive effect of active allocation and the negative effect of passive allocation, the probability of social organizations choosing active allocation increases. When the positive and negative effects gradually increase and exceed the threshold, social organizations change from passive allocation to active allocation, which further verifies Proposition 1. It can be seen that the positive and negative effects have a great impact on emergency supply allocation. When the government uses blockchain platform to practice supervision, the transparency of information will increase, and the flowing speed of information will be accelerated [22]; social organizations will evolve forward active allocation to maintain the reputation and decrease the negative effect.

5.4. The Impact of Effect's Increasing Multiple on the Stability of Game Strategy. To analyse the impact of effect's increasing multiple on the strategy stability, we keep the remaining parameters unchanged, and set the values of λ as follows: $\lambda = 1.1$; $\lambda = 1.5$; and $\lambda = 1.9$ (corresponding the application levels of blockchain platform from low to high). The simulation result is shown in Figure 10.

The figure indicates that as the increasing multiple λ of positive and negative effects increases, social organizations will accelerate forward active allocation, which further verifies Proposition 1. Social organizations' strategy will vary with the different application levels of blockchain platform. That is because when the application level of blockchain platform is lower, the blockchain platform does not practice effective supervision on social organizations, and with the application level increasing, it can decrease the information asymmetry and improve supervision efficiency.

5.5. The Impact of the Public' Informing Cost on the Stability of Game Strategy. To analyse the impact of the public' informing cost on the strategy stability, we keep the remaining parameters unchanged, and set the values of C_r as follows: $C_r = 0$; $C_r = 2$; and $C_r = 5$. The simulation result is shown by Figure 11.

The figure indicates that in the evolutionary process, the probability of the public choosing tolerance will accelerate with the increase of the public' informing cost C_r, which further verifies Proposition 3. It can be seen that the public' informing cost is an important factor affecting the allocation management of emergency supplies. In the absence of blockchain platform, due to the existence of information islands, the public have higher cost of collecting information to conduct supervision, which reduces their enthusiasm for participating.

6. Results and Discussion

The paper concentrates the problems of emergency supply allocation and builds a tripartite evolutionary game model among the government, social organizations, and the public to analyse the impact of blockchain platform on emergency supply allocation. The results show that the initial strategy choices, penalty intensity, positive and negative effects, effect's increasing multiple, and public' informing cost have different influences on the governance of emergency supply allocation.

(1) From the perspective of initial strategy choices, the strategy choices of the government have a great impact on the evolution and stability of social organizations. It needs a long term to guide social organizations to actively take part in the emergency supply allocation, and the government should speed up the construction of blockchain platform to promote this process (different from [25, 26]).

(2) With the help of blockchain platform, increasing penalty intensity for social organizations' passive allocation will increase the probabilities that social organizations' active allocation and the government's strict supervision.

(3) The blockchain platform has a significant impact on social organizations' positive and negative effects, effect's increasing multiple, and public' informing cost, and improving the blockchain platform is of great significance to improve the robustness of social organizations' active allocation.

Based on the above research conclusions, we construct an emergency supply allocation governance system based on blockchain, which includes coordination mechanism, trust mechanism, supervision mechanism, and incentive mechanism, as shown in Figure 12.

(1) *Coordination Mechanism.* Based on the distributed consensus technology of blockchain, all nodes can participate in governance equally. After social organizations and the public join blockchain, the information of supply allocation will be shared among

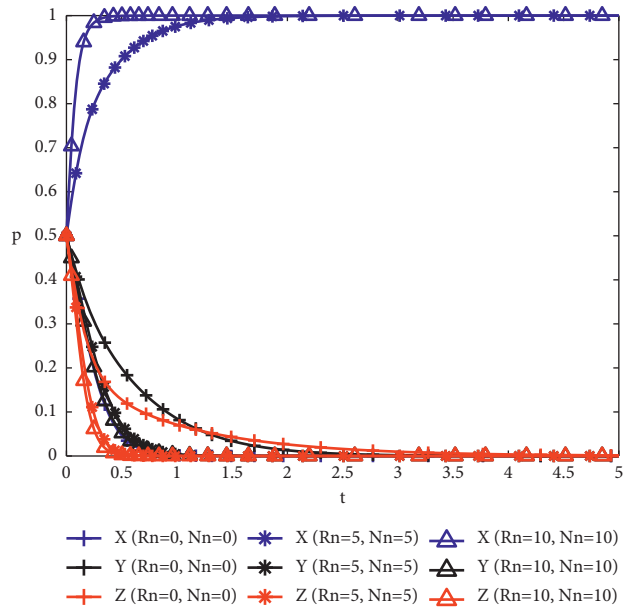

Figure 9: Evolution path under different positive and negative effects.

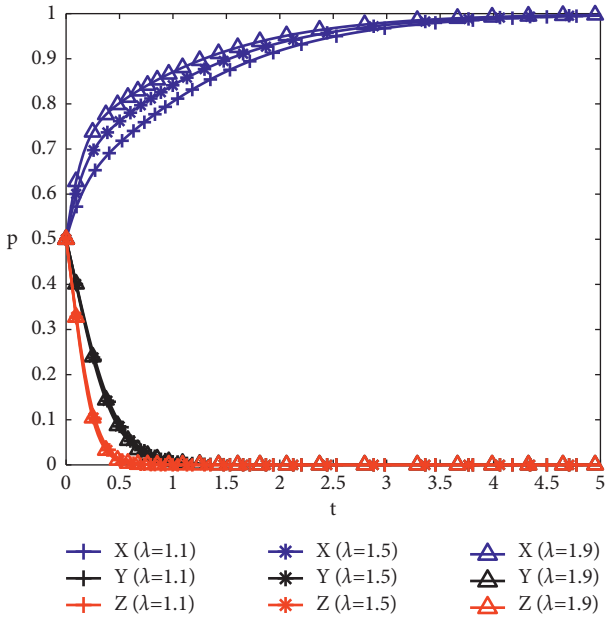

Figure 10: Evolution path under different effect's increasing multiples.

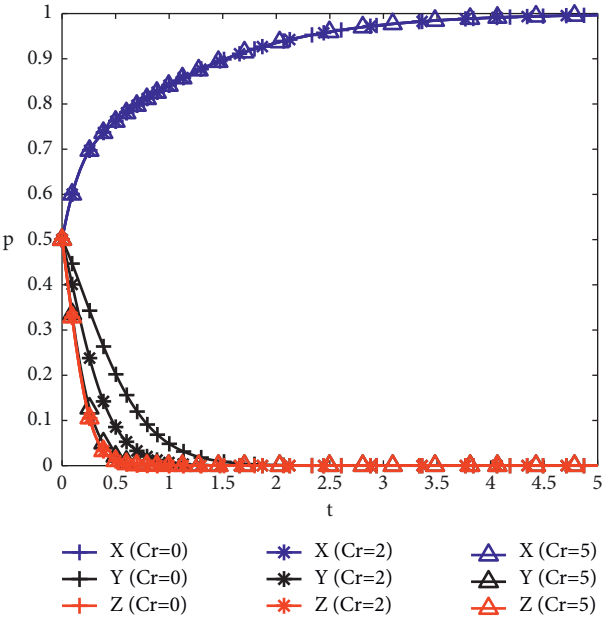

Figure 11: Evolution path under different costs of informing.

multiple subjects, which will increase the positive and negative effects and effectively promote the collaboration among subjects.

(2) *Trust Mechanism*. The traceability mechanism and tamper-proofing mechanism of blockchain technology can ensure the authenticity of information, facilitate the public's evidence collection and rights protection, and realize penetrating supervision in the whole process. In addition, asymmetric encryption technology will ensure the security of information. These all reduce the public's informing cost and the government's supervision cost.

(3) *Supervision Mechanism*. Through the smart contract mechanism, the rights and responsibilities of participants are clearly defined in the form of codes. Once the trigger conditions are satisfied, the smart contract will be enforced, which will improve the self-discipline consciousness of each node. At the same time, intelligent matching of supply and demand information of supplies can be realized through smart contract technology, which avoids human interference and improves the accuracy and efficiency of emergency supply allocation.

(4) *Incentive Mechanism*. The foothold of promoting sustainable emergency management lies in incentive

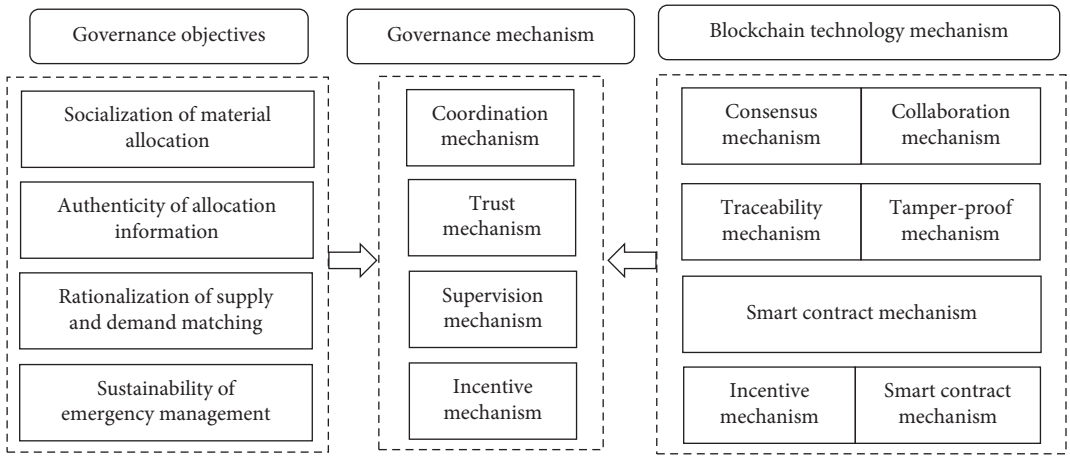

Figure 12: Emergency supply allocation governance system based on blockchain.

mechanism. By issuing tokens using blockchain and using tokens as rewards, the system will arouse the enthusiasm of multiple subjects [22].

Based on the above conclusions and mechanism design, this paper puts forward the following suggestions to promote the process of emergency supply allocation governance.

(1) In the emergency supply allocation, social organizations hardly can practice active allocation consciously. And in order to guide social organizations allocating supplies actively, the government should speed up the construction of information communication platform based on blockchain, practice real-time supervision based on coordination mechanism, trust mechanism, supervision mechanism and incentive mechanism, and provide according supports in terms of policies, regulations, talents, and funds [4].

(2) The government should set reward and penalty mechanism through smart contracts to increase the punishment for illegal activities of social organizations seeking extra income and increase incentives for the public who informs in compliance and social organizations that practice active allocation, so as to improve the efficiency of government supervision.

(3) In emergency supply allocation, even if there is a blockchain platform, social organizations may still allocate emergency supplies passively. Therefore, the public should be guided to actively supervise the allocation of emergency supplies and timely feedback the problems of social organizations, which is conductive to safeguard their own legitimate rights and interests [22].

Emergency supply allocation has a great significant on dealing with emergent events and ensuring the people's wellbeing, and the government should take full advantage of blockchain technology to build a co-governance system to guide all parts taking part in the emergency supply allocation management actively. This paper combines the evolutionary game theory and simulation method to analyse the participants strategies in emergency supply allocation; it is a new try and will enrich the co-governance theory on the realm of emergency management.

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 regarding the publication of this paper.

Acknowledgments

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Volume 2023, Article ID 9796231, 1 page
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Retraction

Retracted: Research on the Recommendation Algorithm of Rural Tourism Routes Based on the Fusion Model of Multiple Data Sources

Discrete Dynamics in Nature and Society

Received 15 August 2023; Accepted 15 August 2023; Published 16 August 2023

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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.

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[1] H. Li, M. Qiao, and S. Peng, "Research on the Recommendation Algorithm of Rural Tourism Routes Based on the Fusion Model of Multiple Data Sources," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2262148, 10 pages, 2022.

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Discrete Dynamics in Nature and Society
Volume 2022, Article ID 2262148, 10 pages
https://doi.org/10.1155/2022/2262148

RETRACTED

Research Article

Research on the Recommendation Algorithm of Rural Tourism Routes Based on the Fusion Model of Multiple Data Sources

Hong Li,[1] Man Qiao,[1] and Shuai Peng[2]

[1]*Henan University of Animal Husbandry & Economy, Zhengzhou 450046, Henan, China*
[2]*Guangdong University of Finance and Economics, Guangzhou 510320, Guangdong, China*

Correspondence should be addressed to Shuai Peng; 20191021@gdufe.edu.cn

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Rural tourism has become an important force in implementing the rural revitalisation strategy and accelerating rural economic development. The hectic pace of life has made more and more city dwellers yearn for rural life, and travelling in the countryside has become their weekend choice. However, the current level of rural tourism informationization is low, the publicity is insufficient, the tourists' awareness is low, and the source of customers is seriously insufficient. To this end, this paper proposes a relatively novel multidata source fusion tourism recommendation algorithm, which adopts the idea of tensor orthogonal decomposition and fuses multisource data models to predict the target domain's for rating. The integrated consideration of multiple data sources under the do-it-yourself approach assists the target domain to discover the target user neighbourhood users more quickly and to discover the user's interest degree more accurately. It is worth pointing out that the recommendation algorithm proposed in this paper under the fusion of multiple data sources is not necessarily applicable to data sources with weak correlation, such as travel data sources and music data sources, which are relatively weakly correlated, and the algorithm is slightly weak in making predictions of user preferences.

1. Introduction

With the national economy entering a new normal, tourism has ushered in a golden period of rapid development [1], and rural tourism has become an important part of China's tourism industry. The busy pace of life has made more and more city dwellers yearn for rural life, and travelling in the countryside has become their weekend choice. However, at present, the level of information technology for rural tourism is low, the publicity is not strong enough, tourists are less aware of it, and the source of visitors is seriously insufficient. In this context, rural tourism urgently needs information technology to increase publicity and improve service levels [2].

In practical recommendation systems, the most common method of fusing multiple data sources is matrix decomposition. Decomposed user feature matrix U and item feature matrix V are obtained by training the loss function, and finally the scoring matrix is reduced by matrix inverse operation [3]. However, in the traditional matrix decomposition process, the data structure information is often lost in the matrix decomposition process due to data sparsity, making the results distorted. Tensor is a way of storing multidimensional data, and the concept of tensor decomposition is based on the idea of matrix completion, which aims to fill in the missing (or unobservable) parts of the target matrix [4]. In simple terms, this means that matrix A is used to approximately evaluate matrix B (there is some inherent correlation between A and B). The invisible parts of the matrix B are filled in by the matrix A.

This study, through the platform of rural tourism products on the malefactor research, found that the content of these rural tourism products is mainly concentrated in the better economy and tourism industry of more developed areas, while the economy in relatively backward areas is not covered [5] or there is also incomplete information, not enough to meet the rising demand of users. For example, the interface of searching for any area on the Nongjiale platform

simply shows a little of the same scenery and cuisine information, there is no user search function on the rural tourism service platform, and the product description is simple, which cannot hook the people's desire to travel [6]. The development of rural tourism products has a very far-reaching significance in promoting the economic development of rural areas, combining field research, literature analysis, and data from existing rural tourism platforms to construct a rural tourism product model and a user model. The aim is to improve the quality and efficiency of users' access to useful information, so that rural tourism products are more accurately submitted to users. Combining users' personalised characteristics to recommend the rural tourism products they really need to have has become a valuable and challenging research topic.

2. Related Work

While China's economy is growing rapidly and people's living standards are steadily rising, the tourism industry, as a sunrise industry, is receiving increasing attention from the government and enterprises [7], and tourism has become an important driver to stimulate consumption and induce rapid upgrading and transformation of the industry. Just as China's tourism industry is moving towards mass tourism and global tourism, the development of information technology and mobile Internet applications has given rise to a new concept of smart tourism for the tourism experience. The combination of tourism and information technology constitutes smart tourism, which is a necessary path for the current development of tourism [8].

Tourism websites, tourism APPs, and tourism WeChat applets are current manifestations of smart tourism, and with the rapid development of smart phones and mobile networks, many smart tourism products have emerged, such as Ctrip, founded in 1999, whose mobile APP was launched in 2010, and its acquisition of the UK-based airfare search platform Skyscanner Limited was in November 2016, which means that Ctrip has started to enter the road of internationalisation [3, 9]. Where to Go was established in 2005, and in 2010 it launched its APP, the same as Ctrip; it is a comprehensive travel APP that provides a collection of business travel management, hotels, airline tickets, holiday booking, and travel information. In October 2015, the two travel giant APPs announced a merger. In 2006, the Ma Hive travel website was launched and became popular with users, and its mobile APP was launched in 2011. Just as smart tourism was being widely promoted and applied, China's rural tourism industry also stepped into a path of rapid development [10]. Previous rural tourism products can no longer meet the tourism needs of the people, and there is an urgent need to introduce intelligent rural tourism into rural tourism. That is why MPPs such as Meiju Countryside, Find the Yard, Go Farm, He Xiang You, Meet the Countryside, and Down to the Country Guest have emerged, and corresponding WeChat platforms such as Countryside Tourism Service Platform, Countryside Tourism Merchant, Nongjia Platform, and Shanghai Nongjia Platform have appeared on WeChat mini-programs.

Through the study of the above rural tourism wisdom products, we found that these rural tourism wisdom products are mainly concentrated in the more developed tourism industry and the better economic regions, while the relatively more economically backward regions rural tourism wisdom products either do not have complete information or are not covered, and the scope of operation is narrow, the services provided are limited and not well known, and their service content cannot meet the needs of users [11]. For example, the interface of searching for any area on the WeChat platform of Nongjiale is just to show a little scenery and dish information, there is no user search on the WeChat miniprogram of rural tourism service platform, and the product introduction is simple, which cannot hook the people's desire to travel.

Through literature research, the academic world has also seen more research on intelligent rural tourism; for example, [12] published in the China Tourism News about the new mission given to tourism in the new era, [13] conducted an in-depth analysis of the problems in the development of rural tourism information technology and believes that the factors that inhibit the development of rural tourism information technology are publicity, information management level, information infrastructure construction, etc., [14] argues that there is a certain difference between the demand and supply of tourists in rural tourism and that measures should be provided to reduce the difference between the two, [15] designed an ecological service system for rural tourism from three aspects: service design process, interactive experience, and branding, and [16] argues that, with the help of mobile Internet, a seamless connection between tourism enterprises and tourists can be achieved and a bridge for efficient communication between them can be built.

Although smart tourism is a unique concept in China, similar projects with smart tourism have emerged internationally earlier than in China, with USA, Singapore, Korea, England, and other countries being among the more representative ones. The smart wrist system online in the United States in 2005 opened the beginning of smart tourism; the feedback system equipped with radio frequency technology positioning device one by one Mountainwatch was the first to be used by the Colorado Steamboat Ski Resort in the United States, which can provide tourists with real-time consumption and ski routes. Touchwood, a service platform in Seoul, South Korea, is aimed at self-guided, rural travellers, who can use the platform to perceive tourist information [17, 18].

3. Construction of User Ontology Model for Rural Tourism Platform

Personalised recommendation for users is the ultimate goal of an intelligent recommendation system, and the construction of a good user ontology model is a prerequisite for implementing intelligent recommendations. The user ontology model in this study requires the acquisition of data related to the user's interests in the field of rural tourism, and then combining the user's personal information to

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eventually build a model that can be recognised by our computer. The construction process of the user personalised interest model [19] is shown in Figure 1.

3.1. Countryside Tourism Platform User Information. The format and quality of the acquired data directly affect the quality of the user model. Currently, there are two common techniques used to obtain user interest information, specifically:

(1) Display feedback technology: the main way to record user preferences is through the user's evaluation of the corresponding product. This requires the user to actively participate and actively evaluate the product, which takes up more of the user's time and does not allow for good access to the user's personal interest information when the user's participation is not high.

(2) Implicit feedback technology: it is mainly through the system to view and analyse the user's behavioural data to obtain personalised information about the user's interests. Implicit feedback technology does not require active participation of the user, mainly through the platform's back-end system to obtain the corresponding information of the user, such as the number of visits to a product, the length of stay of each visit (because of the number of visits to products of interest to the user, the length of stay may be longer), the number of searches, etc.

3.2. Personal Information of Rural Tourism Platform Users. Usually, the user's basic personal situation will make the user's interests relatively stable [20]; for example, users with young children have a greater interest in parent-child rural tourism tours, and low-income people will generally choose rural tourism products with lower or free costs.

In this paper, the authors conclude from the corresponding literature, research on existing user information on rural tourism platforms, and field surveys that the personal information affecting users' choice of rural tourism products mainly includes income status, age range, address of residence, user's gender, nature of work, knowledge composition, and education level received.

3.3. User Model Construction. Rural tourism websites currently on the market have functions such as searching and recommending [21], but the following problems still exist:

(1) The accuracy rate of search and recommendation is not high.

(2) The correlation between recommended attractions is not great. Through analysis, it is found that the root cause of the problems is the lack of modelling of user information.

In this study, the user model is constructed by using the relevant information generated by the platform users in the process of browsing and purchasing products to automatically build their interest models. The user model is an abstract representation of the personal information and interest information of the system users. The basic personal information in the user model is relatively stable, while the user's interest information fluctuates greatly with time and product attributes, so how to accurately express the user's interest and facilitate the calculation becomes the key to the implementation of the user model.

Considering the probabilistic topic representation, the core idea is to understand each text message as a mixture of multiple topical features, where each topic is the distribution probability of the corresponding feature [22].

In the rural tourism platform study, the rural tourism product ontology is used to represent the user's interests, which is relatively simple in structure and can be implemented by the keyword vector space representation method. The user model consists of the user's interest set, the user's interest attribute set, the user's attention and weight for each interest in the interest attribute values, and 3 parts, which are the user's interest set, i.e., the product's key attribute set; the user's interest attribute set, i.e., the product attribute value set.

3.4. Dynamic User Interest Model. The user model contains two types of information: static, such as basic information about the user, such as gender, occupation, and knowledge background; and dynamic, which changes over time. In this study, we mainly consider the part of dynamic updates. Users' interests change with the environment and psychological factors, so the common methods used to update dynamic user models are the forgetting function method and the time window method. The forgetting function method is similar to the law of memory forgetting in that, without external stimuli, a user's interest in something will decay over time [23]. In this study, the user interest model is considered to change with the combination of time forgetting and frequency of access. User interest forgetting function is used to dynamically update the user interest model based on the forgetting factor, which is calculated using

$$f(t) = \exp\left(-k\frac{t - T_{\min}}{T_{\max} - T_{\min}}\right), \quad (T_{\min} \le t \le T_{\max}), \tag{1}$$

where $T_{\min}$ is minimum forgetting interval and represents the forgetting process, i.e., the buffer period, and the value is the difference between the interest Ts and the interest reference time; $T_{\max}$ is maximum forgetting interval, indicating the decay cycle, i.e., the time required for the interest to decrease to its original value; t is user access interval; T is the time of the last visit on the current date (in days); k is interest decay rate, where the value of k is proportional to the decay rate, here defined as 1 (the specific value can be adjusted according to the actual needs of the user).

Equation (1) considers the case of a forgotten decay cycle, i.e., $(T_{\min} \le t \le T_{\max})$, when $t > T_{\max}$ or $t < T_{\min}$ is not involved, as defined in this study.

When $t < T_{\min}$, f() = 1, it means that the interest is not decreasing.

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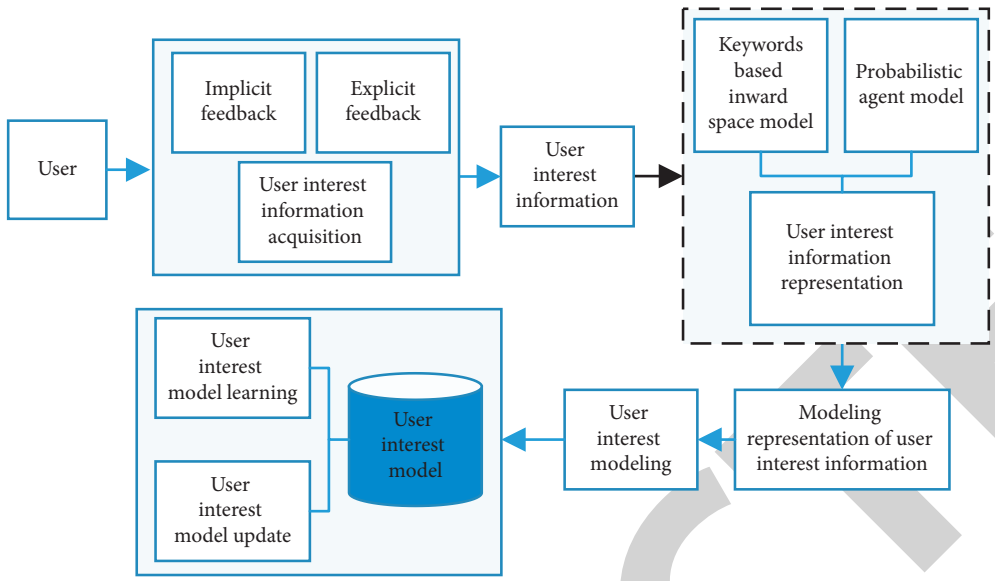

Figure 1: Selected photographic records of participants.

When $t > T_{\max}, = 0$, it means that the user has lost the interest and is removed from the user model.

The exponential forgetting function allows users' interest weights to decay according to the length of the time interval. This forgetting function takes into account the laws of human memory and treats interest as a special kind of memory.

The dynamic user interest weighting formula that combines the frequency of visits to the dynamic user interest model can consider not only the one factor of time, but also the frequency of visits to the interest. In this study, the dynamic user interest model [24] is constructed by combining the time forgetting factor and the frequency of access to the interest, as shown in (1)

$$v_i(t, N_i) = \begin{cases} 1, \\ \exp\left(-\frac{1}{Ni}\right) * fi(t), \\ 0, \end{cases} \quad (2)$$

where N_i indicates the frequency of the user's visit to the ith interest point; $v_i(t, N_i)$ indicates the weight of the user's interest in the ith interest point at time t. The initial value of the user's interest in all interests is 0, the weight of the user's interest in "parent-child" recreation at the current moment is V_i, and according to the time cycle of rural tourism, the minimum forgetting interval is 30 days and the maximum forgetting interval is one year, i.e., 365 days.

4. Tensor Decomposition-Based Fusion Model for Multiple Data Sources

4.1. Tensor Models. The reason for applying the idea of tensor decomposition to the collaborative filtering recommendation algorithm is that collaborative filtering essentially evaluates the preference information of most users and then makes a recommendation for a particular user. Once the set of users' rating vectors is constructed, the target user's rating vectors from other rows are used to predict the target user's rating of the product (filling in the missing values of the target user's rating in one row). A tensor is a multilinear vector space, where first-order tensors can be considered as vectors and second-order tensors can be represented by matrices. Tensors larger than second order are uniformly called higher order tensors. The rank of a tensor is defined as if a tensor can be expressed as an outer product of N vectors, and then the rank of the tensor is said to be N. The rank of a tensor means a tensor of rank one, which can be expressed by the outer product of vectors [25]. Figure 2 shows a third-order tensor, whose outer product is of the form $x_1.x_2.x_3$.

The cp decomposition of a tensor is based on the basic concept of a rank one tensor, which is a decomposition of a multiorder tensor into the form of an outer product of multiple rank one tensors. For example,

$$X = \sum_{r=1}^{K} x_1^r, x_2^r, \ldots, x_N^r, \quad (3)$$

where K denotes the number of rank one quantities.

In the description of this paper, we need to consider predicting the scoring data in the target data source from the feature vectors of the secondary data source, and here we enhance the correlation between multiple data sources with the help of tensor decomposition techniques between the target and secondary data sources.

4.2. Basic Ideas of the Algorithm. It is assumed that the user has had relevant Internet operations on multiple data sources and has generated a rating matrix in the corresponding data source. The set of data sources is $\mathfrak{R}_i = \{r_1, r_2 \ldots r_i \ldots\}$, and the user's rating matrix is

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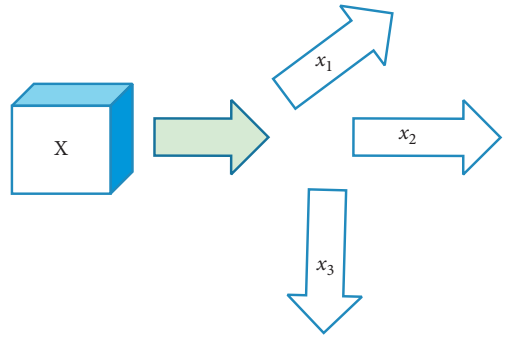

Figure 2: Third-order tensor.

represented by the set q, where $X_1 = \{x_{1p_1}', \ldots, x_{D_t}^t\}$ represents the user's rating of item $Y_t = \{y_{D_1}^1, \ldots, y_{D_t}'\}$.

Here, X, Y denote the corresponding user ratings of items in different data sources, which may be in the same data source or in different data sources where the user ratings of items overlap, e.g., the user ratings of items in the data source and in the data source at the same time in the corresponding data source, and there is also the possibility that the user ratings of items in each data source are unrelated. The data sources are also independent of each other with no overlap [26]. The data sources are considered to be the target data sources, and other relevant data sources are considered to be the secondary data sources.

Assuming that there is partial overlap and interpopulation of users between data sources, the corresponding ratings made by users in different domains are abstracted into n-order tensors according to the idea of tensor, and the tensors in this example all belong to rank one tensor, and the vector model diagram is shown in Figure 3.

4.3. Model Building. The multisource tourism information fusion model proposed in this paper is based on tensor decomposition, and the user's rating matrix in the target data source is regarded as a reorganization of the approximation matrix of the secondary data source through the idea of matrix complementation, and then the elements of the approximation matrix are used as the unobservable part of the target matrix for rating estimation [27].

The main objective of the multidata source fusion travel recommendation algorithm is to construct a global rating matrix model, where the matrix fuses the global rating matrices of users in different data sources. The matrix fusion process is shown in Figure 4.

From the above model, we abstract the three data sources into a third-order tensor model, assuming a global data domain of $\mathfrak{R}$, the third-order tensor is described as $\mathfrak{R} = [[M, T, B]] = \sum_{r=1}^{R} M_{D_r} \circ T_{D_r} \circ B_{D_r}$, where M, T, B correspond to the user ratings in the three data sources of movies, travel, and data, respectively. According to the tensor decomposition model, the fusion of multiple data sources can be normalised into a minimisation solution problem. The solution formula is as follows:

$$\min(M, T, B) = \frac{1}{2}\|\mathfrak{R} - [[M, T, B]]\|^2 + \frac{\lambda_M}{2}\|M\|_F^2 + \frac{\lambda_T}{2}\|T\|_F^2 + \frac{\lambda_B}{2}\|B\|_F^2, \tag{4}$$

where $[[M, T, B]] = \sum_{r=1}^{R} M_{D_r} \circ T_{D_r} \circ B_{D_r}$, a regularization term is added to prevent overfitting of the training results, λ represents the regularization parameter, and the model is trained using stochastic gradient descent.

To ensure that the local optimum result can be achieved in finite time, it needs to be shown that partial derivatives exist for the C data sources in their respective directions. The proof procedure is as follows:

$$\frac{\partial f}{\partial M} = \left(X_{(1)} - [[M, T, B]]_{(1)}\right)(B\Theta T) + \lambda_M M. \tag{5}$$

Similarly it can be shown that the partial derivatives of and c in the respective directions are

$$\begin{aligned} \frac{\partial f}{\partial T} &= \left(X_{(2)} - [[M, T, B]]_{(2)}\right)(M\Theta B) + \lambda_T T, \\ \frac{\partial f}{\partial B} &= \left(X_{(3)} - [[M, T, B]]_{(3)}\right)(M\Theta T) + \lambda_B B. \end{aligned} \tag{6}$$

4.4. Travel Recommendation Algorithm Design. Since the user's scoring matrix in a multidata source environment may not be a regular tensor, it is not possible to use the tensor decomposition model directly, so here it is necessary to introduce an invertible transformation to ensure that the ones in different domains can be transformed into the same dimensional information matrix; i.e., the matrix product of the $[M, T, B]$ score components is expressed in the form of

$$Y_K = M \sum_k B^T + E_k, \tag{7}$$

where A,B denote the tensor matrix vectors in the auxiliary data sources. $\sum_k = \mathrm{diag}(C_k)$ denotes the diagonal matrix of $R \times R$ of the target data sources. E_k denotes the residual terms of the model training. The global scoring matrix for multiple data sources can be obtained by minimizing the objective function:

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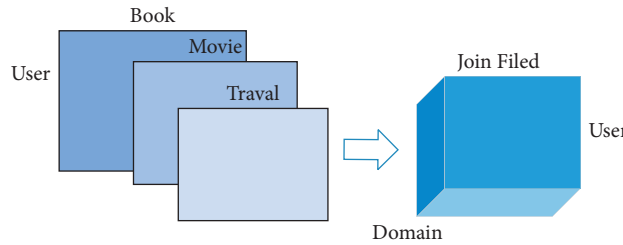

Figure 3: Data fusion model.

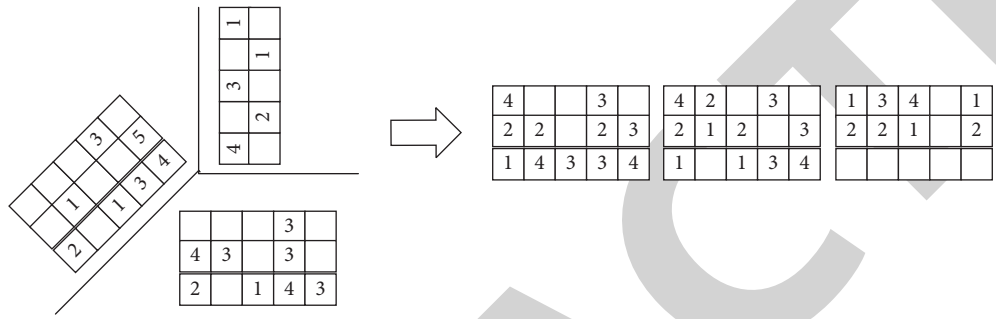

Figure 4: Matrix fusion process.

$$U \approx \min(M, T, B) = \frac{1}{2}\left\| Y_K - M \sum_K B^T \right\|^2 + \frac{\lambda_M}{2}\|M\|_F^2 + \frac{\lambda_T}{2}\|T\|_F^2 + \frac{\lambda_B}{2}\|B\|_F^2. \quad (8)$$

Here it is assumed that $X_D = \{X_1, X_2, \ldots, X_K\}$ is a scoring matrix for K different domains, where X_K has $N \times M_k$ dimensions, N denotes the number of users under the current dimension, and M_k denotes the number of items in the K th data source.

The vectors under different data sources can be iteratively trained and fused under the same data source. With the help of a unified data source model, the similarity of the target data source domain is calculated and the nearest neighbours are selected based on this to obtain global recommendation results [9].

When the global user rating matrix is obtained the target user can be selected to calculate the nearest neighbours for predicted ratings and obtain the final set of recommendation results. The rating prediction formula is as follows:

$$P_{u,i} = \overline{R} + \frac{\sum_{u \in U(u)} \mathrm{sim}(u,u) * (R_u - \overline{R_u})}{\sum_{u \in U(u)} |\mathrm{sim}(u,u')|}, \quad (9)$$

where $U(u)$ represents the global data rating matrix, $\mathrm{sim}(u,u)$ represents the similarity of users on the global data domain, and $\overline{R_u}$ represents the average user rating.

5. Analysis of Experimental Results

5.1. Experimental Data Sets. In order to obtain sufficient experimental data to verify the feasibility of the algorithm, the experimental dataset was processed as follows: firstly, 1039 attractions in six Chinese cities (Beijing, Shanghai, Guangzhou, Guilin, Hangzhou, and Haikou) were crawled from a domestic travel website using the dynamic agent technique of the PythonScrapy crawler framework, which contains 8720 users and 23,305 rating records of the attractions by users; each user can make a range of ratings for the attractions, along with 1,500 travel tips, corresponding types of attractions, the number of visitors to the attractions under different seasons, etc. The information is mined to analyse the relevant characteristics, including gender, age, occupation, travel time, as well as the route, type, and rating of the attraction, and stored in the database for subsequent analysis.

The types of attributes and the corresponding number of ratings for the attractions are shown in Table 1.

The user ratings for the scenic spots are shown in Table 2.

5.2. Experimental Results and Discussion. The experimental dataset was divided into a training set and a test set in the ratio of 8 : 2, and the results were validated by evaluating the data from the training set and using the data from the test set. The test dataset contains over 17 attraction types (historical, scenic, natural, human, etc.) [11].

5.2.1. Effect of Weighting Parameters. The rating similarity and attribute similarity of attractions are combined through (9) to construct a global similarity of attractions, and the proportion in which these parameters are adapted is a focused point of investigation for this section of the

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Table 1: Types of attractions.

POI_ID	POI_NAME	Rating	Type
1	The Great Wall	456	History, scenery
2	Palace Museum	432	History, humanity
3	XiHu	112	Scenery, park
4	Nanshan Temple	321	Buddhism
5	Tiananmen Square	222	Politics, park
6	Fenjiezhou Island	532	Landscape, park

Table 2: User-attraction rating scale.

User_ID	POI_ID	Rating	Times stamp
189	212	3	865454
231	331	2	823213
123	213	4	872443
412	23	3	865231
11	321	5	865454
6	221	3	843233

experiment. From (9), $\mu_a + \mu_p = 1$, to ensure a single controllable experimental variable; here we propose a hypothesis of $\alpha = \mu_a$, and then $\mu_p = 1 - \alpha$, so that a single variable can be controlled to observe the effect of the weighting parameters on the experimental results. In this experiment, the uniform parameter α was taken in the range [0, 1], and the performance of the algorithm was observed by adjusting the different neighbourhood users selected.

As can be seen from Figure 5, the horizontal coordinate represents the range of the parameter values, and the vertical coordinate represents the MAE values, which change differently between different numbers of neighbours k as the parameter goes from 0 to 1. The MAE of the algorithm is optimal when the weight parameter $a = 0.6$ and the number of neighbours $k = 60$. The MAE value decreases at the beginning as the weight parameter a increases and starts to increase when it exceeds $\alpha = 0.6$. This is mainly because the algorithm gradually ignores the evaluation of attraction attributes when the weight parameter exceeds 0.6. In order to find the optimal set of neighbours for the target item, we set the range of neighbours for the target item to 60 and use three different weight control parameters $a = 0.061$ to observe the influence of different number of neighbours on the recommendation result, which was observed by using three different weight control parameters; $a = 0.061$.

As shown in Figure 6, the overall performance of the algorithm's ME value is low after fusing the optimal weight parameters, and the MAE of the algorithm gradually decreases as the number of project neighbours increases and gradually stabilizes when the number of neighbours exceeds 50. The experimental results show that when the number of neighbours is chosen around 40, the algorithm can achieve the optimal recommendation result. Comparing different algorithms, this section compares the algorithms in this paper (RACF with the traditional user-based collaborative filtering algorithm (IBCF) and the improved item-based collaborative filtering algorithm IITEM-CF). 800 users were selected in the experimental dataset, which contained a large

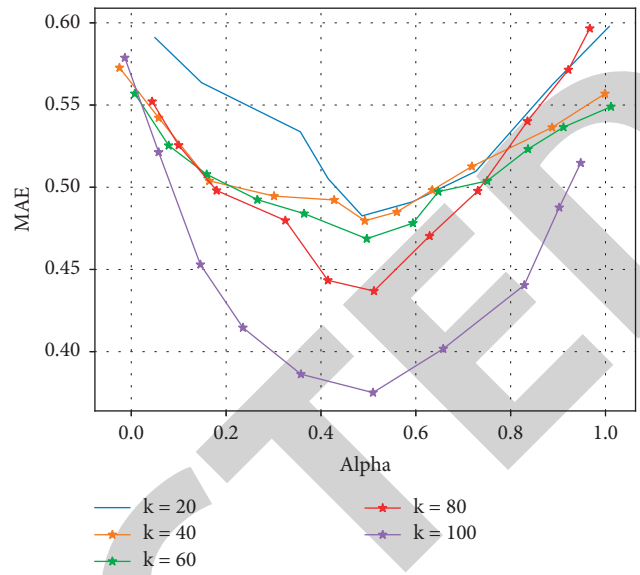

Figure 5: Effect of weighting parameters.

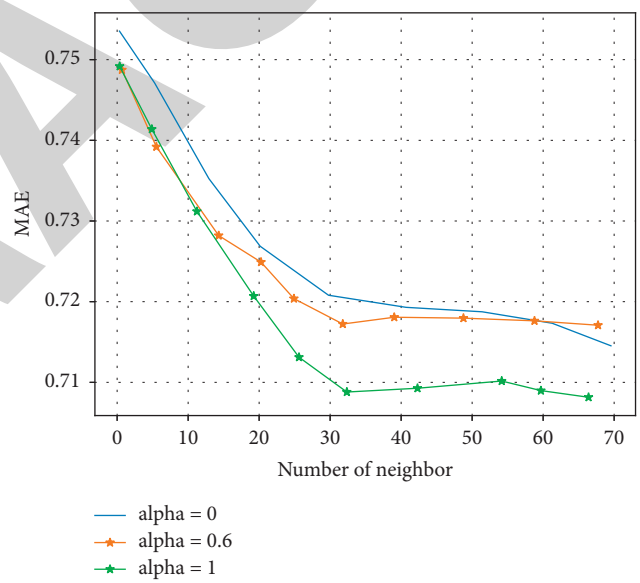

Figure 6: Effect of number of residences.

number of unrated scenic items. The experimental results are shown in Figure 7.

From Figure 7, it can be seen that the MAE values of the algorithms in this paper are relatively low when crossing the other two algorithms. Traditional algorithms IBCF and ITEM-CF have difficulty in obtaining the nearest neighbours of the target items due to the lack of basis for calculating the similarity matrix due to the absence of a large amount of rating data. In this paper, the algorithm uses a combination of attraction scores and project attributes to calculate the global similarity in the absence of project scores, combined with the inherent project attributes to assist in the calculation of global similarity, which alleviates the problem of data sparsity to a certain extent.

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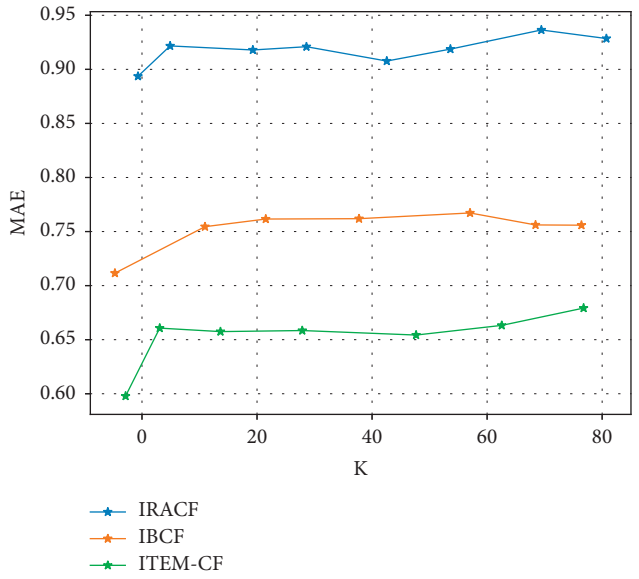

Figure 7: Comparison results of the same algorithm.

5.3. Real Life Examples. Based on the tourism data of domestic Ctrip, we used the dynamic agent technology of Python scratch crawler framework to capture 1039 scenic spots in 6 cities in China (Beijing, Shanghai, Guangzhou, Guilin, Hangzhou, and Haikou) from a domestic tourism website. It contains 8720 users and 23305 scoring records of scenic spots. Each user can store the scenic spots within the range of [1, 5]. At the same time, there are 1500 tourism strategies, corresponding scenic spot types, number of scenic spots visited in different seasons, etc.

In total, the experiments in this section involve three data sources: the movie data sources, book data sources, and travel data sources, using movies and books as secondary data sources to make predictions on the target data source, the travel domain. The experiments in this paper are divided into the following tasks.

(1) The movie data source and the book data source, respectively, are used as auxiliary data sources to calculate the similarity between users, to predict users who did not make a rating, to calculate the nearest neighbours, to calculate the correlation coefficient using the modified cosine similarity, and thus to predict the items that populate the user who did not make a rating.

(2) Based on the similarity between users calculated from the auxiliary data sources, predictions were made to the target according to the source of the items that were not rated.

(3) Fusion of the target data source and the auxiliary data source was carried out. The algorithm in this paper is used to score the target data source.

(4) Without differentiating data sources, the global data are considered, and the movie data source, book data source, and travel data source are considered as the overall target data domain.

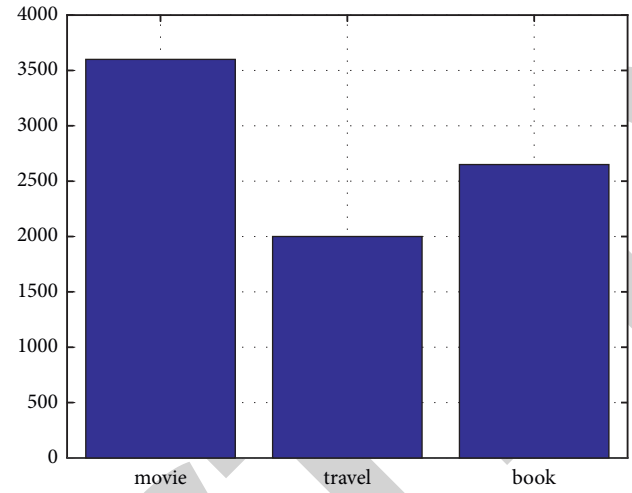

Figure 8: Distribution of test data statistics.

(5) Without distinguishing the data sources, the global data is considered, and the movie data source, book data source, and tourism data source are regarded as the overall target data domain, and the similarity is calculated for the target user in the target data domain and the nearest neighbours are selected, and the missing rating items of the target user are filled to make the user's rating of the attractions in the tourism data source.

The data set division in the experiments is uniformly constructed in the form of proportional division; i.e., the ratio of the training set to the test set is 8 : 2, and the algorithm model is trained based on the data in the training set to predict the users' scores for the unrated items in the test set. Firstly, as shown in the figure, we conducted a statistical analysis of the scores in the secondary data sources to verify the correlation between the data sources, and the experimental results are shown in Figure 8.

Figure 8 shows the number of users who have rated books in the different data sources. Since the number of users selected is fixed (5000), we can observe that there is a certain coverage of users' behaviour in the different data sources. The main reason for this phenomenon is that if a user has marked books on the topic of history and humanities several times in the book data source, he will also pay more attention to movies related to history and humanities in the movie field, and by sending similar users in the secondary data source, it helps the target data source field to discover similar users in the target field faster. This is also a prerequisite for fusion modelling of multiple data sources.

Figure 9 shows the performance of the algorithm in the case of different data sources.

In Figure 9, the horizontal coordinate indicates the number of neighbours of the selected target user, and the vertical coordinate indicates the value of the system average absolute error MAE. From the above figure, it can be seen that the algorithm's prediction in the single data source environment is difficult to find suitable neighbours in effective time due to the sparsity of the data, resulting in low

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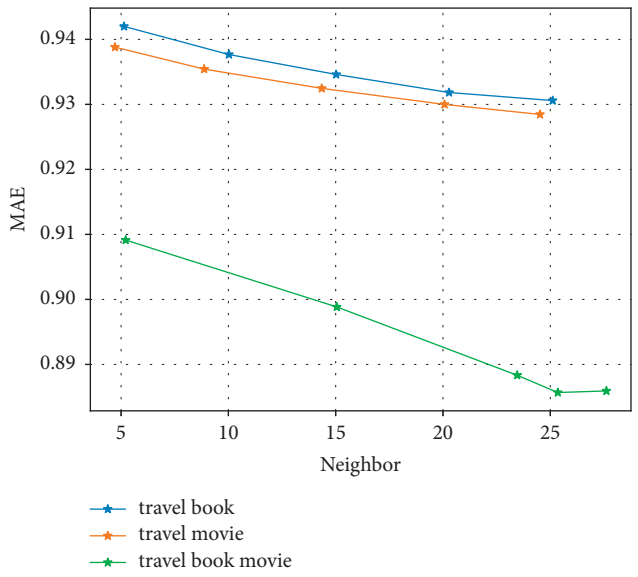

Figure 9: Performance of the algorithm in this paper with the same data source.

recommendation accuracy. As new data sources are added, the algorithm's MAE value starts to decrease compared to the single data source environment, and the algorithm's MAE value is lowest when fusing global data sources and reaches the optimal result when the number of neighbours is 25.

6. Conclusions

This paper proposes a relatively novel travel recommendation algorithm with fusion of multiple data sources. The algorithm adopts the idea of tensor orthogonal decomposition and fuses multiple data models to predict the rating of the target domain. The integrated consideration of multiple data sources under the use of the target domain is to assist the target domain to discover the target user neighbourhood users more quickly and more accurately to discover the user's interest degree. It is worth pointing out that the recommendation algorithm proposed in this paper under the fusion of multiple data sources is not necessarily applicable to data sources with weak correlation. The algorithm has the lowest MAE value when fusing global data sources and reaches the optimal result when the number of neighbours is 25.

Data Availability

The dataset used in this paper is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

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Retraction

Retracted: Research on Spatio-Temporal Complexity Evolution and Influencing Factors of "Nongrain" in Guangxi

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] C. Tang, Y. Yi, and Y. Kuang, "Research on Spatio-Temporal Complexity Evolution and Influencing Factors of "Nongrain" in Guangxi," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 1181108, 14 pages, 2022.

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Research Article

Research on Spatio-Temporal Complexity Evolution and Influencing Factors of "Nongrain" in Guangxi

Chongzhen Tang, Yongyi Yi, and Yani Kuang

School of Public Administration and Communication, Guilin University of Technology, Guilin 541000, China

Correspondence should be addressed to Yani Kuang; yiyongyi123@126.com

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The "nongrain" problem of farmland has an important influence on grain production safety and planting structure stability in China. Using statistical analysis and spatial analysis tools to explore the spatial and temporal distribution characteristics of "nongrain" cultivation trend in Guangxi, and through the geographically weighted regression model to analyze the factors affecting the degree of "nongrain" cultivation trend in Guangxi. The results showed that (1) the proportion of nongrain crops in Guangxi was increasing from 2009 to 2019, and the decrease of rice planting areas and the increase of vegetable planting area were the main reasons for the trend of "nongrain" in Guangxi. (2) the proportion of oil crop planting area increased rapidly in northwest Guangxi, and the overall growth rate was faster in 2009–2014. The proportion of vegetable planting area increased rapidly in the western and central regions, and the overall growth rate was faster in 2014–2019. The proportion of sugarcane and cassava planting area showed a downward trend in most regions, and the sugarcane decreased significantly in the northwest and eastern regions. (3) The effect of urbanization rate on the degree of "nongrain" is positive in southern Guangxi and negative in northern Guangxi. The average annual temperature is positively correlated in the north and negatively correlated in the south. Agricultural population and average annual precipitation are positively correlated in all regions and are the most significant in the northeast and the north, respectively. The ratio of grain production to sowing and the total power of agricultural machinery are negatively correlated in most areas and are most significant in the northeast. Finally, based on the research conclusion, this study puts forward some policy suggestions for preventing "nongrain" and stabilizing grain production in China.

1. Introduction

Food security is an important guarantee for world peace and development. However, global food security is currently facing serious challenges. According to the report released by the Food and Agriculture Organization (FAO) of the United Nations, the world malnutrition rate is stable at 11%. Although the downward trend in the past few decades has ended, the number of global hungry population has grown for three consecutive years, which has exceeded 820 million, and 2 billion people have experienced moderate or severe food insecurity. At the same time, the world's hungry population is unevenly distributed, with more than 500 million people in Asia and nearly 260 million in Africa, of which more than 90% live in sub-Saharan Africa [1]. The trend toward global food security means that achieving the "zero hunger" sustainable development goal by 2030 faces enormous challenges. In recent years, due to the impact of the novel coronavirus pneumonia epidemic, some countries have begun to tighten food exports, raise food export prices, and other factors such as locust plagues in Africa and South Asia will have an impact on global food security.

As a country with large population and scarce land per capita, agricultural development and food security have been the focus of attention in China. Since the founding of the People's Republic of China 70 years ago, China's arable land has increased from 1.468 billion mu to 2.023 billion mu, and grain production has increased from 113.18 million tons to 663.84 million tons. Grain production has achieved a qualitative leap [2]. However, with the development of industrialization and urbanization, capital going to the countryside continues to deepen, the phenomenon of illegal

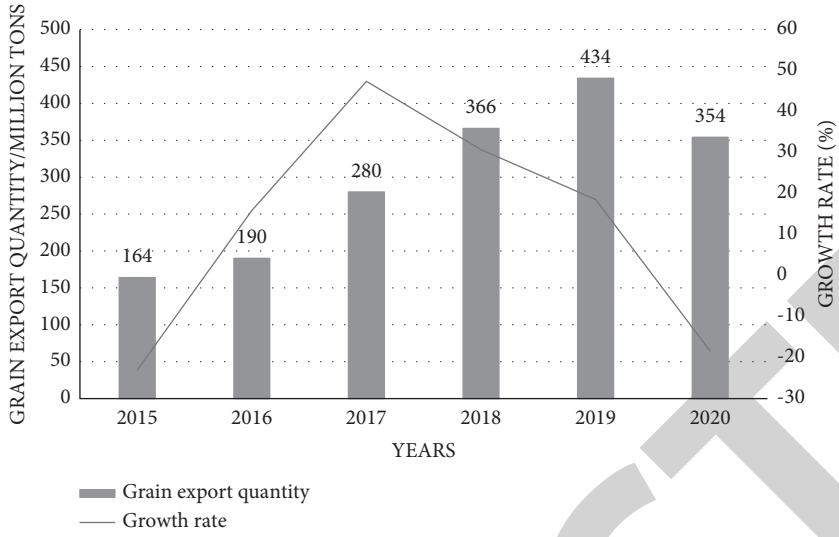

Figure 1: China's grain export quantity and growth rate chart from 2015 to 2020.

planting of permanent basic farmland and the transfer of commercial capital to cultivate nonfood crops has emerged one after another. The phenomenon of "nongrain" cultivated land is becoming more and more serious. The data in recent 10 years show that the proportion of grain crop planting area in China has decreased from 70.12% in 2009 to 69.95% in 2019, the decrease area reached 5.8 million hectares, and China's grain exports in the past five years also showed an inverted "U" trend (as shown in Figure 1). Therefore, in November 2020, the General Office of the State Council issued the "Opinions on preventing 'nongrain' of cultivated land to stabilize grain production," which put forward clear requirements for the understanding, countermeasures, and supervision of the "nongrain" of cultivated land [3].

The so-called "nongrain" refers to a behavioral tendency of farmers to reduce grain planting in the production process of the planting industry. This phenomenon is different from agricultural diversification [4, 5] because this behavior selection process occurs within the cultivated land, it refers specifically to the land used for planting food, not including plantations such as tea and other economic crops [6–8]. The generation of "nongrain" phenomenon is closely related to farmland transfer. Research shows that the "nongrain" ratio of transferred land is five to six times that of original land [9]. Some scholars have found that due to land transfer and large-scale agricultural management, the phenomenon of "nongrain" in major grain depots in coastal and Central China in recent years is particularly obvious [10, 11]. Based on the perspective of regional research, some scholars introduced the current situation of "nongrain" and qualitatively analyzed the potential causes of "nongrain" [9, 10], some scholars examined the factors that affect farmers' willingness to "nongrain" from the microscale, and the subtle differences and complexity of these factors on farmers' decision-making behavior [12, 13]. Other studies focus on the impact of "nongrain" on the environment or social economy, especially its threat to food security [11, 14]. Some scholars found that the expansion of the trend of "nongrain" will lead to the continuous reduction of grain planting area, resulting in fluctuations in grain prices and yields, and thus threatening the food security [15]. In addition, the expansion of the "nongrain" trend will cause damage to the local environment, which will not only accelerate soil erosion [16] and threaten local biodiversity [6], but also aggravate nonpoint source pollution [4] and carbon dioxide emissions [17]. For the influencing factors of "nongrain," some scholars regard the nongrain crop planting ratio as an indicator to measure "nongrain" [18], and some scholars find that factors such as agricultural mechanization level [19] and family labor force [20, 21] will affect the trend of "nongrain"; in addition, scholars consider the impact of urbanization imbalance on "nongrain" [22].

Nevertheless, limited and subjective results were achieved since most investigations were confined to empirical studies based on limited sample survey data. Few studies have analyzed the variability and heterogeneity of "nongrain" from the perspective of time and space. With the increasing number of high spatial resolution remote-sensing images and the wide application of spatial analysis software, the trend of "nongrain" can be quantified timely and effectively. Among them, ArcGIS, as a commonly used spatial analysis software, can present the trend of "nongrain" change through data maps, and explore the influencing factors of "nongrain" change trend through geographical weighted regression.

Through the review of existing literature, it is found that there are still some deficiencies in the research of scholars on the "nongrain" of cultivated land: (1) In the current research on "nongrain," there are a few literature using spatial analysis method to study the evolution trend of "nongrain." Spatial analysis, as a research method to connect time and space with data, can more clearly and intuitively see the trend and evolution characteristics of "nongrain" in the research area. (2) In the current literature on the influencing factors of "nongrain," most of them adopt quantitative research methods, lacking the temporal and spatial

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presentation of the influencing factors on "nongrain," and it is difficult to see the regional differences of the influencing factors. Based on this, this study takes Guangxi as the research object, using statistical analysis and spatial analysis method to study the spatio-temporal evolution and influencing factors of "nongrain," which provides theoretical reference for the study of spatio-temporal characteristics and mechanism of "nongrain" evolution, curbing "nongrain" phenomenon and adjusting crop planting structure, and makes theoretical contributions to the stability of grain production and sustainable development of agriculture in Guangxi.

2. Research Area and Data Sources

2.1. Overview of the Research Area. Guangxi Zhuang autonomous region is located in South China with a high terrain in the northwest and a low terrain in the southeast. Its longitude and latitude range from 104°28′ E–112°04′ E to 20°54′ N–26°24′ N. It has 14 prefecture-level cities and 111 county-level administrative regions. The climate is dominated by the subtropical monsoon climate, and a few regions are tropical climates. The annual average temperature is between 17°C and 24°C, and the annual rainfall is 1000–3300 mm. The annual sunshine hours are 1213–2135 hours, and the frost-free period is more than 300 days. The unique geographical and climatic conditions make Guangxi have unique advantages in developing pollution-free green vegetables and mountain cloud tea and other characteristic agriculture, with grain and fruit as the main planting industries. In recent years, the development of *Momordica grosvenori*, tomato, Nanshan radish, eggplant, and other economic crops. In 2019, the total output value of Guangxi's primary industry was 549.88 billion yuan, of which the agricultural output value was 310.23 billion yuan. The total arable land area for the year was 4.22 million hectares, and total food production was 13.32 million tons, down 3% from the previous year. Total fruit production was 21.4 million tons, up 19.5% from the previous year, and annual vegetable production was 36.36 million tons, up 6% from the previous year.

Due to the low latitude, sufficient heat, abundant precipitation, and sufficient labor force in Guangxi, close to the densely populated Pearl River Delta, the market is broad, so the value of planting economic crops in agricultural land in Guangxi is higher than that of planting grain crops. The level of income will drive farmers to grow nongrain crops, so the phenomenon of "nongrain" in Guangxi will be more obvious. According to the agricultural statistical data of Guangxi in recent years, the grain planting area is in a state of fluctuation, while the economic crop planting area has an obvious upward trend, and the phenomenon of cultivated land "nongrain" has emerged. Therefore, this study identifies Guangxi as the research area.

2.2. Data Sources. In this study, agricultural data in *Guangxi Statistical Yearbook* and statistical yearbook in Guangxi cities are used as the main data sources. Among them, the meaning of cultivated land in *Guangxi Statistical Yearbook* refers to the land that grows crops, including new development, reclamation, and idle land. The planting area of grain crops refers to the area of grain, beans, potatoes, and other grain crops that are actually sown throughout the year. Whether sown on cultivated land or on noncultivated land, the sowing area should be calculated. Based on the statistics of the cultivated land area and the planting area of various crops in the 2009–2019 *Statistical Yearbook*, the trend and degree of "nongrain" in Guangxi are measured, and the corresponding administrative zoning map is generated by ArcGIS10.2. In the case of missing data on individual indicators, it is supplemented by reference to Guangxi "Statistical Bulletin of National Economy and Social Development" in 2009–2019. In addition, to analyze the main factors affecting the degree of "nongrain" in Guangxi, the sources of the relevant indicators also consult the national land use survey data.

3. Results and Analysis

3.1. Statistical Analysis. The planting area of crops, grain crops, and nongrain crops (including economic crops and other crops) in Guangxi from 2009 to 2019 was counted, and the results were shown in Figure 2. It can be seen that during 2009–2019, the overall trend of the total planting area of crops increased at first and then decreased, but the total amount remained relatively stable. Among them, there was an upward trend from 2009 to 2014, with an increase of 386.7 thousand hectares in five years, an increase of 6.66%. The largest increase was recorded in 2012, at 119.1 thousand hectares, an increase of 1.99% over the previous year. In 2015–2019, the area decreased by 3.27% to 202.7 thousand hectares. Of these, the largest decline in 2018 was 180 thousand hectares, a decrease of 2.92% over the previous year. In 2009–2019, the planting area of grain crops also showed a trend of first increase and then decrease, and the decrease was greater than the increase. In 2009–2013, grain crop acreage increased by 80.6 thousand hectares, an increase of 2.65%. From 2014 to 2019, there was a significant reduction in the area of grain crops, a total of 372.3 thousand hectares, a decrease of 11.94%, of which 202.6 thousand hectares were reduced in 2018 (since the cities adjusted their original planting areas according to the second land survey data in 2018, the actual reduction was smaller than the above), a decrease of 6.76% compared with the previous year. Different from the first two, the nongrain crop planting area showed a continuous upward trend from 2009 to 2019, with an increase of 475.77 thousand hectares in 10 years, an increase of 17.19%. It can be seen from Figure 1 that the proportion of nongrain crops in the total planting area of crops increased year by year in the past 10 years, from 47.66% in 2009 to 54.13% in 2019.

In general, from 2009 to 2019, the changes in the total crop planting area and grain planting area in Guangxi were relatively stable, but the nongrain crop planting area increased rapidly and the proportion continued to increase. The changes showed a certain trend of "nongrain" crops and had a certain impact on grain production in Guangxi.

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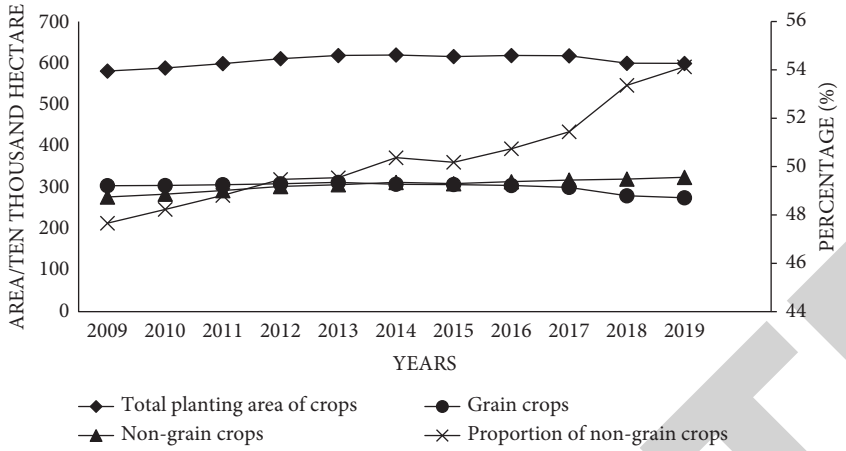

Figure 2: Change of crop area in Guangxi from 2009 to 2019.

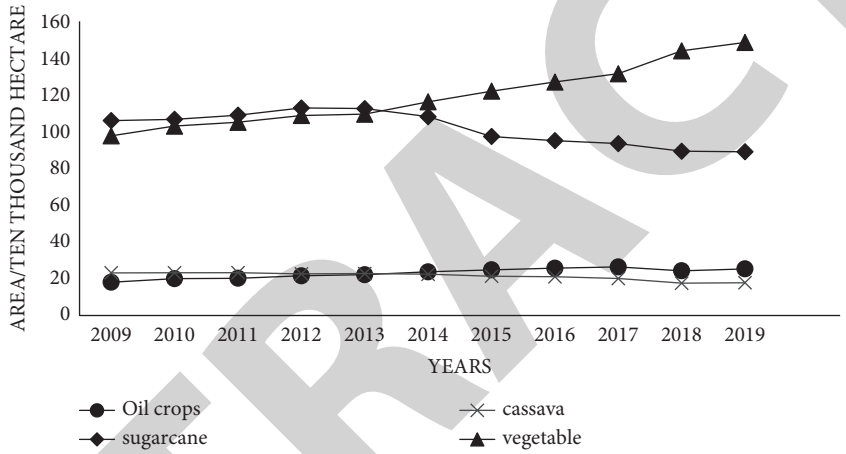

Figure 3: Change of main nongrain crop area in Guangxi from 2009 to 2019.

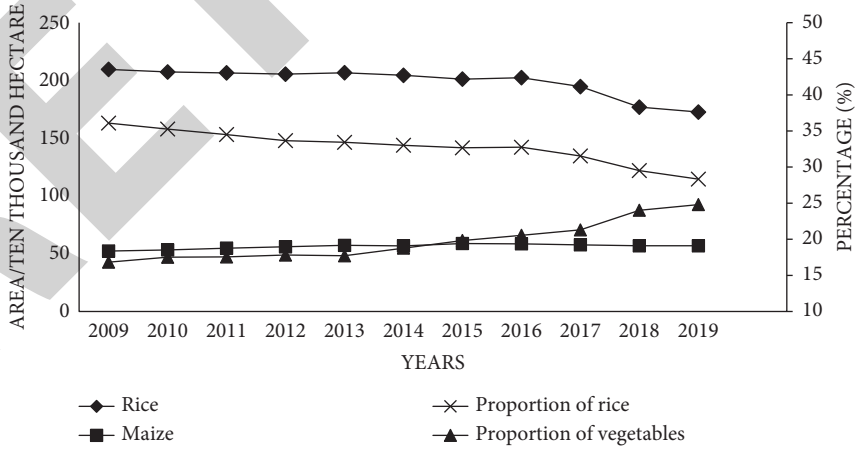

Figure 4: Change of main grain crop area in Guangxi from 2009 to 2019.

After investigating the main cultivated grain crops and nongrain crops in Guangxi, six crops, including rice, maize, oil crops, sugarcane, cassava, and vegetables, were selected and their planting areas and proportions from 2009 to 2019 were counted, as shown in Figures 3 and 4. It can be seen that the planting area of oil crops and cassava showed a stable upward and downward trend from 2009 to 2019, respectively. The area of oil crops increased by 72.8 thousand hectares in the past 10 years, and the planting area of cassava decreased by 53.6 thousand hectares, with an increase of 40.24% and a decrease of 23.13%, respectively. The overall trend of sugarcane planting area increased first and then

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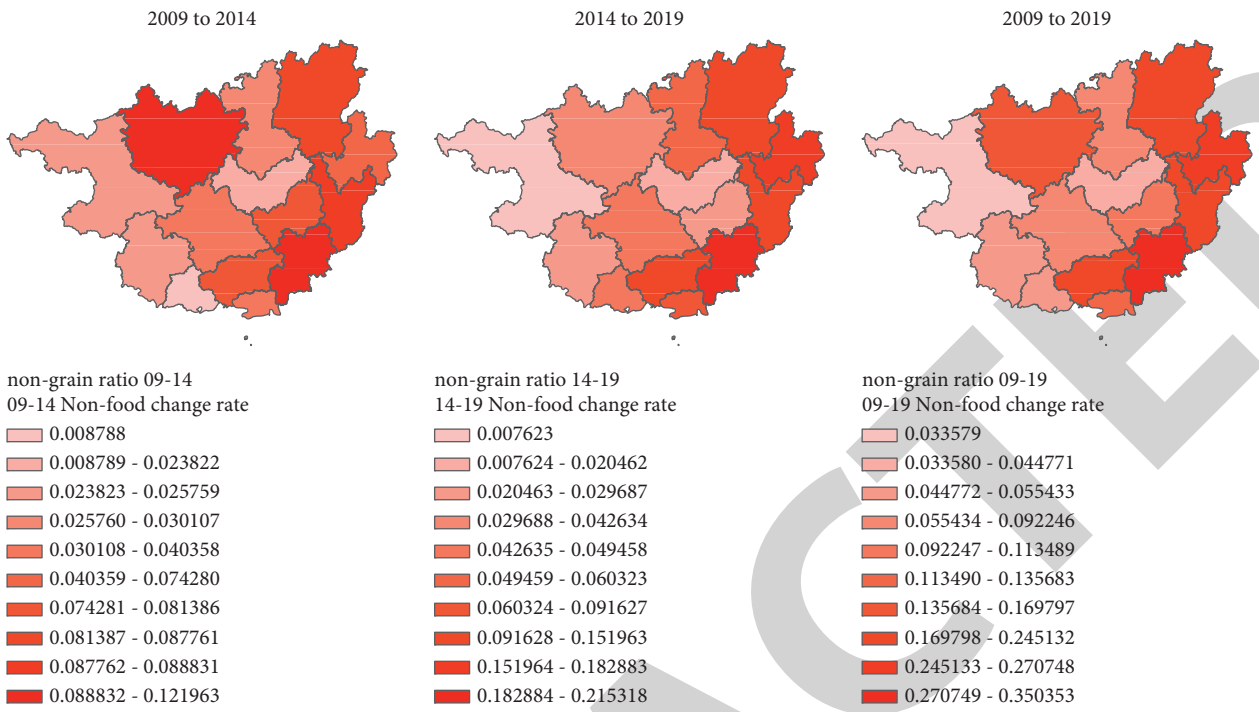

Figure 5: Change rate map of the proportion of nongrain crop planting area in Guangxi from 2009 to 2019.

decreased, with an increase of 6.47%, less than a decrease of 21.13%, and an overall decrease of 16.02%. There was a significant reduction in the area of sowing in 2015, a decrease of 107.6 thousand hectares compared with 2014, a decrease of 9.95%. The vegetable planting area changed most obviously between 2009 and 2019, from 977.3 thousand hectares in 2009 to 1.49 million hectares in 2019, an increase of 51.97%. The growth process can be divided into three stages according to the growth rate. The growth rate of 2014–2017 and 2018–2019 is relatively rapid, and the annual average growth rates are 4.67% and 6.28%, respectively. From Figure 3, it can be seen that the rice planting area continued to decline from 2009 to 2019, with a total decrease of 368.8 thousand hectares in 10 years, a decrease of 17.6%. Among them, the decline in 2017–2019 was more obvious, at 297.6 thousand hectares, with an average annual decline rate of 5.16% (since the cities adjusted their original planting areas according to the second land survey data in 2018, the actual reduction was smaller than the above). The maize planting area showed a small increase and then a decrease trend in 10 years, and the increase was greater than the decrease. From 2010 to 2015, the planting area of maize increased by 65.2 thousand hectares, an increase of 12.46%. From 2016 to 2019, the planting area decreased by 19.5 thousand hectares, a decrease of 3.31%.

Overall, the planting area of major nongrain crops in Guangxi showed an upward trend from 2009 to 2019, while the main grain crop planting area showed a downward trend. It can be seen from Figures 3 and 4 that the continuous decrease of rice planting area and the substantial increase of vegetable planting area are the main reasons for the increase of the proportion of nongrain crop planting area, which makes Guangxi present a "nongrain" crops trend.

3.2. The Spatio-Temporal Evolution of the "Nongrain" Trend in Each City. In order to further explore the change rate of "nongrain area" in Guangxi and its spatial differences, the change rates of the total nongrain planting area and the proportion of the main nongrain crop planting area in the total crop planting area of each city from 2009 to 2019 were calculated. The calculation formula is as follows:

$$v_{ij} = \frac{\left(M_{ij} - M_{ik}\right)}{M_{ij}}. \quad (1)$$

Among them, v represents the change rate, M represents the sowing area, i represents the crop species, j represents the year, and k represents the previous year of the current year. ArcGIS software is used to fill the calculated values into the administrative division map of Guangxi Zhuang autonomous region, as shown in Figures 5–9.

It can be seen from Figure 5 that the cities with the rapid increase in the proportion of nongrain crop planting area from 2009 to 2019 mainly concentrated in the southeast of Guangxi and gradually decreased along the northwest direction. Among them, Qinzhou, Wuzhou, Hezhou, and Guilin all grew by more than 20% in the proportion of nongrain crop planting area within 10 years, and Yulin had the highest growth rate of 35%. In stages, from 2009 to 2014, Hechi and Yulin had a high growth rate, of which the growth rate of Hechi reached 12% in five years, whereas that of Fangchenggang remained low, with only 0.88% growth in 5 years. In 2014–2019, the growth rate of the proportion of

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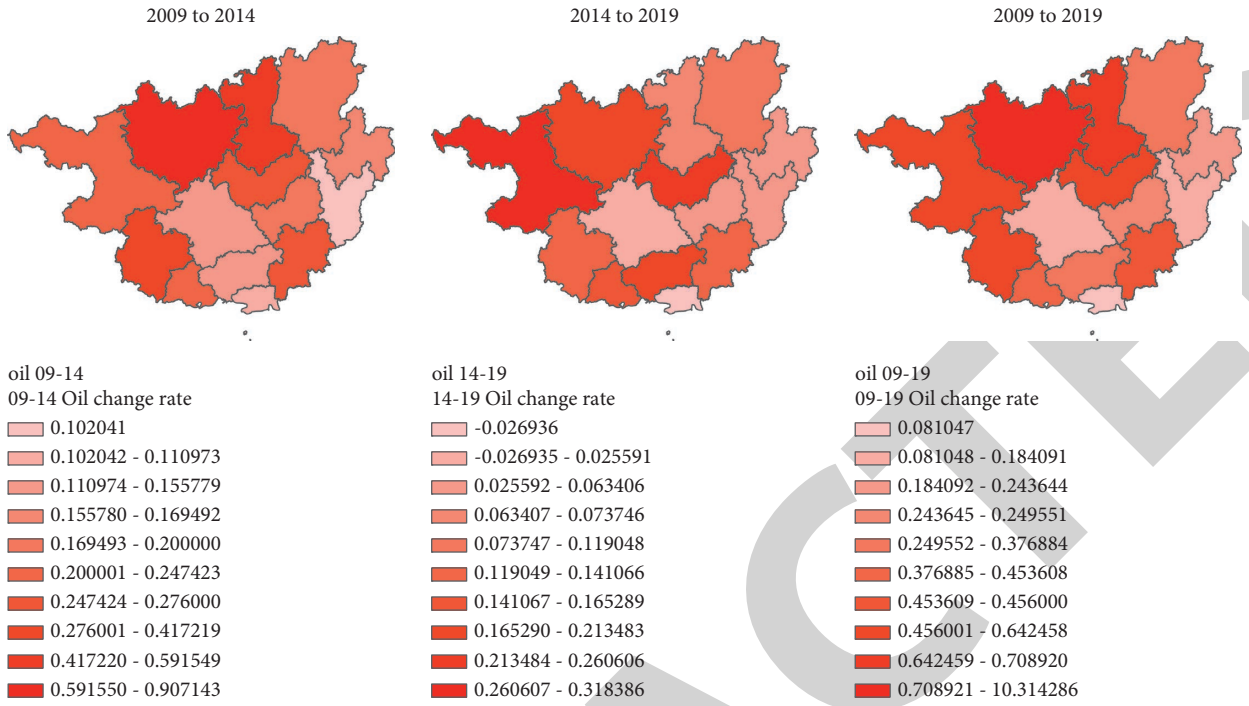

Figure 6: Change rate map of the proportion of oil crop planting area in Guangxi from 2009 to 2019.

nongrain crop planting area in each city of Guangxi was basically the same as that in 2009–2019, with the highest growth rate of 21% in Yulin as the center and decreasing to the northwest. It can be seen that the growth rate of each city from 2014 to 2019 was significantly higher than that from 2009 to 2014, indicating that the proportion of nongrain crop planting area has grown rapidly in recent years, showing a certain trend of "nongrain" crop area.

The change rate of cultivation area proportion of oil crops (mainly peanut and rapeseed) is shown in Figure 6. During the period of 2009–2019, the cities with the fast growth rate of oil crops were mainly concentrated in the northern part of Guangxi. The growth rates of Laibin, Chongzuo, and Baise in the past 10 years reached 60%. The growth rates of Yulin and Fangchenggang in the southern region also reached 45%, while the growth rate of Hechi reached 130%. The proportion growth rate from 2009 to 2014 is basically consistent with the overall trend in the past 10 years, with the growth rate of 90% in Hechi decreasing to 11% in Beihai and 10% in Wuzhou in the southeast. From 2014 to 2019, the change of growth rate decreased from west to east in Baise, the highest, with Beihai accounting for −2.69%, indicating a decrease in the proportion of oil crops. In addition, the images from 2009 to 2014 show that they had a great influence on the changing trend in the past 10 years, indicating that the growth of the proportion of oil crops in the sowing area has slowed down in recent years.

Since sugar crops in Guangxi are mainly sugarcane, the growth rate of the proportion of sugarcane planting area is plotted as shown in Figure 7. From 2009 to 2019, the growth rate of sugarcane planting areas in Guangxi showed an increasing trend from north to south. However, except for 3.13% of the Beihai and 5.71% of Yulin in the south, the growth rates of other regions were negative. The values of Hechi and Wuzhou were lower than −30%, and Baise and Guilin reached below −40%, which indicated that the proportion of sugarcane planting areas in Guangxi showed a significant decrease in 2009–2019. In addition, the changing trends of the proportion of sugarcane planting area in different regions are different at different time stages. From 2009 to 2014, the figures of Liuzhou, Cuigang, and Baise were below −10%, and figures of most of the cities fluctuated slightly between −5% and 5%. The growth rate in Wuzhou during the 5 years was just 0%, which means the share had not changed. The figures for Hezhou in the eastern region and Yulin in the southeastern region were 8.04% and 18.21%, indicating a significant increase in the proportion of sugarcane planting areas in the region from 2009 to 2014. From 2014 to 2019, the proportion of sugarcane planting area in the whole Guangxi region decreased significantly. The values of Baise, Hechi in the northwest, and Wuzhou and Hezhou in the east were all lower than −30%, and only Beihai was 5.4% positive, indicating that the proportion of sugarcane planting area in Guangxi has decreased significantly in the past 5 years. Due to the large overall planting area, the trend of "nongrain" crop area was inhibited to some extent.

The growth rate of cassava planting area in Guangxi from 2009 to 2019 was shown in Figure 8. From 2009 to 2019, the growth rate of cassava planting area was mostly negative, indicating that the overall proportion of cassava planting area showed a downward trend. Only Qinzhou, Fangchenggang, and Yulin in the south maintained a positive growth rate, the highest was 20.12% of Qinzhou, and gradually decreased in the northwest direction. In 2009–2014, Guigang and Wuzhou in the south-eastern region accounted for the main increase in cassava

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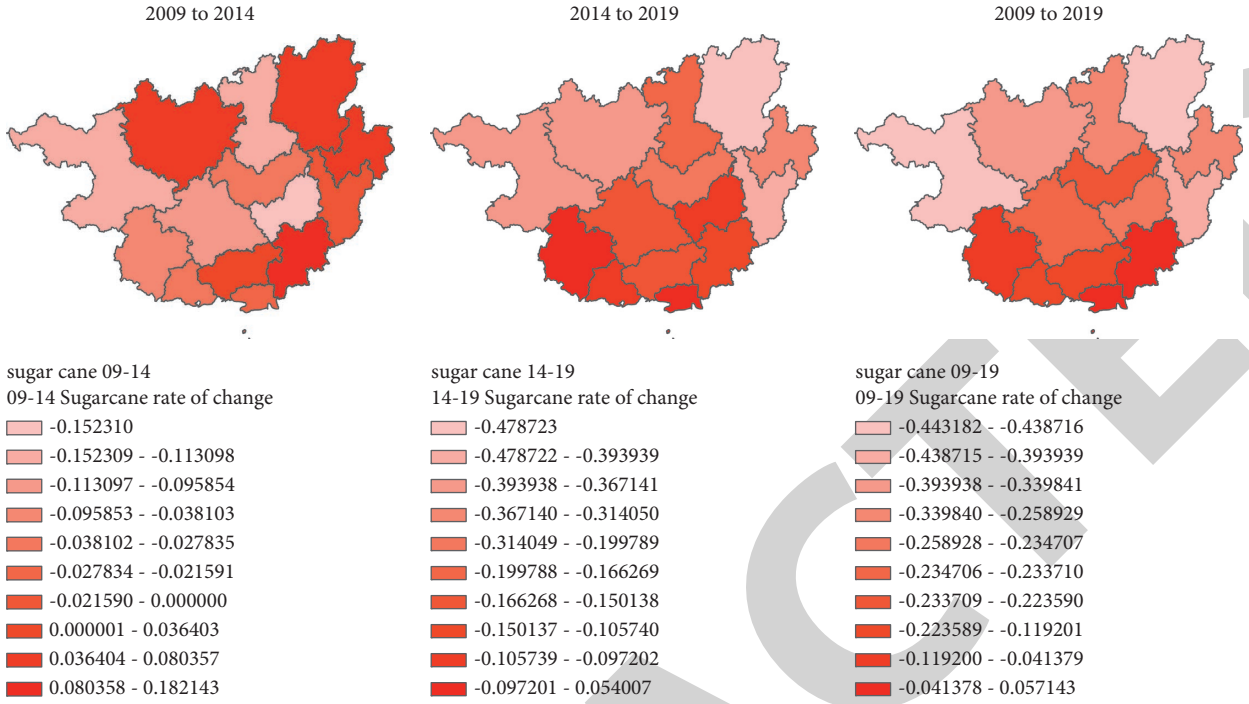

Figure 7: Change rate map of the proportion of sugarcane planting area in Guangxi from 2009 to 2019.

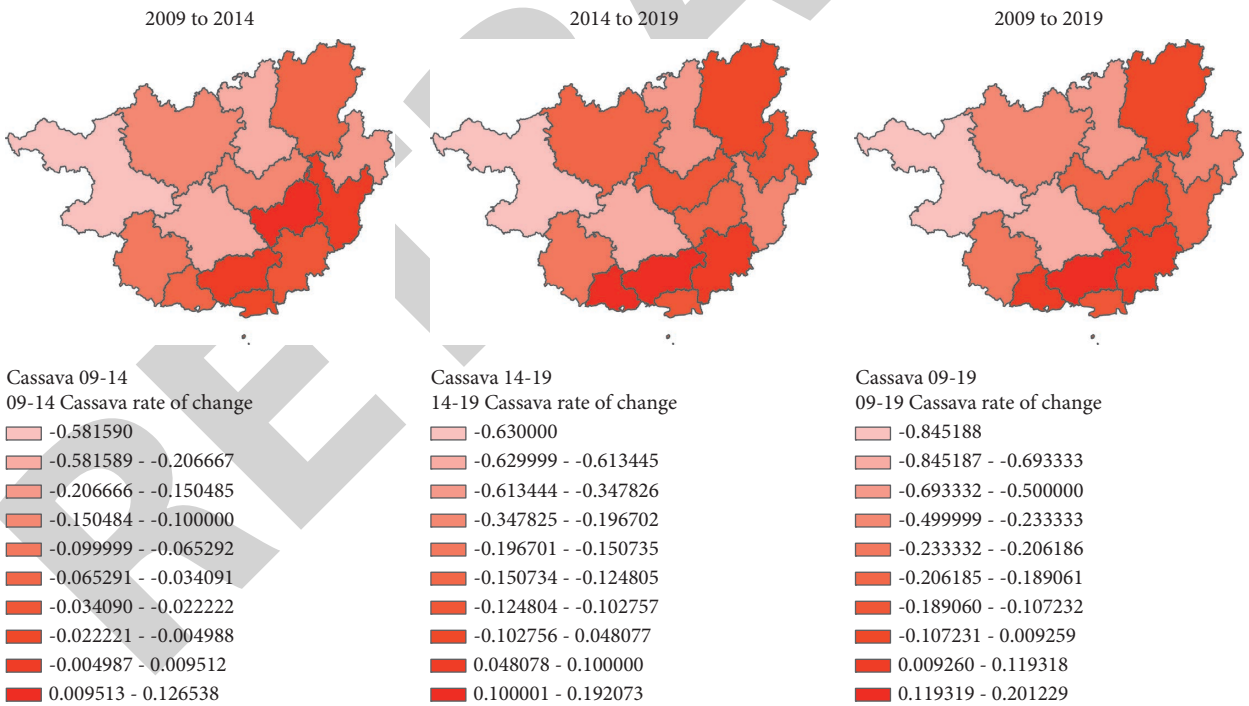

Figure 8: Change rate map of the proportion of cassava planting area in Guangxi from 2009 to 2019.

planting area, but the growth rates did not exceed 10%. The northwest region has a low negative growth rate, such as the growth rate of Baise reaching −58.16%. From 2014 to 2019, only a few southern cities maintained a positive growth rate, and the negative growth rate of most central and northern regions reached below −10%. Among them, the negative growth rate of Baise and Nanning is less than −60%. It can be seen that the proportion of cassava planting area continued to decrease from 2009 to 2019, and the decreasing trend was more obvious in recent years. However, due to the limited overall planting area, there was no significant effect on inhibiting the trend of "nongrain."

The growth rate of the vegetable planting area in Guangxi from 2009 to 2019 was statistically shown in

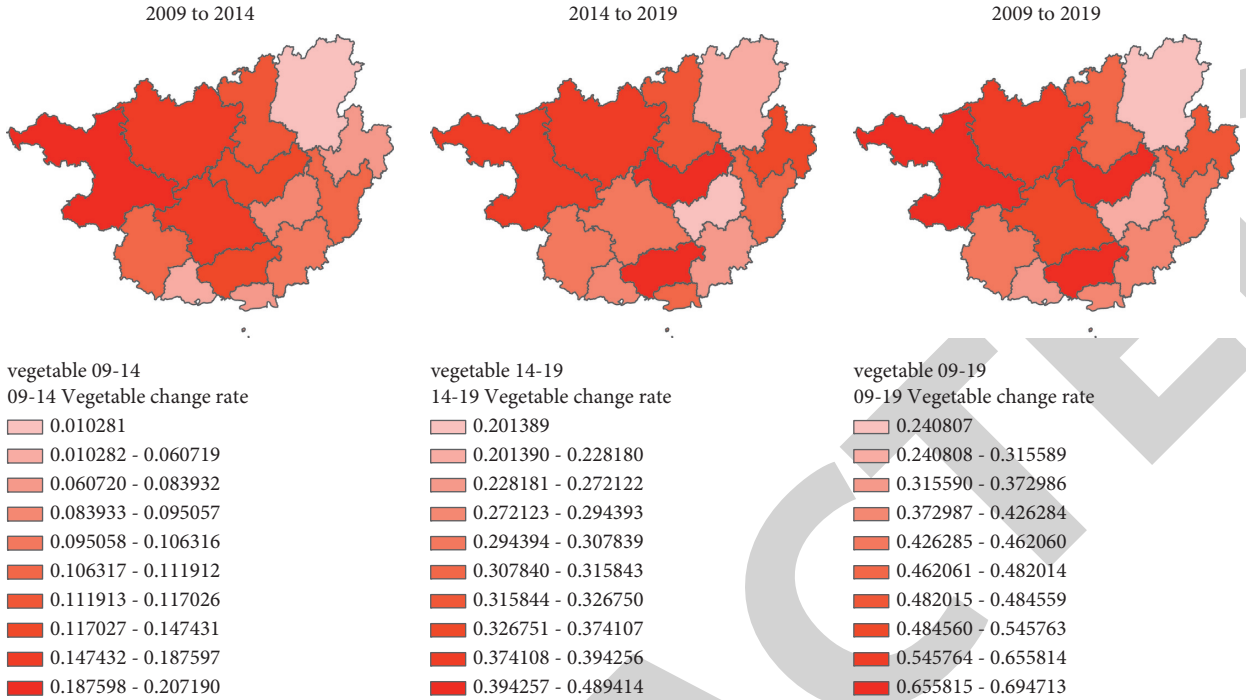

Figure 9: Change rate map of proportion of vegetable planting area in Guangxi from 2009 to 2019.

Figure 9. During the period of 2009–2019, the proportion of vegetable planting area in each city of Guangxi maintained a high growth rate on the whole. Taking Baise in the western region, Laibin city in the central region, and Qinzhou in the southern region as representatives, the growth rate in the past 10 years reached more than 65%, and Guilin in the lowest northeast region also reached 24.08%. From 2009 to 2014, the growth rate of each city showed a gradual upward trend from east to west, and the overall growth rate was relatively low. The highest growth rate was 20.72% in Baise, which was in sharp contrast with the lowest growth rate of 1.03% in Guilin. The growth rate of each city from 2014 to 2019 was between 25 and 50% as a whole and was similar to the trend map from 2009 to 2019, indicating that the vegetable planting area in Guangxi has grown rapidly in the past 5 years. Due to the large overall planting area, the trend of "nongrain" crop area in Guangxi is obvious.

Finally, in order to measure the changing trend of "nongrain" crop area in Guangxi as a whole, the period from 2010 to 2018 is selected as the research object, and the ratio of nongrain crop planting area to the cultivated area of each city (denoted as "nongrain cultivated ratio") is introduced to calculate the growth rate of each year. The calculation formula is as follows:

$$I = \frac{M_i}{M_k}, \tag{2}$$

where I represents the nongrain cultivated ratio of a city, M_i represents the total planting area of nongrain crops in a city, and M_k represents the cultivated area of a city. ArcGIS software is used to draw the data in the administrative division map of Guangxi Zhuang autonomous region, as shown in Figure 10.

From Figure 10, it can be seen that from 2010 to 2018, the growth rate of the nongrain cultivated ratio in Guangxi gradually decreased from northeast to west and southeast, and was divided into three regions. The northeast region represented by Guilin has the highest growth rate, and the nongrain cultivated ratio of growth rate in Guilin has reached 47.06% in eight years. Qinzhou and Yulin as the representatives of the southeast region's growth rate ranks second, are more than 30%, the surrounding city growth rate also reached 20%. The growth rate of the western region represented by Baise and a small number of central cities, such as Laibin, in the past 8 years was negative, indicating that the nongrain crops planted per unit of arable land gradually decreased. From 2010 to 2014, the growth rate of nongrain cultivated ratio in each city was relatively flat, with the highest rate of 36.51% in Qinzhou, the growth rates in the remaining cities were below 20%, and the growth rate in Nanning was negative. From 2014 to 2018, the growth rate of nongrain cultivated ratio in each city is basically the same as that from 2010 to 2018, indicating that the trend of sowing nongrain crops in-unit cultivated land in recent years is rising, and the phenomenon of "nongrain" crop area in the eastern region is more obvious.

3.3. Factors Influencing the Evolution Trend of "Nongrain" Crop Area. The change rate of nongrain cultivated ratio in each city from 2010 to 2018 was a selected trend based on literature review [18–22] as the explained variable to further

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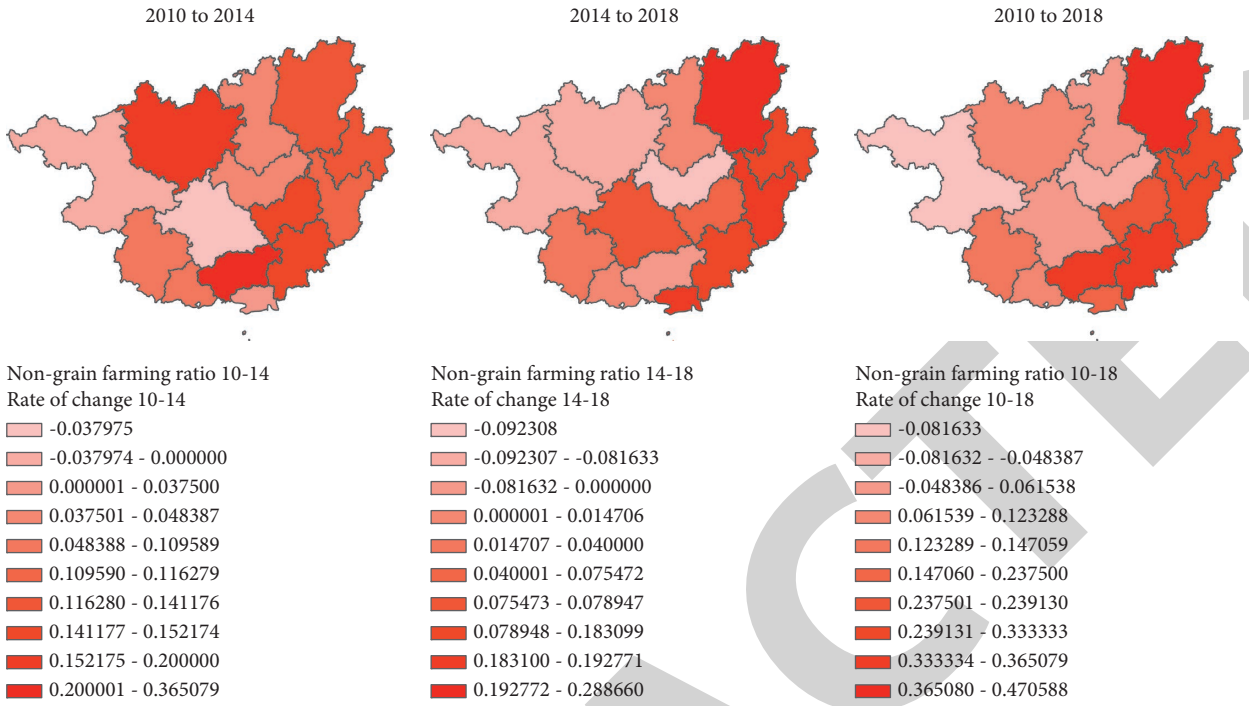

Figure 10: Change rate map of nongrain cultivated ratio in Guangxi from 2010 to 2018.

Model parameters.,	2010-2018.,
Neighbors.,	14.,
Residual Squares.,	0.053303.,
Effective Number.,	11.151984.,
Sigma.,	0.136806.,
AICc.,	111.059949.,
R^2.,	0.853872.,
R^2 *Adjused.,*	0.332989.,

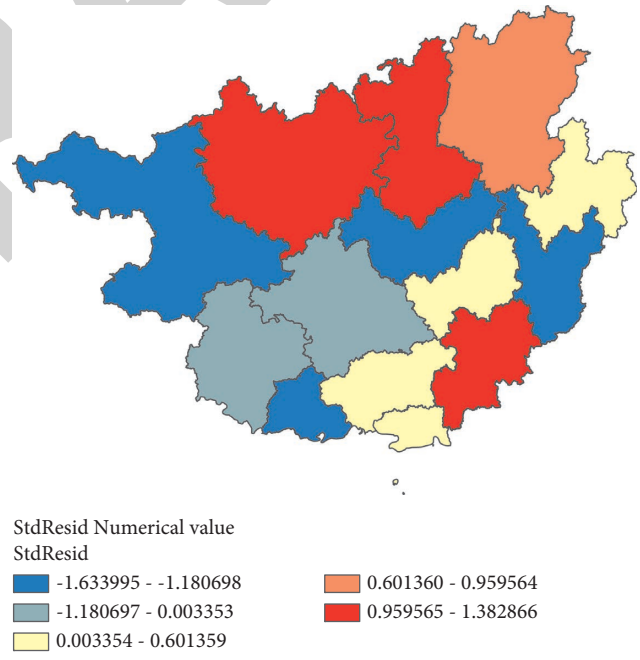

Figure 11: Results diagram of GWR model.

explore the influencing factors of Guangxi's "nongrain" trend. The change rate of urbanization rate, agricultural population, average annual precipitation, average annual temperature, grain production, and grain cultivation area ratio (denoted as "grain production–cultivation ratio"), and total power of agricultural machinery in each city from 2010 to 2018 were selected as explanatory variables. ArcGIS software was used to establish GWR model for geographically weighted regression. The results of the model and the spatial distribution of the regression coefficients of each explanatory variable are shown in Figures 11 and 12.

Using the AIC information criterion method, the parameters of the variable GWR model affecting the trend of "nongrain"cultivated area in Guangxi from 2010 to 2018 are obtained as shown in Figure 11. The overall R^2 value of the model is 0.85, and the goodness of fit of the adjusted model is

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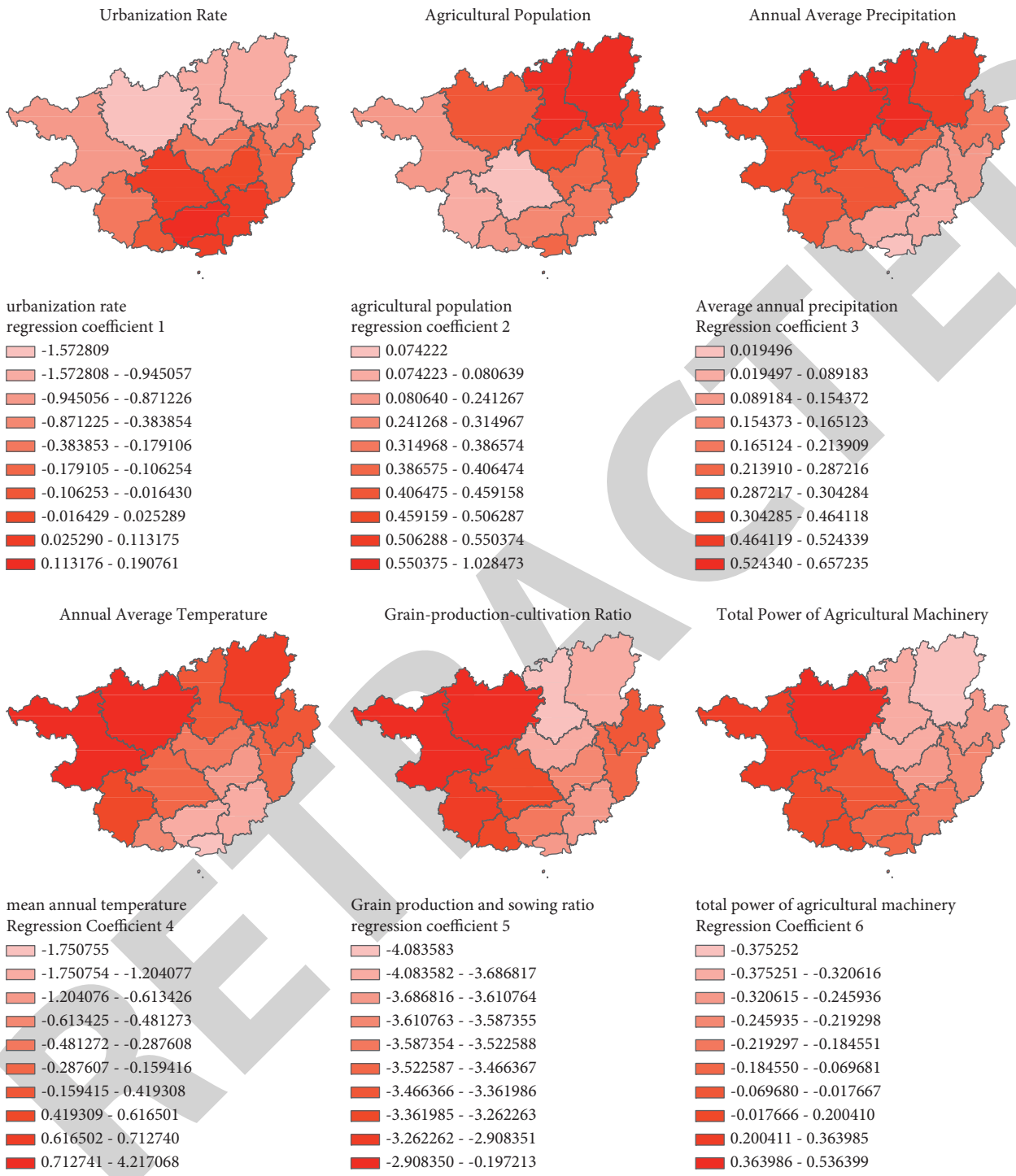

Figure 12: Spatial distribution of regression coefficients of explanatory variables.

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also above 33%, and the standard error of the regression coefficients of each city in the map is less than 1.5, indicating that the entire GWR estimation model can better explain the impact of various variables on the trend of "nongrain" cultivated ratio.

The change of urban urbanization rate can not only reflect the flow rate of urban population but also reflect the speed of economic development of a city. It can be seen from the diagram that the regression coefficient of urbanization rate and nongrain cultivated ratio in Guangxi shows a decreasing trend from south to north, and the cities with positive coefficient show agglomeration in the southern region. Among them, the regression coefficients of the surrounding cities centered in Qinzhou are all positive, indicating that the urbanization rate is positively correlated with the growth rate of nongrain cultivated ratio. When the

urbanization rate increases faster, the trend of "nongrain" cultivated ratio is more obvious. In addition, the regression coefficient of the rest areas of Guangxi is negative, indicating that it is negatively correlated with the growth rate of nongrain cultivated ratio. The faster the urbanization rate increases, the more obvious the inhibitory effect on "nongrain" cultivated ratio, while the values of Hechi and Baise are the lowest, and the inhibitory effect on "nongrain" is the most obvious. It can be seen that since most cities in the southern region are coastal or offshore cities, the current stage of urban economic development is faster than that of inland cities. The improvement of urbanization level can accelerate the transfer of labor force, increase the price of the rural labor force, and reduce the multiple cropping index of grain crops, which reflects the "nongrain" phenomenon.

Changes in agricultural population will also have an impact on changes in urban planting structure and "nongrain" trends. It can be seen from the figure that the change of regression coefficient between agricultural population and nongrain cultivated ratio in Guangxi shows an increasing trend from southwest to northeast, and the regression coefficients are positive, indicating that the growth rate of agricultural population in each city is positively correlated with the growth rate of nongrain cultivated ratio. The faster the growth rate of the agricultural population is, the more obvious the trend of "nongrain" cultivation in each city is. Among them, the coefficient values of Guilin and Liuzhou are the highest, indicating that they have the most obvious effect on promoting the trend of "nongrain" cultivation. However, the regression coefficient of Nanning in the middle and Chongzuo in the southwest is low, which has no obvious effect on promoting "nongrain" cultivation. It can be seen that when the urban agricultural population increases, farmers tend to plant nongrain crops rather than grain crops, which is related to the base and proportion of urban agricultural population. When the urban agricultural population base is small and the proportion is small, the labor force engaged in grain planting has not reached saturation, so agricultural population increases, there are still some farmers who choose to plant grain crops. When the urban agricultural population base is large, the number of farmers engaged in grain planting first reaches saturation. When the agricultural population continues to increase, more farmers will choose to plant nongrain crops, which are also corresponding to the degree of urban economic development.

Urban precipitation and temperature are natural factors affecting crop planting, and their change rates affect farmers' choice of planting behavior, thus affecting the "nongrain" phenomenon. It can be seen from the figure that the spatial distribution of the regression coefficients of annual precipitation and annual temperature is roughly the same, showing an increasing trend from south to north. Among them, the regression coefficients of annual precipitation in each city are positive, indicating that the greater the growth rate of precipitation, the more obvious the trend of "nongrain" area. The regression coefficient of average annual temperature is bounded by the central region and is positive in the northern region of Guangxi, showing the promotion effect on "nongrain" area and negative in the southern region, showing the inhibitory effect on "nongrain" area of cultivation. It can be seen that the influence of natural factors on the trend of "nongrain" cultivation is more spatial in the north–south direction, and the influence mechanism of precipitation and temperature on "nongrain" cultivation area is different. The change of precipitation mainly affects the cultivation of nongrain crops in Guangxi, whereas the change of in temperature mainly affects the cultivation of grain crops in Guangxi. Affected by the unique climatic characteristics, Guangxi is rich in precipitation, and vegetables and fruits need adequate water supply in the process of planting. Therefore, the increased rainfall in Guangxi will make farmers grow nongrain crops in large quantities, especially in Hechi, Guilin, and Liuzhou. Temperature has a significant impact on the crops. As the southern part of Guangxi has a relatively high temperature, when the temperature increases, it will increase the multiple cropping index of farmers, reflecting the effect of restraining "nongrain" cultivation, whereas the cooler northern Guangxi shows the promotion of "nongrain" trend.

The ratio of grain production to total planting area can roughly reflect the grain production efficiency of the year, and the change rate can reflect the improvement or reduction of grain production efficiency. It can be seen from the figure that the regression coefficients of the change rates of nongrain cultivated ratio and grain production–cultivation ratio in each city of Guangxi are negative and show a trend of first decreasing and then increasing from west to east, indicating that the change rates of the two are negatively correlated. This shows that in Guangxi, the higher the grain production efficiency is, the lower the growth rate of nongrain cultivated ratio is, or even negative, thus inhibiting the trend of "nongrain" cultivated ratio. Among them, the absolute values of the regression coefficients of Liuzhou and Guilin in the northeastern region are the highest, and the inhibitory effect is the most obvious. Second is that the central and southern cities also show a strong inhibitory effect. In contrast, the absolute value of regression coefficient in Baise and Hechi in the northwest is the lowest, and its inhibitory effect on "nongrain" cultivation ratio is weak. Cost–benefit is one of the important factors affecting agricultural planting structure, which will have a direct impact on farmers' choice of planting behavior. Although the price of grain crops has still shown a downward trend since 2010, with the improvement of grain production efficiency, the grain yield per unit of sowing area has increased, which makes the income of farmers continue to increase. To a certain extent, it makes up or even covers up the "nongrain" cultivation behavior of farmers that may be caused by the decline in grain prices, and to some extent, it can inhibit the "nongrain" production trend.

The total power of agricultural machinery plays an important role in grain production, and its change rate reflects the total power input in the planting process. It can be seen from the diagram that the spatial distribution of the total power regression coefficient of agricultural machinery is similar to that of grain production–cultivation ratio, and it shows a decreasing trend from southwest to northeast, and

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the regression coefficient in most areas is negative. This shows that the change rate of the total of agricultural machinery in most cities is negatively correlated with the change rate of nongrain cultivated ratio, and has a certain inhibitory effect on the trend of "nongrain" cultivated area. In the negative correlation area, the regression coefficient value of Guilin is the lowest, indicating that it has the most obvious inhibitory effect on "nongrain" cultivated ratio. Cities in the east, southeast, and central regions also have a certain inhibitory effect on "nongrain" cultivated ratio, whereas cities in the west, such as Nanning and Chongzuo, have the lowest inhibitory effect on "nongrain" cultivated ratio. In Hechi and Baise in the northwest and Fangchenggang in the southwest, the regression coefficient is positive, indicating that the more the total power input of agricultural machinery is, the more obvious the trend of "nongrain" cultivated area is, but the effect is not significant. It can be seen that the improvement of the total power of agricultural machinery is more favorable for grain farmers. On the one hand, the extensive use of agricultural machinery can improve the production efficiency of grain crops. On the other hand, agricultural machinery replaces manual labor, which not only changes the mode of grain farming but also reduces the cost of farmers to plant grain, which has a certain role in inhibiting farmers' nongrain cultivation behavior.

4. Conclusion, Suggestion, and Prospect

4.1. Conclusion. Based on the statistical analysis, spatial analysis method, and ArcGIS10.2 statistical spatial analysis tool, this study takes the agricultural statistical data of Guangxi from 2009 to 2019 as the research sample, and comprehensively analyzes the spatial distribution characteristics of "nongrain" cultivated area in 14 prefecture-level cities in Guangxi and the influence degree of various influencing factors on "nongrain" cultivated area in each city, and provides clear spatial visualization results. The conclusions are as follows:

In terms of the general trend of "nongrain" production, the planting area of crops in Guangxi showed a general trend of "nongrain" cultivation from 2009 to 2019, especially from 2014 to 2019. In nongrain crops, the increase of vegetable planting area is the main reason for the "nongrain" trend, and the increase of oil crops planting area also promotes the "nongrain" trend to some extent. In addition, the decrease of planting area of sugarcane and cassava inhibited the trend of "nongrain" to some extent, and the inhibitory effect of sugarcane on "nongrain" was more obvious. In grain crops, the continuous decrease of rice planting area is also the main reason for the "nongrain" trend. Although the maize planting area has a trend of first increase and then decrease, the impact on the "nongrain" trend is not obvious.

In terms of the impact of nongrain crops on the trend of "nongrain" in Guangxi, the cities with rapid growth in the proportion of total nongrain crop planting area from 2009 to 2019 were mainly concentrated in the southeast of Guangxi and decreased along the northwest direction, and the overall growth rate was faster from 2014 to 2019. From 2009 to 2019, the cities with the higher growth rate of oil crop planting area were mainly concentrated in the northern part of Guangxi and decreased along the southern and eastern directions, and the overall growth rate was faster from 2009 to 2014. From 2009 to 2019, the growth rate of sugarcane planting area was negative in most areas of Guangxi and decreased along the northern direction. From 2009 to 2014, the growth rate of cities in eastern Guangxi was positive, while from 2014 to 2019, only Beihai was positive, and the remaining cities were negative, the inhibitory effect on "nongrain" trend was more obvious. From 2009 to 2019, the growth rate of cassava acreage proportion was negative in most regions of Guangxi, and only some southern cities were positive, and decreased along the northwest direction. From 2014 to 2019, the inhibitory effect on nongraining was more obvious. The proportion of vegetable area increased rapidly from 2009 to 2019, with Baise in the west, Laibin in the middle, and Qinzhou in the south growing significantly, and the promotion effect on the trend of "nongrain" was the most obvious.

In terms of the influencing factors of Guangxi's "nongrain" degree, the regression coefficient of urbanization rate to the "nongrain" degree shows a decreasing trend from south to north, and is positively correlated in the southern region, which promotes the "nongrain" trend. The northern region was negatively correlated, inhibiting the trend of "nongrain." The regression coefficient of agricultural population to the degree of "nongrain" decreases from northeast to southwest, and is positively correlated in all regions, which promotes "nongrain." In terms of natural factors, the regression coefficient of annual precipitation to the degree of "nongrain" decreases from north to southeast, and is positively correlated in all regions, which promotes the trend of "nongrain." The effect of annual average temperature on the degree of "nongrain" cultivation was positively correlated in the north and negatively correlated in the south. The regression coefficient of grain production–cultivation ratio on the degree of "nongrain" was negative in all regions, which had an inhibitory effect on the trend of "nongrain," and the inhibitory effect was obvious in the eastern and northeastern regions. The impact of the total power of agricultural machinery on the degree of "nongrain" is positively correlated in southwest China, promoting the trend of "nongrain." There is a negative correlation in the rest of the areas, which inhibit the trend of "nongrain," with the most obvious inhibitory effect in the northeast [15].

5. Suggestion

At present, food security has become one of the hottest issues of global concern. As a big agricultural country, in the context of the increasingly severe trend of "nongrain" in China, how to adjust the planting structure and stabilize grain production requires the central and local governments to formulate effective policies according to local conditions. On the other hand, it requires the academic circles to carry out relevant research on "nongrain" trend to provide theoretical support for the prevention and control of "nongrain" of cultivated land. Based on the above research

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conclusions, the countermeasures and suggestions of this study are as follows:

The state should do top-level design to curb the trend of "nongrain" from the institutional level. On the basis of an overall grasp of the status quo of "nongrain" trend in China, the state should formulate strategic plans for the prevention and control of "nongrain" cultivation pattern from a macro perspective, optimize and adjust the planting structure, and enhance the awareness of government departments and the public on the issue of "nongrain." At the same time, the government should formulate corresponding grain subsidy policies, refine the types of subsidies, and fully stimulate the enthusiasm of farmers. In addition, relevant government departments should make good urban land planning, improve the utilization of idle and abandoned land, protect high-quality cultivated land resources, refine the types of agricultural land, and strictly delimit the scope of permanent basic farmland. Finally, the early warning mechanism of "nongrain" should be established, and the real-time monitoring system of crop planting area covering the whole country should be constructed to monitor and control the trend of "nongrain" in time. It is necessary to improve the "nongrain" supervision mechanism, strictly control, strengthen supervision, and timely punish illegal occupation of cultivated land.

To balance the relationship between urbanization and agricultural population. It has been proved that the rapid development of regional economy will have a certain impact on the regional food production and stability, and balancing the relationship between urbanization and agricultural population is the key to solving the problem. When the process of urbanization is too fast, it will cause the rapid loss of agricultural population, and the lack of rural labor force will cause the phenomenon of "farmland without planting" in rural areas. When the process of urbanization is too slow, a large number of agricultural population accumulation, surplus labor in rural areas will cause the phenomenon of "people without farmland," will also exacerbate the "nongrain" trend. Therefore, it is necessary to balance the process of urbanization and the transfer of agricultural population, pay attention to the internal relationship between regional economic development rate, urban and rural population change and "nongrain," and give some policy attention to agricultural population while steadily promoting urbanization, so as to realize the win-win situation of economic development and curb "nongrain" cultivation trend.

It is necessary to improve the efficiency of grain production and increase farmers' grain income. The state should pay attention to the development of agricultural science and technology, increase investment in research and development, improve the level of mechanization and science and technology of agriculture in China, and improve the efficiency of grain production by increasing grain yield. It is necessary to adjust the planting structure of grain crops, take actions that suit local circumstances, plant high-quality and high-yield grain crops suitable for local production conditions, and improve the overall quality of grain production. Finally, it is necessary to control the investment in the total power of agricultural machinery and the use of fertilizer and plastic film, reduce the cost of farmers' grain production, attract farmers with the improvement of grain level, so as to fundamentally curb "nongrain" and ensure the safety and stability of grain production.

Strengthen exchanges and collaboration among countries to build a global "nongrain" research system. Affected by new coronal epidemics, global warming, and other factors, the reduction of grain production and the northward movement of farming belt will also exacerbate the global "nongrain" trend, which should be paid attention to by all countries in the world. Therefore, on the basis of the research on China' s "nongrain" issue, we should strengthen the relevant academic exchanges among countries, establish professional research teams in various regions, share academic achievements, and empirical research, and build a global "nongrain" research system to maintain the security and stability of world food production.

6. Prospect

Based on statistical data, this study studies the spatial and temporal evolution and influencing factors of "nongrain" in Guangxi from 2009 to 2019. However, this study still has the following shortcomings. First, the scope of the study area is small, which cannot well prove the general relationship between the trend of "nongrain" and various influencing factors. Second, the statistical data is not accurate enough, as the standard for statistical crop acreage changes around 2018 will lead to inaccurate calculations. Based on this, this study presents the following prospects:

Expand research scope on the basis of existing research areas. This study only selects a coastal province in China to explore the trend of "nongrain," and the conclusion is not universal. In future studies, the study area can be expanded to study the trend of "nongrain" in China's inland provinces, China as a whole, Asia, and even the world, and gradually form a research system to explore the trend of "nongrain" in the region.

Strengthening linkages between "nongrain" research and other areas. At present, most of the "nongrain" studies are related to land transfer, and the influencing factors involved are relatively limited. In future research, we can strengthen the research on the relationship between "nongrain" and other fields, such as the impact of policies on the trend of "nongrain," the relationship between the trend of "nongrain" and the ecological environment, and the impact of farmers' psychological willingness to plant on the trend of "nongrain." We can more comprehensively explore the factors affecting "nongrain" and provide more effective countermeasures and suggestions to curb "nongrain."

Data Availability

The statistical data used were taken from CNKI (https://data.cnki.net/) and the "Statistical Bulletin of National Economic and Social Development" of various cities in Guangxi (http://tjj.gxzf.gov.cn/tjsj/tjgb/). The map data were drawn by ArcGIS software using statistical data and the administrative division map of Guangxi and have been sent to the

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Retraction

Retracted: Econometric Analysis of the Hot Research of Marxist Theoretical Journals Based on Knowledge Map

Discrete Dynamics in Nature and Society

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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. Wang and K. Wang, "Econometric Analysis of the Hot Research of Marxist Theoretical Journals Based on Knowledge Map," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 3806576, 10 pages, 2022.

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Research Article

Econometric Analysis of the Hot Research of Marxist Theoretical Journals Based on Knowledge Map

Lan Wang[1] **and Kai Wang**[2]

[1]*School of Marxism, Weinan Normal University, Weinan 714099, Shaanxi, China*
[2]*School of Physics and Electrical Engineering, Weinan Normal University, Weinan 714099, Shaanxi, China*

Correspondence should be addressed to Lan Wang; wanglan@wnu.edu.cn

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In recent years, the research on Marxist theory has received a lot of attention. Many studies use quantitative research methods such as statistical keywords and constructing knowledge map to carry out Marxist theoretical analysis. In this paper, by constructing a self-expanding Chinese word separation and self-expanding address data knowledge graph, matching Marxist Chinese addresses based on the full-text indexing knowledge graph, incorporating a weighted pinyin full-text search mechanism to improve the matching accuracy of misspelled addresses, constructing a multiple matching mechanism for Marxist addresses by combining an online geographic parsing interface, and performing semisupervised matching for a small number of difficult addresses, a complete system of Marxist address matching methods is formed. By studying and analyzing the basic orientation and attention to academic hotspots, we can gain insight into the characteristics, rules, and problems of academic hotspots in Marxist theory journals.

1. Introduction

The term Ecology is derived from the Greek words by Oikos (dwelling or place of living) and Logos (discipline or theory) and is interpreted in its own sense as the science of the habitat of living organisms. This includes both the living and the nonliving environment. Ecology seeks to harmonize human beings with their natural environment. However, human beings depend on the natural environment and are individuals of the social environment. The information environment, consisting of information infrastructure, information resources, information technology, information culture, and information ethics, is an important part of the social environment, which leads to the study of people, social organizations, and the information environment, that is, information ecology [1].

Information ecology is a brand-new research field bred from the integration of information science and ecology, aiming to promote the orderly operation of human and information environment, the balance of information ecosystem, and even the sustainable and healthy development of human society [2–4]. The research method of information ecology is also a forward-looking research and design method, which focuses on the macroscopic examination and analysis of the relationship between information, people, and information environment from the perspective of promoting and maintaining the balance of the whole information ecosystem from the system as a whole and carries out reasonable planning, layout, and regulation of the information ecosystem in order to realize the stability and order of the information ecology [5]. Based on the above explanation, thinking about the relationship between human and information environment from the perspective of ecology is not only important for the field of information management discipline but also has practical significance for its study of today's information society [6].

On the basis of quantitative bibliographic statistics, CiteSpace knowledge mapping software was used to summarize the hotspots of journal concerns in the discipline of Marxist theory. The evaluation of professional journals in the discipline of Marxist theory by four academic evaluation institutions, namely, Chinese Academy of Social Sciences,

Nanjing University, Peking University, and Wuhan University, supplemented by the classification of professional journals in the discipline of Marxist theory by three journal databases, namely, China Knowledge Network, Wanfang, and Vipshop, was integrated to meet the requirements for the analysis of hotspots of attention of journals in the discipline of Marxist theory [7–9].

2. Research Methodology and Sample Selection

2.1. Principles of Coword Analysis. The object of bibliographic research is rooted in the voluminous literature of all kinds. It uses statistical and mathematical methods to quantitatively analyze the characteristics of knowledge carriers on the basis of the "quantitative" output of various types of literature, so as to study and reveal the laws of literature and intelligence, grasp the hot spots of literature research, and foresee the development trend of scientific fields. Bibliolatrous involves methods such as citation analysis, coauthorship analysis, and coword analysis [10]. Coterm analysis is a content analysis technique that analyzes the number of occurrences of a pair of words in the same document, and then clusters these words hierarchically to reveal their affinities and relationships, and then analyzes the structural changes of the disciplines and topics they represent [11–13].

The key to the coword analysis method is the selection of representative words. Since title words, keywords, and subject words are often refined by authors or editors based on the main idea of the article and express the research theme of the field to which they belong, such words are used as the carrier of coword analysis. In addition, because the selected literature involves a large number of keywords and subject terms, the threshold value is often limited according to the frequency of key terms to ensure the representativeness of the field to which they belong [14]. By counting the frequency of high-frequency subject terms and keywords in literature, a word-part coword matrix consisting of subject terms and keywords is formed, which can be analyzed by clustering and multidimensional regression analysis with statistical analysis software and supplemented by visualization analysis software to graphically express the research hotspots-visualization mapping [15–17].

2.2. Selection of Sample Data. The common word analysis is based on the extraction of high-frequency keywords from the literature base. In the Chinese journal full-text database (CNKI), the exact search of journal literature using "information ecology" as the subject term is voluminous, and the selection of all journal literature is not worth the cost in terms of economic and feasibility [18]. On the one hand, CSSCI journals represent a certain academic influence, and their publications have academic influence; on the other hand, the purpose of this study is to trace and prospect hot topics, so the time interception of the literature is the latest decade. In order to ensure the reliability of the hot topics of "information ecology", 6 nonacademic documents such as notices and news reports were deleted, and finally, 500 documents were selected as the research sample, and the information was listed in the "Document Management Center" of China Knowledge Network. We downloaded the title information of these documents into the local literature database [19–22].

As shown in Figure 1, Marxist theory journals focused heavily on the 18th Party Congress, a major political event. "Scientific outlook on development", "Marxism Chineseization", "General Secretary Hu Jintao", "reform and opening up", "common prosperity" and "common wealth". The keywords "socialism with Chinese characteristics", "scientific development outlook", "Marxist Chineseization", "General Secretary Hu Jintao", "reform and opening up", "common prosperity", and "18th National Congress" are directly related to the 18th Party Congress held in this year. Other keywords such as "socialist core value system" and "ecological civilization construction" are also intrinsically related to the 18th Party Congress [23].

3. Matching Based on Self-Extending Knowledge Graphs for Full-Text Search

3.1. Semisupervised Splitting Method. Whether building Chinese full-text indexes or preprocessing source addresses, credible Chinese word separation methods are needed. In this paper, we combine the advantages of lexical word separation and statistical-based word separation methods to avoid a large amount of training and huge dictionary construction requirements by using statistical word separation models on the one hand and to expand the dictionary on a rolling basis based on correctly identified data and threshold judgment mechanism on the other hand. The basic dictionary consists of short name data of national townships and above, administrative regions and enterprise suffix words, and data tables of petrochemical enterprise information in Ningbo [24], and the structure of the dictionary is as follows:

$$\{v_i = (w, f, t)\}, \tag{1}$$

where $i \in \mathrm{N}$, v_i denote the i-th word, and w, f, and t denote the address short name, word frequency, and the word nature, respectively. When building the basic dictionary, the word frequency is set to 10 by default, and the subsequent successful word separation results and matches will be increased automatically by the program. Only three types of lexical properties are considered in the basic dictionary, namely, ns (place name), hm (enterprise, mainly chemical plant), su (suffix words, such as province, city, district, autonomous region, limited company, and other place name) [25].

The prefix dictionary, TRIE dictionary tree, which is a type of hash lookup tree, is constructed before the word division to enable fast dictionary lookup. The DAG is stored in the form of a dictionary with the following structure:

$$\{P_i\colon\ [n_a + n_b, \cdots, n_x]\}, \tag{2}$$

where $i, a, b, \cdots, x \in \mathrm{N}$. P_i denotes the index of the i-th word in the input address and n_a denotes the end position of the a-

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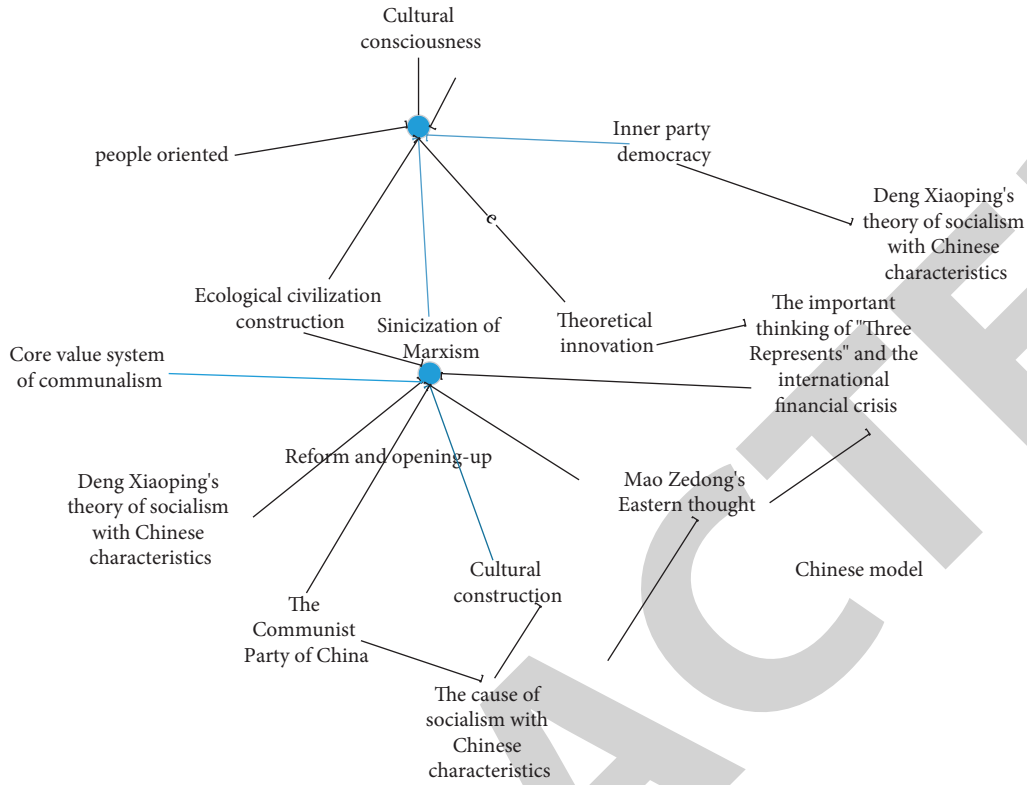

Figure 1: Keyword mapping of Marxist theory journals.

th divisor of P_i as the prefix that has a word frequency greater than 0. Thus, the DAG records all possible cuts of the input address, and the next step is to find the path with maximum probability based on dynamic programming. The probability of each word is equal to the frequency of the word in the prefix divided by the sum of all word frequencies; if the word frequency is 0 or does not exist, it is set to 1. The probability of each word is calculated as follows:

$$p_j = p_{j,a} \times p_{j,\mathrm{b}} \times \cdots \times p_{j,\mathrm{x}}, \tag{3}$$

where $j, a, b, \cdots, x \in \mathrm{N}$, p_j denotes the probability of the jth cut or the jth path, and $p_{j,a}$ denotes the ath word frequency in the jth path. To facilitate the calculation, the above equation is taken logarithmically to obtain

$$\log p_j = \log p_{j,a} + \log p_{j,\mathrm{b}} + \cdots + \log p_{j,x}. \tag{4}$$

In the Marxist address text, the semantic focus comes first, and the dynamic programming method is used to calculate the probabilities of all paths from front to back and select the path with the highest probability among them, that is, to obtain the better partitioning result applicable to the current dictionary [26, 27]. Since the basic lexicon already has more complete data, the above process can already get the correct word separation results for most of the input. In order to make up for the shortcomings of the basic dictionary, we set a minimum probability threshold of $P_{\min}$ in this paper, so that the cut score result for any input address has

$$\max\left(\log p_j\right) < P_{\min}. \tag{5}$$

Then, the input address is recorded, the word is manually split, and the valid result is added to the dictionary and inserted at the end of the address to be split. If an invalid address is detected, the address is marked as invalid. Based on the calculation of the maximum $\log p_j$ for 1000 groups of words, $P_{\min}$ is set to 80 based on a semisupervised intervention rate of 2%.

3.2. Full-Text Search Matching Score Mechanism. The full-text search matching score mechanism is built based on TF-IDF (term frequency-inverse document frequency) [28] technology to calculate the matching relevance of full-text search results, and the scoring function is calculated as follows:

$$s(q, \mathrm{d}) = \mathrm{N}(q).\mathrm{coord}(q, \mathrm{d}).(tf(t\mathrm{ind}).idf(t).\mathrm{norm}(t, \mathrm{d})), \tag{6}$$

where q and d are the text of the query and the matching documents, and $N(q)$ is a predefined normalized query statement, which usually has no effect on a particular query application. $\mathrm{coord}(q, \mathrm{d})$ indicates the number of query responses in a document, and the more query items appear in a document, the better the query matches the document, which is mainly used in a multicriteria query environment. In the address query, the successful query results can be used to build a perfect syllogism dictionary to convert a single query into multiple queries to improve the matching accuracy of q [29].

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idf denotes inverse document frequency (IDF), which is calculated as follows:

$$idf(t_i) = \log \frac{|D|}{\left|\left\{j: t_i \in d_j\right\}\right|}, \tag{7}$$

where D is the number of documents and $|\{j: t_i \in d_j\}|$ denotes the total number of words t_i in the document d_j. The fewer the occurrences of a word in a single document or more documents it appears in, the higher the relevance of the match, which can exclude the influence of various dummy words to some extent. In addition, this element indicates that a certain address gets a higher matching rate when it appears in more entities, so the later section will keep using the successfully matched addresses to extend the knowledge graph in the process of constructing the knowledge graph, so that the probability of partially matching the wrong address by chance decreases as the matching process proceeds.

norm(t, d) denotes the field length normalized value, which is related to the result of word separation and can generally be reduced to the reciprocal of the square root of the number of words, implying that the full-text search gives priority to matching long fields, so the long address fields will be established later in the process of building the knowledge graph to improve the success rate of address search and matching.

3.3. Knowledge Graph. Knowledge graphs are structured semantic knowledge bases that can well describe concepts and interrelationships in the physical world. The following are some of the new types of entities that are created in the updated knowledge graph: factory, chemical company, and others [30].

According to the research of the full-text search for matching score mechanism, in order to improve the accuracy of address matching, the knowledge graph is constructed according to the fields as shown in Table 1.

In order to correctly parse the address misspellings in hazardous chemical manifest addresses, this paper establishes a field corresponding to the phonetic field with tone to obtain credible search results. In order to obtain more accurate address matching for full-text search, the knowledge graph is constructed by taking into account the influence of the full-text search for matching score calculation function on the full-text indexing results, and the detailed address field location is designed in this paper. The location field and short_location field enable the full-text address search to better avoid matching the wrong renamed addresses [31].

The relationships between the knowledge graph entities include the dependent belong, which is expressed as

$$a - [rel: \text{belong}] - > b, \tag{8}$$

where a and b denote entities, rel is a sign word indicating the relationship, belong indicates that the relationship is subordinate, and the arrow indicates the direction of the relationship. In the critical transport address analysis, the navigation distance relationship between cities is also involved:

Table 1: Knowledge graph field information table.

	Corresponding phonetic field	Explain
Name	Pinyin	Address name
Short name	Short pinyin	Desuffix
Index name	Short index	Custom index name
Code	—	Administrative region code
Location	Location pinyin	Normalized address
Short location	Short location pinyin	Desuffix specification address

$$a - [\text{rel: distance}] - b, \tag{9}$$

where $a, b \in$ (city) is the combination of all entities of type city. The distance relationship does not need to define the direction. Its value is the navigation distance between the city center coordinates calculated using the Gaode Map navigation API.

After the basic knowledge graph is established, this paper constructs full-text indexes for Chinese and Pinyin based on the full-text search matching score mechanism described in Section 2.2 for all entities in the knowledge graph, where the Chinese index uses the semisupervised word separation method described in Section 2.1, and the Pinyin index uses a simple space (unicode-whitespace) word separation method.

3.4. Full-Text Search Is Applied to Address Matching. There are generally two Chinese data items in the single address data of the electronic waybill for hazardous chemicals, one is the actual address and the other is the enterprise address. The actual address is more reliable information, while the enterprise address has limited reliability, and only when the actual address cannot be matched, the enterprise address is used for address search.

The value of match score for full-text search results is calculated as follows:

$$\text{score} = w_a S_a + (1 - w_a) S_c. \tag{10}$$

Among them, S_a and S_c are the full-text search matching scores of the actual address and enterprise address, respectively; w_a is the weight, and this paper mainly takes the matching result of the actual address as the basis, so the value is set to 0.8. S_a, S_c the calculation method is as follows:

$$S = S_{\text{kanzi}} \times w_{\text{hanzi}} + S_{p_{inyin}} \times (1 - w_{\text{hanz}}). \tag{11}$$

S_{kanzi} and $S_{p_{inyin}}$ are the matching score obtained by Chinese and Pinyin full-text search, respectively, and w_{hanz} is the weight of Chinese full-text search score, set to 0.8. If the full-text search returns empty results, the score is set to 0.

Limited by multiple safety factors such as high-speed control and parking restrictions for dangerous goods, long-distance transportation of dangerous goods accounts for a relatively small percentage. The distance adjustment coefficient is added in the calculation of the matching degree value, which is calculated as follows:

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$$S_{\text{after}} = S_{\text{before}}.\theta. \tag{12}$$

Among them, S_{after} and S_{before} are the full-text search matching scores before and after adjustment, respectively, and θ is the distance adjustment factor. The calculation is as follows:

$$\left\{C_i\colon \left\{l_{i,1}\colon s_{i1}, l_{i,2}\colon s_{i,2}, \cdots, l_{i,n}\colon s_{i,n}\right\}\right\}, \tag{13}$$

where C_i denotes the i-th city, $l_{i,n}$ denotes the n-th full-text search result address belonging to C_i, and $s_{i,n}$ denotes the full-text search matching score corresponding to $l_{i,n}$. Let

$$\begin{aligned} \overline{s} &= \text{aver}\left(s_{i,1}, s_{i,2}, \cdots, s_{i,n}\right), \\ s_{\max} &= \max\left(s_{i,1}, s_{i,2}, \cdots, s_{i,n}\right). \end{aligned} \tag{14}$$

Let m denotes the number of $s_{i,1}, s_{i,2}, \cdots, s_{i,n}$ s greater than $\overline{s}$, and then, the matching score of city C_i is calculated as follows:

$$S\left(C_i\right) = s_{\max} \cdot \frac{2m}{n}. \tag{15}$$

As can be seen from the above equation, the greater the number of matched results and the larger the score, the greater the $S(C_i)$ is and the higher the error tolerance for partial accidental mismatches. The final matching result is $S(C_i)$.

If $s_{i,n} \leq 3$, then the match is considered invalid, the address is skipped, and the address is added to the geographic resolution interface of Baidu or Gaode Maps, and the search result is confirmed only if the results output by the two major service providers is consistent; otherwise, it is added to the address to be supervised for classification. If $s_{i,n} > 3$, then the matching result is entered, the word frequency of the subword dictionary is updated, and the result to the knowledge graph to form a new entity is pushed.

The function of θ coefficients is plotted in Figure 2.

The adjustment factor is close to 1 for d values less than 500 km, which has almost no effect on the matching score, and then decays exponentially, and the true score converges to 0 for matching to transport destinations larger than 2000 km.

In order to reduce the redundancy, only the top 10% of the results are retained in each query. In order to further reduce the impact of matching to districts and counties with the same name or similar names and to reduce the impact of incorrect word separation results, this paper clusters the matching results by city and obtains the following output in the form of a dictionary.

In summary, the techniques used in this paper are summarized in Figure 3. As shown in Figure 3, the Chinese address syllabification technique is not only applied in the construction and extension of the knowledge graph update but is also a necessary technique for the full-text search and matching of Chinese addresses. Chinese address full-text search technology is applied to the knowledge graph to both accurately identify the input addresses and automatically expand the knowledge graph. The specific flow of complete address search and matching is shown in Figure 4.

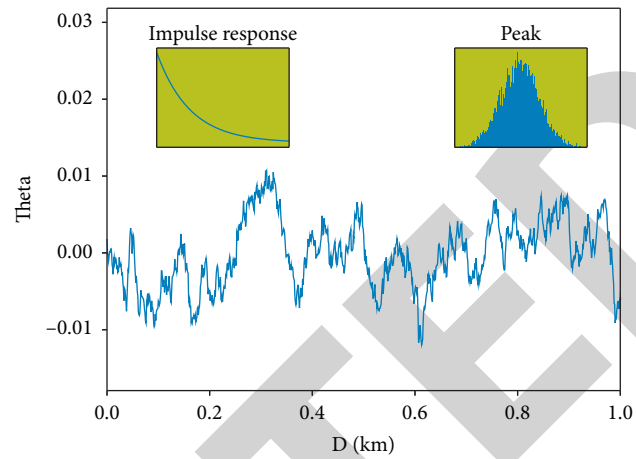

Figure 2: Adjustment factor function.

4. Results

4.1. Multidimensional Scale Analysis. The core idea of multidimensional scale analysis is dimensionality reduction, and the connection between research objects is expressed as a flat distance, which is transferred to coword analysis; that is, the degree of closeness between keywords or subject words is reflected as flat distance. In multidimensional scale analysis, the research objects are represented as points, and the objects with close connection will be clustered into a class group, and the core states objects will be in the middle of the class group. In this paper, we use spss21.0 statistical analysis software to reduce the dimensionality of the information ecology coword dissimilarity matrix and use the multidimensional scale (ALSCAL) tool in the scale function to generate the visual knowledge map as shown in Figure 5.

The two-dimensional analysis map of multidimensional scale analysis is basically consistent with the knowledge map of cluster analysis, but there are new content structure features. As shown in Figure 5, the information ecology high-frequency keywords are clustered and distributed into four more concentrated clusters. According to the internal keyword meanings and characteristics of each cluster, the clusters are divided into the first quadrant in clockwise order, information ecology chain formation mechanism and e-commerce, information library and business website, network information ecosystem evaluation and balance, and information ecology and education informatization. Multidimensional scale analysis mapping is a reaggregation of the cluster analysis mapping. In general, the first quadrant of the multidimensional scale analysis mapping has closely linked themes and is in the center of the research network; the second quadrant has a looser theme structure and has further potential research value; the third quadrant has a tight and structured theme, and there exists formal research by related institutions, but it is at the edge of the research network; the fourth quadrant is less important and is at the edge of the research network [6].

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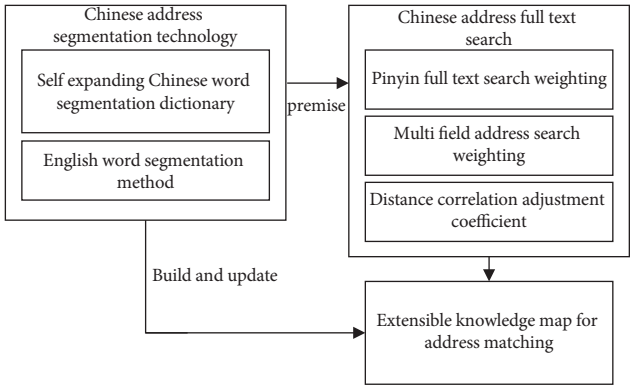

Figure 3: Technical route.

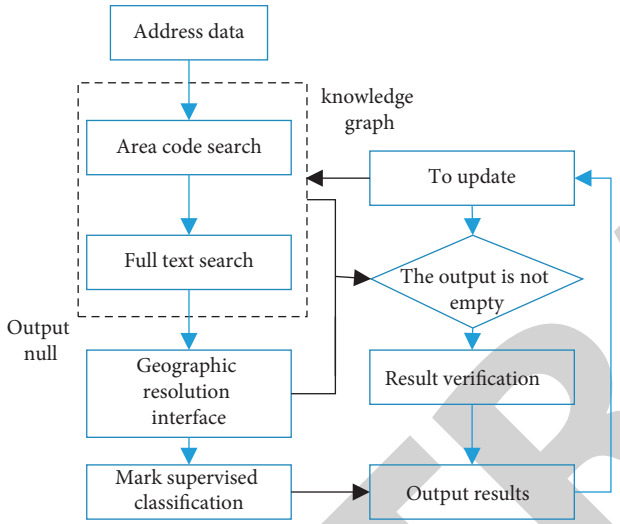

Figure 4: Address matching process.

4.2. Social Network Analysis. The social network approach is a social research method that expresses the interaction between social actors in the form of a network map. Social networks are collections of nodes and links. Nodes symbolize actors of social networks, people, places, and institutions that can be regarded as social actors, and links represent connections among actors of social networks. In the common word analysis, keywords and subject words play the role of social actors, and they appear in the same article as links between each other and are expressed in the form of links. Generally speaking, the higher the frequency of keywords and keywords in the same document, the more closely they are linked to each other, and the more dense the social network visualization map will be [32].

According to the analysis of social network centrality, the knowledge map shown in Figure 6 is formed, and the connection between nodes is the co-occurrence relationship of the original matrix, and the size of nodes is proportional to the frequency of co-occurrence network keywords and network status, and the thickness of the connection indicates the strength of keywords.

Social network centrality analysis clarifies the general overview and the internal structure of information ecological themes with the help of quantitative indicators such as network density and central potential. Network density reflects the closeness of network members' connection, and the greater the density, the closer the relationship between network members [7]. In terms of its value, the more the network density tends to be close to 1, the more closely connected the network is. The analyzed data show that the co-occurrence network density is 0.4319 with a standard deviation of 1.32, which is a good density and significant frequency difference. However, if only relying on the network density does not give an interpretation of the degree of density of social network ties, this paper uses the central potential of the social network graph as a supplementary variable of network density. The central potential is the overall principle aggregation degree evaluation, and the central potential of the common word network degree value is 37.89%, which shows that there is a concentration trend of the network. In addition, the graph clearly shows the centrality of information ecology and information ecosystem.

The degree centrality of a point is the number of points in the social network that is directly connected to other members. In other words, if a node has established direct connections with many nodes, then that point is considered to have a high degree of point centrality. The analysis results show that the top eight of degree centrality are information ecosystem, information ecology, information ecological chain, information ecological niche, operation mechanism, library, theoretical research, and information ecological environment, which are also well reflected by the size of node area. Through the analysis of the social network information ecology map, it can be concluded that the existing research field of information ecology presents a relatively decentralized pattern. For example, in addition to these hot topics such as information niche and library, other relevant research concerns are relatively scattered.

4.3. Integrated Perspective Information Ecology Analysis. Based on the above clustering analysis, multidimensional scale analysis, and social network analysis knowledge mapping expression, the information ecology research themes and content structure can be presented, but each of the three types of mapping has shortcomings only for a certain method, so it is more rigorous and scientific to combine the information of the three types of mapping to present. Cluster analysis mapping aggregates nine categories of information ecology, but the drawback is that it follows the criterion of unique attribution and fails to express the connection with other categories of keywords; multidimensional scale analysis aggregates four categories of research themes and presents location information, but the strength of connection among keywords is not expressed; social network analysis mapping presents the content connection and strength among keywords but does not take into account the clustering analysis categorization. Therefore, based on the above three analyses and asking relevant experts and scholars in the field of information ecology, I manually reorganized the keywords in the field of information ecology research in

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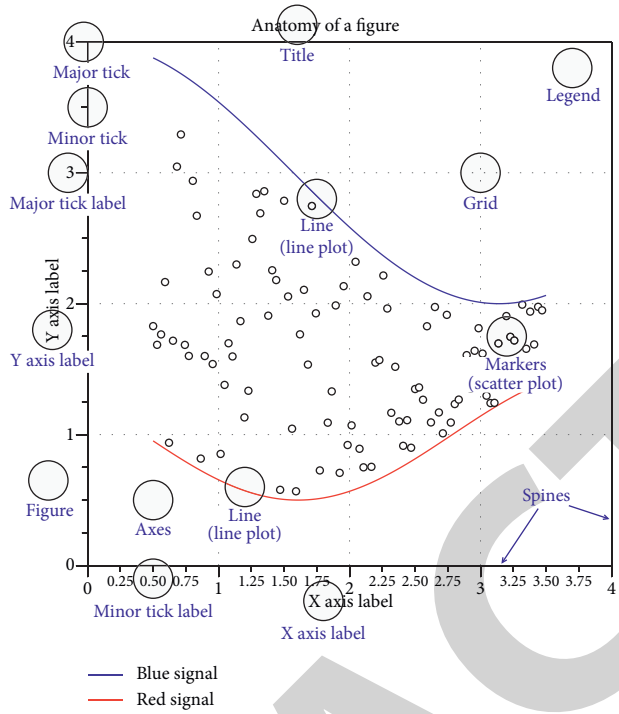

Figure 5: Multidimensional scale analysis mapping.

China and formed the social network mapping of high-frequency keyword reclustering in a comprehensive perspective as shown in Figure 7.

The mapping results in Figure 7 show that the core keyword of the information ecology research theme is "information ecology", which is not only the logical starting point of this paper but also describes the disciplinary affiliation of information ecology and radiates all aspects of information ecology research. The core keyword is surrounded by four research areas composed of closely related keyword clusters, each of which has a relatively key core vocabulary representing such cluster themes. By using the results of cluster analysis, multidimensional scale analysis, and social network analysis, the research fields are integrated with a comprehensive vision, showing "information ecology" as the core, "information ecosystem" as the auxiliary, "information ecological chain ", "information ecological niche", "information ecological environment" as the main direction of the three-level research trend.

4.4. Knowledge Graph Construction Effect. Based on the keyword mapping of Marxist theory journals in 2013 (Figure 8), the focus of attention of Marxist theory journals was on the propagation and study of the spirit of the 18th Party Congress. This year was the 120th anniversary of Mao Zedong's birth, and the study of Mao's thought became a hot topic. It was also a year when the propaganda and research on the Chinese dream were widely carried out. As an integral part of the propagation and study of the spirit of the 18th CPC National Congress, these two major topics became the focus of attention of Marxist theory journals in this year.

Based on the keyword mapping of Marxist theory journals in 2014 (Figure 9), hotspots of interest in 2014 were the comprehensive deepening of reform.

Interviews are also one of the main methods used by journals to conduct research on the comprehensive deepening of reform. For example, Issue 1 of Scientific Socialism features Professor Yan Jirong, Director of the Department of Political Science, School of Government Management, Peking University, and Researcher He Zengke, Director of the Department of World Development Strategy, Central Compilation and Administration Bureau, on "What is national governance and its modernization? Why should we promote the modernization of national governance? How to promote the modernization of the national governance system and governance capacity? The researcher discussed in depth such questions [33].

Based on the keyword mapping of Marxist theory journals in 2015 (Figure 10), the hot topic of attention in 2015 was the comprehensive and strict governance of the Party. Since the 18th Party Congress, General Secretary Xi Jinping has put forward many new ideas and requirements from the aspects of "what is a comprehensive and strict governance of the Party", "why a comprehensive and strict governance of the Party", "how to achieve a comprehensive and strict governance of the Party". In December 2014, General Secretary Xi Jinping emphasized the strict comprehensive governance of the party during his research in Jiangsu. In December 2014, General Secretary Xi Jinping emphasized the comprehensive and strict governance of the party during his research in Jiangsu.

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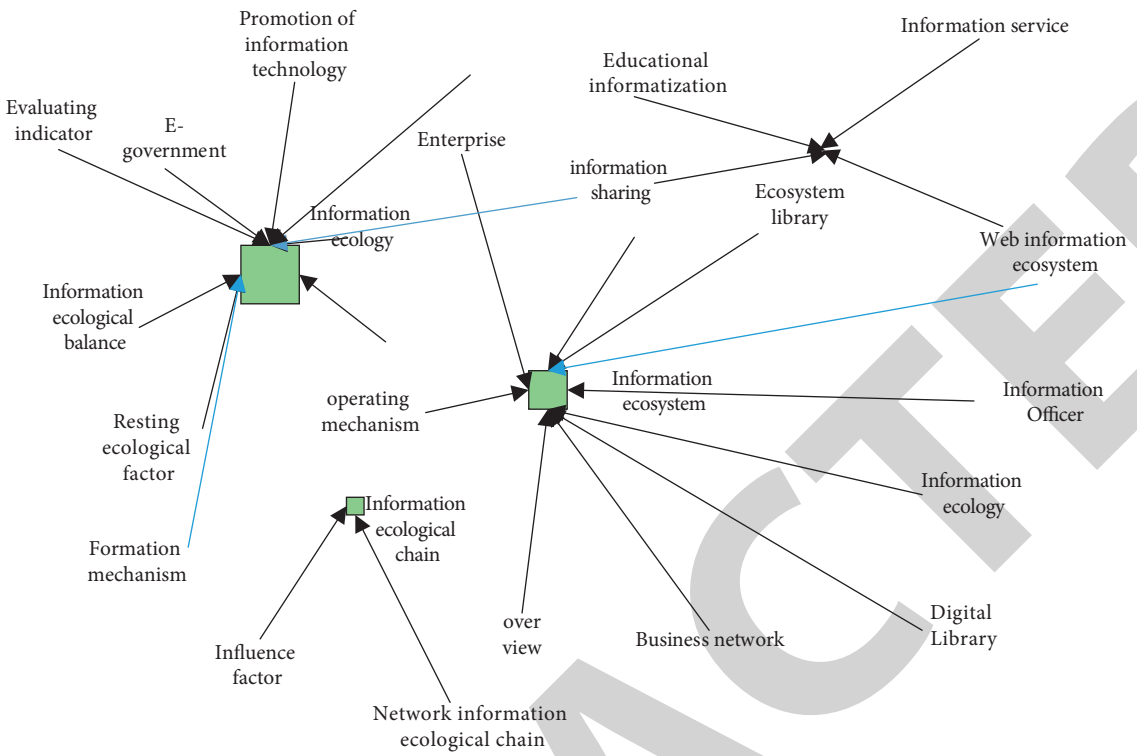

Figure 6: Social network analysis knowledge map.

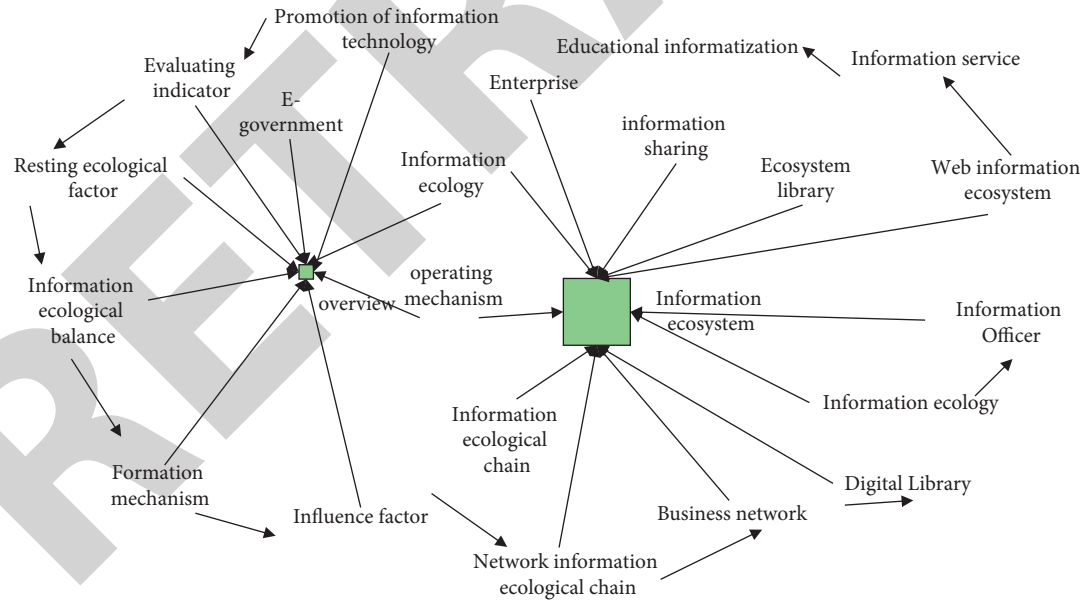

Figure 7: Knowledge mapping of information ecology research from an integrated perspective.

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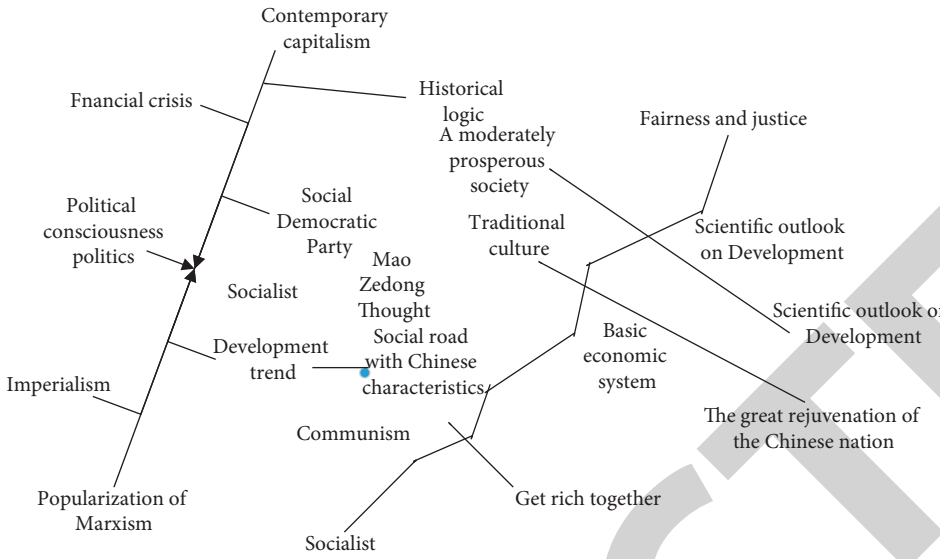

Figure 8: Keyword mapping of Marxist theory journals in 2013.

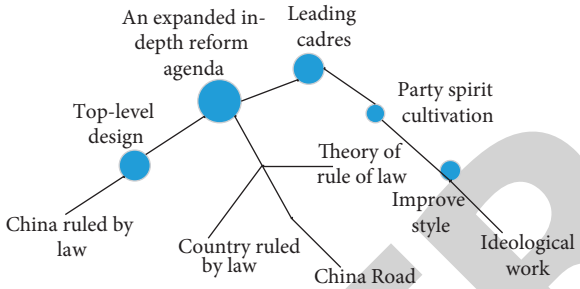

Figure 9: Keyword mapping of Marxist theory journals in 2014.

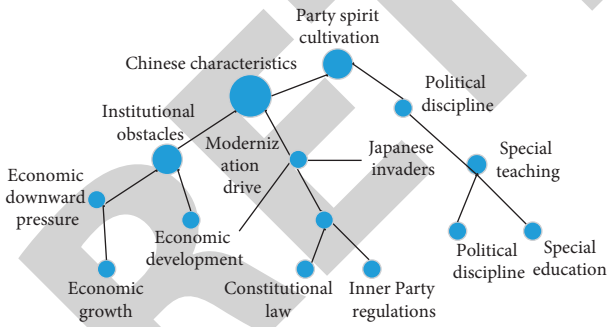

Figure 10: Keyword mapping of Marxist theory journals in 2015.

5. Conclusions

Using bibliographic coword analysis methods and related visualization techniques, this paper depicts the knowledge map of domestic Marx research in recent years and outlines the overall situation of domestic information ecology. The relevant themes are explored based on qualitative and quantitative analyses, which are of great significance for the development of the discipline. The key hot spot in the Internet era is information transfer, and the current information ecology research has shown networked features, with high-frequency keywords expressing information ecology networked combination, such as networked information ecosystem and networked information ecological chain. However, combining of mapping and literature shows that information ecology research in the network era has not yet entered the standardized research stage, and more theoretical and applied research only stays in the networked era background and information ecology superficial concept combination, and its related mechanism and operational characteristics still need the deep deduction.

Data Availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Coupling Coordination Degree Measurement and Forecast of Poverty Alleviation, Energy Conservation, and Ecological Protection: Evidence from 30 Provinces and Cities in China

Shuai Guan [1] **and Qichun Zhang** [2]

[1]*School of Public Administration, Faculty of Political Science, Central China Normal University, Wuhan 430019, China*
[2]*Institute of China Rural Studies, Faculty of Political Science, Central China Normal University, Wuhan 430019, China*

Correspondence should be addressed to Qichun Zhang; 1019061260@qq.com

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As China experiences rapid economic development, tasks involving poverty alleviation, energy conservation and ecological protection need to be addressed. Whether poverty alleviation, energy conservation and ecological protection in China have coordinated development has become a question worth studying. Based on the coupling coordination degree model and the GM (1, 1) model, this paper calculates and forecasts the development level of poverty alleviation, energy conservation and ecological protection of 30 provinces (cities) in China and analyses the synergy of the three systems spatially and temporally. The results show that first, from 2010 to 2019, the development level of China's poverty alleviation system, energy conservation system and ecological protection system presented increasing trends, but regional differences could be seen in development trends. Second, the coupling coordination degree of the three systems in China showed an upwards trend. The average coupling coordination degree of 30 provinces (cities) rose from slight coordination in 2010 to moderate coordination in 2019. Third, in the following years, development level will still be on an upwards trend in the four regions of China from 2020 to 2025. The development level of the ecological protection system will be the highest in China, and poverty alleviation and energy conservation will rank second and third. Fourth, the coupling coordination degree of the three systems of 30 provinces (cities) in China will rise significantly, indicating that the development of the three systems in China will be more coordinated in the following years.

1. Introduction

Since the reform and opening up in the late 1970s, China's economy has developed rapidly. According to the National Bureau of Statistics, China's GDP exceeded 100 trillion yuan in 2020, making it the world's second largest economy. Scholars believe that China's economy was in an extensive development stage in recent years, which depended on factor input and fossil energy consumption [1] that has caused ecological and environmental deterioration [2]. Meanwhile, according to the 3% threshold set by the World Bank, China has already eliminated abject poverty [3]. However, the Gini coefficient of Chinese residents' income has been above 0.4 for a long time [4], which means that the challenge of relative poverty remains to be addressed. With rapid economic development, China needs to address the tasks of poverty alleviation, energy conservation and ecological protection. Whether poverty alleviation, energy conservation and ecological protection in different regions of China have coordinated development has become a question worth studying.

Research on the relationship among the economy, energy and ecological environment has evolved from the dual system of economy and ecological environment, economy and energy, and energy and ecological environment to the multisystem. The famous environmental Kuznets curve (EKC) [5] is used to show the inverted U-shaped relationship between the ecological environment and economic

development [6]. Scholars have analysed the relationship between environmental pollution and residents' income through the EKC and found that when in the low-income level, people would rather sacrifice the environment to pursue higher income, but when at the high-income level, people's tolerance of environmental pollution decreases [7]. In terms of the relationship between the ecological environment and energy, scholars have reached a consensus that the increase in energy consumption and the problem of energy consumption structure have aggravated ecological environmental pollution [8–10]. In terms of the relationship between the economy and energy, scholars have found that socioeconomic factors are direct and important factors that affect residents' energy choice through the energy ladder hypothesis. With the improvement of economic development and the increase in income, household energy consumption will gradually shift to clean and efficient modern low-carbon energy [11–13]. In addition, with more in-depth research, scholars found that there have been interactions among multiple systems and began to study the relationship among the economy system, energy system and ecological environment system, thus forming the 3E (Economy-Energy-Environment) system theory. Research on the 3E system mainly focused on the measurement of its coordinated level, and the methods of the coordination level mainly include the analytic hierarchy process method [14], principal component analysis method [15], entropy weight method [16], data envelopment analysis method [17], and fuzzy comprehensive evaluation method [18]. For example, Zhu and Wang [19] demonstrated the feedback among the economy, resources and ecology environment through the system dynamic production model and explored the sustainable development capacity of Jiangxi, China. Wang et al. [20] used the entropy weight method to establish the capability evaluation index system and measured the regional sustainable development capacity of Shandong, China. Scholars also studied the key influencing factors of the coordination development of the 3E system. Wu and Ning [21] combined a system dynamics model and geographic information system to analyse the 3E system both temporally and spatially, which explored the interaction of economics, energy, and the ecological environment and the effects of key influencing factors. Zhao et al. [22] constructed a 3E system model based on the theory of system dynamics and studied the internal operation mechanism of the carbon emissions trading system and its impact on the 3E system of the Beijing-Tianjin-Hebei region.

By reviewing the above studies, we found that most of the existing studies focused on the relationship among economic development, energy conservation and ecological protection systems, while few studies focused on poverty alleviation, energy conservation and ecological protection systems. The economic development of a region does not equal poverty alleviation. Poverty was initially defined as an economic phenomenon, a condition in which the income of an individual household does not meet the basic standards of living [23]. With socioeconomic development, the definition of poverty has gradually shifted from the shortage of an economic income to a multidimensional measurement, including the lack of access to basic education, medical care, housing and other social deprivations [24–26]. Therefore, based on studies of the relationship of the 3E system, this paper builds a poverty alleviation indicator system using an economic development indicator, income indicator, education indicator, medical and health indicator and public service indicator. The coupling coordination degree model and the GM (1, 1) model were used to measure and forecast the development level of each system and the relationships between poverty alleviation, energy conservation and ecological protection systems to analyse the coordination degree of the four major regions in China spatially and temporally, thus promoting high-quality development in the poverty alleviation, energy conservation and ecological protection of China.

2. Study Area and Data

2.1. Study Area. To formulate long-term national development plans, regional policies and services, China is divided into four major regions: the eastern region, northeast region, central region, and western region [27]. To observe the results of the study, we selected 30 Chinese provinces (cities) and divided them into four regions. The eastern region includes ten provinces (cities): Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan. The northeast region includes three provinces: Liaoning, Jilin, and Heilongjiang. The central region includes six provinces: Shanxi, Henan, Hubei, Hunan, Anhui, and Jiangxi. The western region includes twelve provinces (cities): Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Inner Mongolia, Ningxia, Xinjiang, and Tibet. Due to the unavailability of data from Tibet, the sample for statistical analysis does not include Tibet. This paper separately calculates different provinces (cities) or regions for a more convenient analysis.

2.2. Data Source. To ensure the study's authenticity, integrity, and continuity, all data used for this paper are from the China Statistical Yearbook (2011–2020), China Energy Statistical Yearbook (2011–2020), China Statistical Yearbook on Environment (2011–2020), China Health Yearbook (2011–2020), and the official website of the National Bureau of Statistics (http://www.stats.gov.cn/).

2.3. Index Selection. Researchers have studied poverty alleviation [28], energy conservation [29], and ecological protection [30] and presented different evaluation indicators. Among them, Xin et al. [31] evaluated poverty alleviation from two aspects, infrastructure perfection and residents' living standards. Qin et al. [32] used poverty alleviation pressures, poverty alleviation inputs, and poverty alleviation effects and fifteen basic indicators to evaluate the poverty alleviation system. In terms of energy conservation, Wang et al. [33] established an indicator system based on three input indicators, one good output indicator, and four bad output indicators to estimate energy-environment efficiency. Yan et al. [34] used six indicators to build up the

energy system, such as primary energy production, primary energy consumption, energy intensity index, net energy imports, and carbon dioxide emissions. Regarding the ecological environment, Liu et al. [35] studied the ecological environment from three aspects with seven basic indicators, such as total water resources, the green coverage rate of built-up areas, green areas, and household garbage harmless disposal rates. Liao [36] established an ecological environment system with two targets: ecological environmental pollution and ecological environment management. Based on the research above and considering data availability and regional situation, we establish a comprehensive evaluation index system including three parts: the poverty alleviation index, energy conservation index, and ecological protection index. The detailed explanation of the three parts is as follows:

2.3.1. Poverty Alleviation System Index Selection. The poverty alleviation system index includes three scales: the economic development scale, livelihood scale, and social security scale. First, the economic development scale adopts per capita GDP, ratio of the output value of the service industry, and gross industrial output value. The per capita GDP reflects the overall level of economic development, and the ratio of the output value of the service industry and gross industrial output value are used to reflect the promotion of economic growth. Second, the livelihood scale adopts the per capita disposable income of the urban population, which reflects the livelihood of the urban population. Third, the social security scale adopts fiscal expenditures on public services, total retail sales of consumer goods, the student-teacher ratio of primary schools, the number of medical staff, and the number of beds in health care institutions. Fiscal expenditure on public services and total retail sales of consumer goods reflects the structure of social security, and the student-teacher ratio of primary schools, number of medical staff for every 10000 people, and number of beds in health care institutions for every 10000 people reflects the situation of social security.

2.3.2. Energy Conservation System Index Selection. The energy conservation system index includes four scales: energy security pressure, energy supply and demand state, energy system impact and energy development response. First, we use the ratio of energy consumption per GDP to reflect the energy security pressure scale, which combines energy pressure with economic development. Second, the energy supply and demand state scale adopts the energy supply and demand rate, fossil energy production share, growth rate of total energy consumption, and fossil energy consumption share. These indicators reflect the current situation and development of China's energy supply and demand, and the indicators of fossil energy production and consumption reflect the development of nonrenewable energy. Third, the energy system impact scale adopts energy consumption elasticity. Finally, we use the proportion of electrical energy to reflect the energy development response, which could provide a decision-making reference for the sustainable and healthy development of energy consumption and utilization.

2.3.3. Ecological Protection System Index Selection. The ecological protection system index includes three scales: ecological environment level, ecological environment pollution and ecological environment protection. First, we use the cover rate of forests and water resources per capita to reflect the state of the ecological environment. The increase in forest and water resources is conducive to improving the ecological environment. Second, the ecological environment pollution scale adopts the discharge capacity of wastewater and the discharge capacity of sulfur dioxide, since they are the main pollutants of the urban ecological environment, and the increase in wastewater and sulfur dioxide emissions can increase the degree of ecological pollution. Third, the ecological environment protection scale adopts the investment in environmental pollution regulation and the harmless treatment rate of domestic garbage. Increasing investment and ratios in government environmental pollution regulations and improving the harmless treatment rate of domestic garbage are conducive to the improvement of ecological environmental protection.

The indices of the poverty alleviation system, energy conservation system and ecological protection system and the corresponding variables are shown in Table 1.

3. Methods

3.1. Coupling Coordination Degree (CCD) Model. Coupling is a concept in physics that describes the interaction and degree of interaction between two or more related systems. The CCD model can be used for research in multiple fields, such as the relationship between tourism and finance [37], urbanisation and geological hazards [38], and water governance and tourism [39].

To reflect the development level and the coordination effect of the regional poverty alleviation system, energy conservation system and ecological protection system and to measure the level of coordinated development among the three systems effectively, we collect the relevant data of the three systems in 30 provinces (cities) in China. The coupling definition and coefficient model in physics are used to measure the coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system.

First, we employ the entropy value method to evaluate the comprehensive indices for the poverty alleviation system, energy conservation system and ecological protection system. According to the methods, the raw data are standardised by formula (1) or (2) in positive or negative dimensions, respectively, to reduce the differences caused by the different units of measurement of different indicators:

$$x_{ij}^{+} = \frac{x_{ij} - \min\{x_{1j}, \ldots, x_{nj}\}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}}, \quad (1)$$

$$x_{ij}^{-} = \frac{\max\{x_{1j}, \ldots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}}, \quad (2)$$

Table 1: Descriptive statistical analysis of the variables.

System	Scale	Variable	Mean	Std. dev	Min	Max
Poverty alleviation	Economic development	Per capita GDP (yuan)	50105.7	26529.8	12882.0	164563.0
		Ratio of the output value of the service industry (%)	48.1	9.1	32.5	83.7
		Gross industrial output value (100 million yuan)	9816.0	8667.8	444.2	43507.5
	Livelihood	Per capita disposable income of urban population (yuan)	29184.7	10463.0	13189.0	73849.0
	Social security	Fiscal expenditure on public services (100 million yuan)	433.0	265.5	51.8	1855.3
		Total retail sales of consumer goods (100 million yuan)	9351.3	7904.6	351.0	42951.8
		Student-teacher ratio of primary schools (students for every teacher)	16.4	2.4	11.3	22.0
		Number of medical staff (for every 10000 people)	60.0	17.2	25.0	155.0
		Number of beds in health care institutions (for every 10000 people)	50.4	11.1	25.1	75.5
Energy conservation	Energy security pressure	Ratio of energy consumption per GDP (tons of standard coal for every 10000 yuan)	0.9	0.5	0.2	2.3
	Energy supply and demand state	Energy supply and demand rate (%)	97.3	111.8	9.7	484.3
		Fossil energy production share (%)	8.7	16.0	0.0	80.3
		Growth rate of total energy consumption (%)	3.7	5.3	-18.0	24.2
		Growth rate of fossil energy consumption (%)	18.0	16.3	0.0	97.9
	Energy system impact	Energy consumption elasticity	0.2	2.2	-34.8	10.8
	Energy development response	Proportion of electrical energy (%)	15.9	3.7	8.0	25.8
Ecological protection	Ecological environment level	Cover rate of forests (%)	34.3	18.1	4.2	66.8
		Water resources per capita (m^3)	2180.3	2540.8	51.9	16018.3
	Ecological environment pollution	Discharge capacity of wastewater (10000 tons)	56.1	50.9	2.0	293.8
		Discharge capacity of sulfur dioxide (10000 tons)	49.5	40.2	0.2	182.7
	Ecological environment protection	Investment in environmental pollution regulation (100 million yuan)	137.6	94.6	14.9	747.4
		Harmless treatment rate of domestic garbage (%)	90.6	13.1	38.0	100.0

where x_{ij} represents the value of indicator j in region i ($i = 1,...,n$, $j = 1,...,m$), $\max\{x_{1j}, \ldots, x_{nj}\}$ and $\min\{x_{1j}, \ldots, x_{nj}\}$ are the maximum and minimum values of indicator x_{ij}, respectively, x_{ij}^{+} represents the positive dimension indicator, and x_{ij}^{-} represents the negative dimension indicator.

Then, we can calculate the sample index weight p_{ij} by $p_{ij} = x_{ij} / \sum_{i=1}^{n} x_{ij}$. To avoid the situation of $\ln p_{ij} = 0$, the denominator and numerator of p_{ij} need to pulse 1 by

$$p_{ij} = \frac{\left(1 + x_{ij}\right)}{\sum_{i=1}^{n}\left(1 + x_{ij}\right)}. \tag{3}$$

Second, we calculate the entropy of indicator j by

$$e_j = -k \sum_{i=1}^{n} p_{ij} \times \ln p_{ij}, \tag{4}$$

where the constant variable k is related to the sample number n and estimated by $k = 1/\ln n$, and $0 \le e_j \le 1$. We obtain the utility value d_j of each index by using $d_j = 1 - e_j$, and the informational entropy weight w_j can be calculated by. $w_j = d_j / \sum_{j=1}^{m} d_j$

Third, the standardised data of each description index are multiplied by the corresponding weight value, and the development level U of the poverty alleviation system, energy conservation system and ecological protection system is calculated by

$$U = \sum_{i=1,j=1}^{n,m} x_{ij}^{+}\left(\text{or } x_{ij}^{-}\right) \times w_j. \tag{5}$$

We calculate the coupling correlation of the three systems as follows:

$$c = \frac{3\left(U_1U_2 + U_2U_3 + U_1U_3\right)}{\left(U_1 + U_2 + U_3\right)^2}, \tag{6}$$

$$d = \sqrt{c \times t}, \tag{7}$$

$$t = \alpha U_1 + \beta U_2 + \gamma U_3. \tag{8}$$

For formulas (6)–(8), c indicates the degree of coupling correlation among the three systems, d indicates the degree of coupling coordination among the three systems, t indicates the comprehensive development level of the three systems, and α, β, and γ are weights of the three systems. We consider α, β, and γ to be 1/3 in this study.

The coupling coordination degree refers to the relative product coefficient. According to the research [40], we classify the coupling of these three systems into the following levels, as shown in Table 2.

3.2. The GM (1, 1) Model. The grey forecasting model theory includes four kinds of models, the GM (1, 1) model, the

Table 2: The coupling coordination degree standard.

Level	Degree
$0.8 < D \leq 1$	Superior coordination (V1)
$0.7 < D \leq 0.8$	Moderate coordination (V2)
$0.6 < D \leq 0.7$	Slight coordination (V3)
$0.5 < D \leq 0.6$	Slightly incoordination (V4)
$0.4 < D \leq 0.5$	Moderately incoordination (V5)
$0 < D \leq 0.4$	Extremely incoordination (V6)

DGM (1, 1) model, the GM (1, N) model and the Verhulst model, among which the GM (1, 1) model is the most commonly used. The GM (1, 1) model is a time series forecasting model that requires less data, high accuracy, and simple calculation principles. The GM (1, 1) model has three basic operations: (1) accumulated generation, (2) inverse-accumulated generation, and (3) grey modelling. The GM (1, 1) model can be used for research in multiple fields, such as forecasting electricity consumption [41] and annual net income of rural households [42]. In addition, scholars found that the GM (1, 1) model can be used to predict the coupling coordination degree [43].

The GM (1, 1) model, i.e., a single variable first-order grey model, is summarised as follows:

First, for an initial time sequence

$$X^{(0)} = \left\{X^{(0)}(1), X^{(0)}(2), \ldots, X^{(0)}(i), \ldots, X^{(0)}(n)\right\}, \quad (9)$$

where $X^{(0)}(i)$ is the time series data at time i, and n must be equal to or larger than 4.

Second, a new sequence $X^{(1)}$ is set up on the basis of the initial sequence $X^{(0)}$ through the accumulated generating operation to provide the middle message of building a model and to weaken the variation tendency, as follows:

$$X^{(1)} = \left\{X^{(1)}(1), X^{(1)}(2), \ldots, X^{(1)}(i), \ldots, X^{(1)}(n)\right\}, \quad (10)$$

where

$$X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i)(i) \quad k = 1, 2, \ldots, n. \quad (11)$$

Third, the first-order differential equation of the GM (1, 1) model is then the following:

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = b, \quad (12)$$

and its difference equation is

$$X^{(0)}(k) + aZ^{(1)}(k) = b, \quad (13)$$

and from formula (13), we can obtain

$$\begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ \vdots \\ X^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -Z^{(1)}(2)1 \\ -Z^{(1)}(3)1 \\ \vdots \\ -Z^{(1)}(n)1 \end{bmatrix} \times \begin{bmatrix} a \\ b \end{bmatrix}, \quad (14)$$

where a and b are the coefficients to be identified.

Let

$$Y(n) = \left[X^{(0)}(2), X^{(0)}(3), \ldots, X^{(0)}(n)\right]^T. \quad (15)$$

$$B = \begin{bmatrix} -Z^{(1)}(2) \\ -Z^{(1)}(3) \\ \vdots \\ -Z^{(1)}(n) \end{bmatrix}. \quad (16)$$

Take

$$Z^{(1)}(k+1) = \frac{1}{2}\left(X^{(1)}(k) + X^{(1)}(k+1)\right) \quad k = 1, 2, \ldots, (n-1), \quad (17)$$

and

$$A = [a, b]^T, \quad (18)$$

where $Y(n)$ and B are the constant vector and the accumulated matrix, respectively. $Z^{(1)}(k+1)$ is the $(k+1)^{\text{th}}$ background value. Applying the ordinary least-square method to formula (17) based on formulas (15)–(18), the coefficient A becomes

$$A = \left(B^T B\right)^{-1} B^T Y_n. \quad (19)$$

Fourth, substituting A in formula (13) with (19), the approximate equation becomes

$$\hat{x}^{(1)}(k+1) = \left(X^{(0)}(1) - \frac{b}{a}\right) \times e^{-ak} + \frac{b}{a}, \quad (20)$$

where $\hat{x}^{(1)}(k+1)$ is the predicted value of $x^{(1)}(k+1)$ at time $(k+1)$. After the completion of an inverse-accumulated generating operation on formula (20), $\hat{x}^{(0)}(k+1)$, the predicted value of $x^{(0)}(k+1)$ at time $(k+1)$ becomes available and

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \quad k = 0, 1, 2, \ldots, n. \quad (21)$$

4. Results and Analysis

4.1. Indices of the Development Level. According to formula (5), we use the panel data of poverty, energy and ecology of 30 provinces (cities) in China from 2010 to 2019 to calculate the development level of the poverty alleviation system, energy conservation system and ecological protection system. The comprehensive development level of the three systems in different regions is shown in Figure 1.

Figure 1 shows the calculation results of the development levels for the three systems in different regions, which comprehensively reflects China's developing trends in the poverty alleviation system, energy conservation system and ecological protection system. From the perspective of the time series, the development level of the poverty alleviation system, energy conservation system and ecological protection system in the four regions showed upward trends from 2010 to 2019, but the trends of the development level for the three systems showed differences during the study period. First, the poverty alleviation system level in 2010 was lower

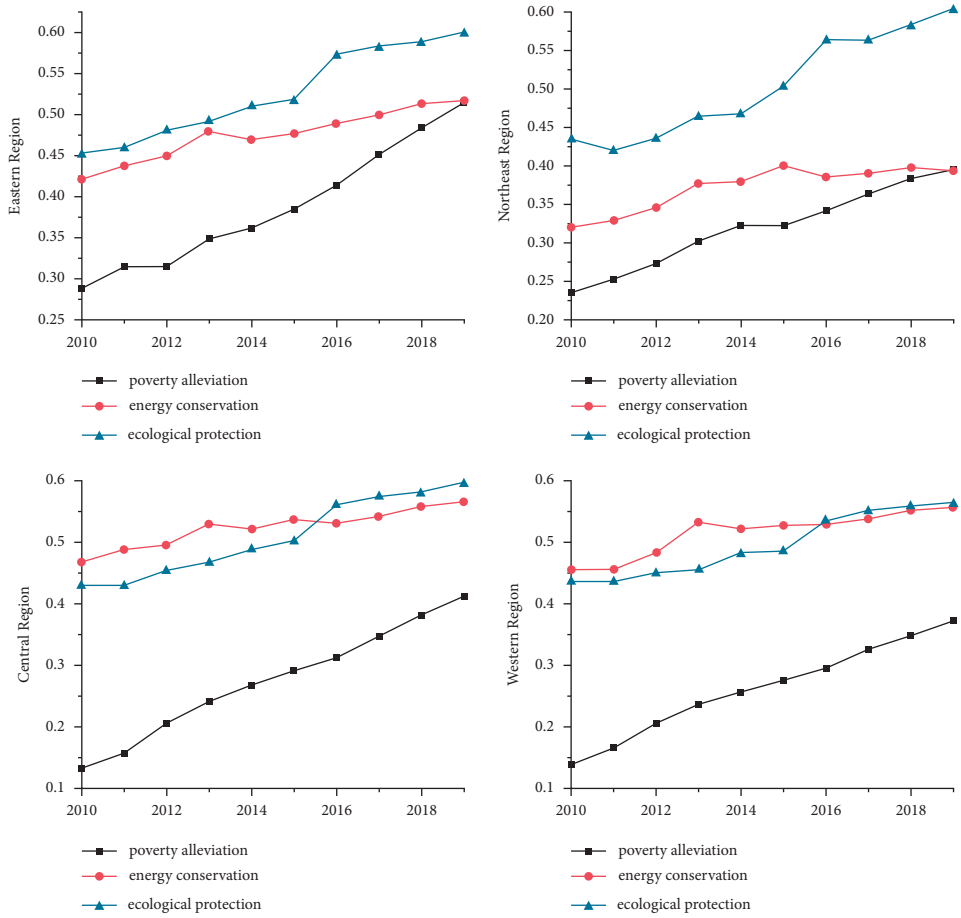

Figure 1: Results of the indices from 2010 to 2019.

than 0.3 in all four regions, which was the lowest among the three systems. However, the increase in the poverty alleviation system level was obvious, and in 2019, it was higher than the energy conservation system level in the eastern and northeast regions. Second, the energy conservation system level showed an upward trend during the study period, but the added value was lower than that of the poverty alleviation system level and the ecological protection system level. In 2019, the index for the energy conservation system level was lower than that of the poverty alleviation system level in the eastern and northeast regions and lower than the index of the ecological protection system level in the central and western regions. Third, the ecological protection system level was the highest among the three systems at the end of the study period. In terms of regional differences, the tendency of the three systems showed two types. In the first type, the ecological protection system level was always the highest in the study period, and the poverty alleviation system level was the lowest at the beginning of the study period, but it was higher than the energy conservation system level at the end of the study period. The second type was in the central and western regions, which showed that the energy conservation system level was the highest at the beginning of the study period but lower than the ecological protection system level at the end of the study period, while the poverty alleviation system level was the lowest during the study period. Although the three systems showed a positive correlation during the study period and were in a state of mutual promotion and coordinated development, there were great differences in the development level and developing speed of China's poverty alleviation system, energy conservation system and ecological protection system. Therefore, we next analyse the coupling coordinated development among the poverty alleviation system, energy conservation system and ecological protection system.

4.2. Results of the CCD Model

4.2.1. The Temporal Trend of the Coupling Coordination Degree. We calculate the average coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system of 30 provinces (cities) in China from 2010 to 2019 and present it as a time series. The result is shown in Figure 2.

The result can be seen in Figure 2. From the perspective of the time series, the average coupling coordination degree of 30 provinces (cities) in China shows fluctuations, but overall, there is an upward trend and three stages in the standard of coupling coordination degree can be seen during the study period. The first stage was from 2010 to 2011. During this period, the average coupling coordination

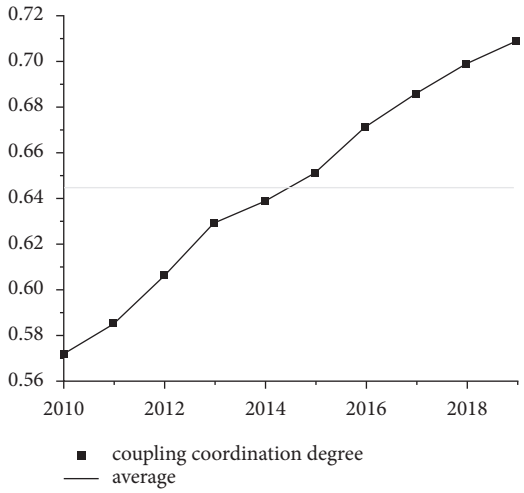

Figure 2: Average coupling coordination degree in China.

degree in China was between 0.5 and 0.6, which was at the slightly incoordination (V4) stage. The second stage was from 2012 to 2018. In this period, the average coupling coordination degree in China was between 0.6 and 0.7, which was slight coordinated (V3). The last stage was in 2019. During this period, the average coupling coordination degree in China rose to 0.709, which was moderate coordinated (V2). In general, the average coupling coordination degree of poverty alleviation, energy conservation and ecological protection in 30 provinces (cities) in China has risen from slightly incoordination (V4) to slight coordination (V3) in seven years and entered the stage of moderate coordination (V2) in 2019.

Figure 3 shows the coupling coordination degree distribution of 30 provinces (cities) in China. From 2010–2019, the coupling coordination degrees were 0.33%, 21.67%, 52.00%, 25.67%, and 0.33%, corresponding to superior coordination (V1), moderate coordination (V2), slight coordination (V3), slightly incoordination (V4), and moderately incoordination (V5), respectively. The order of proportion from large to small was slight coordination (V3), slightly incoordination (V4), moderate coordination (V2), moderately incoordination (V5) and superior coordination (V1). From 2010 to 2019, the superior coordination (V1) and moderate coordination (V2) increased gradually, slightly incoordination (V4) decreased from 76.67% in 2010 to 0 in 2017, and moderately incoordination (V5) decreased from 3.33% in 2010 to 0 in 2011. From the above analysis, we concluded that the coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system in China steadily improved during the study period.

4.2.2. The Temporal Differences of Coupling Coordination Degree among Regions. We calculated the coupling coordination degree of four regions in China from 2010 to 2019 based on the CCD model, and the regional coupling coordination degree is shown in Figure 4.

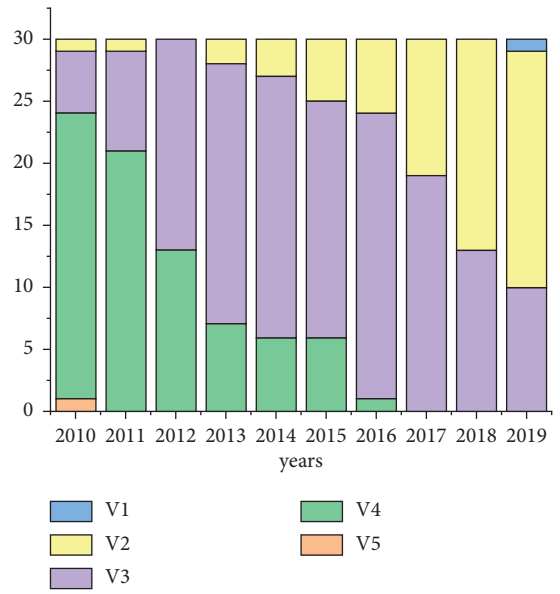

Figure 3: Coupling coordination degree stage distribution.

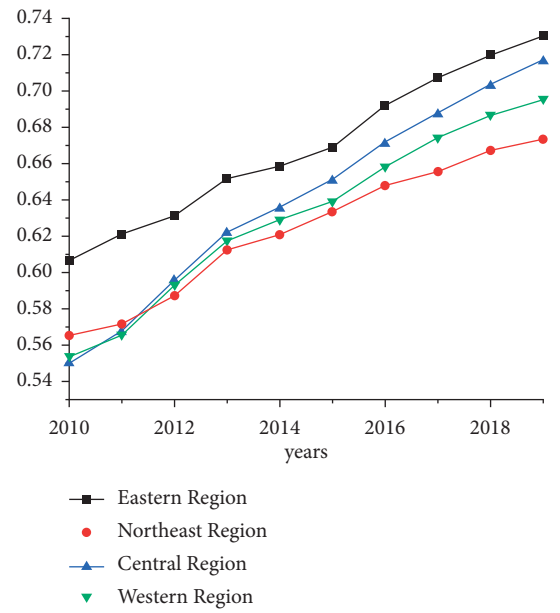

Figure 4: Regional coupling coordination degree.

The result can be seen from Figure 4. The coupling coordination degrees of the poverty alleviation system, energy conservation system and ecological protection system in the four regions of China show upward trends during the study period. In 2010, the four regions in China were categorised as slightly incoordination (V4) and slight coordinated (V3) in the coupling coordination degree standard. However, in 2019, the coupling coordination degree of the four regions increased to some extent. The coupling coordination degree was categorised as slight coordinated (V3) or moderate coordinated (V2). In terms of regional differences, the average coupling coordination degree of the eastern region during the study period was the highest of all four regions in China in terms of the standard of coupling

coordination degree, from slight coordination (V3) to moderate coordination (V2), reflecting that the poverty alleviation, energy conservation and ecological protection systems had more coupling coordination in the eastern region. In 2010, the average coupling coordination degree in the central region and the western region was close, both at the level of slightly coordination (V4). However, in 2019, the average coupling coordination degree in the central region was at the stage of moderate coordination (V2), which was higher than the stage of slight coordination (V3) in the western region. It is worth noting that the change in the average coupling coordination degree in the northeast region was the smallest among the four regions. In 2010, the average coupling coordination degree in the northeast region was in second place among the four regions and was slightly coordinated (V4), but in 2019, the average coupling coordination degree in the northeast region was slight coordinated (V3) and ranked last among the four regions.

4.2.3. The Spatial Distribution of the Coupling Coordination Degree. The spatial distribution of the regional coupling coordination degree from 2010 to 2019 was drawn by ArcGIS 10.5 software, as shown in Figure 5.

The spatial distribution of coupling coordination degrees in China from 2010 to 2019 is shown in Figure 5. The coupling coordination degree of the four regions in China shows a great difference in spatial distribution. First, Guangdong achieved the highest degree of coupling coordination in eastern China, and China's first superior coordination (V1) stage emerged in Guangdong Province in 2019. Other coastal provinces in the eastern region, such as Fujian, Zhejiang, Shanghai, Jiangsu and Shandong, also achieved a high value of coupling coordination degree. However, Tianjin and Hebei in the eastern region performed poorly, with a slight coordination (V3) coupling coordination degree in 2019, which was lower than that in other provinces in the eastern region. Second, the coupling coordination degree in the northeast region was the lowest among the four regions. From 2010 to 2019, the coupling coordination degree of all three provinces in the northeast region increased from slightly incoordination (V4) to slight coordination (V3). Third, the coupling coordination degree in the western region increased greatly. In 2010, 10 out of 11 provinces in western China had a slightly incoordination (V4) degree, while Gansu had a moderately incoordination (V5) degree. However, in 2019, Shaanxi, Qinghai, Ningxia and Xinjiang's coupling coordination degree rose by one stage to slight coordination (V3). The coupling coordination degree of Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou and Yunnan increased by two stages, reaching moderate coordination (V2). The coupling coordination degree of Gansu also rose from 0.48 in 2010 to 0.66 in 2019, reaching the moderate coordination (V2) stage. Fourth, the coupling coordination degree of all six provinces in the central region increased by two stages from slightly incoordination (V4) in 2010 to moderate coordination (V2) in 2019. In general, the provinces (cities) with high values were concentrated in the eastern and central regions, while the provinces (cities) with low values were concentrated in the western and northeast regions.

4.3. The Result of the GM (1, 1) Model

4.3.1. Estimation of the Development Level. We used the GM (1, 1) model to estimate the development level of the poverty alleviation system, energy conservation system and ecological protection system in 30 provinces (cities) in China from 2020 to 2025. Some indices are above 1, such as poverty alleviation indices in Jiangsu in 2024 and 2025 and Henan in 2025, energy conservation indices in Shaanxi in 2025, and ecological protection indices in Guangdong in 2025. According to the definition of the index, we replace the indices above 1 with 1. The results are shown in Figure 6.

In Figure 6, the development levels of 2019 and before are the actual measured data, while the development levels of 2020 and after are the predicted data using the GM (1, 1) model. As seen in the figure, on the premise that other socioeconomic factors remain unchanged, the poverty alleviation system level, energy conservation system level and ecological protection system level would still be on an upwards trend in the four regions of China from 2020 to 2025. Among the indices of the three systems, the development value of the ecological protection system level was the highest in the four regions. However, there would be regional differences in the trends of the energy conservation system level and poverty alleviation system level. The trends of the energy conservation system level and the poverty alleviation system level in the eastern and northeast regions would be similar. In the next few years, the poverty alleviation system level would be higher than the energy conservation system level, but the added value of the poverty alleviation system level in the eastern region would be greater than that in the northeast region. The trends of the energy conservation system level and the poverty alleviation system level would be similar in the central and western regions. The poverty alleviation system level would surpass the energy conservation system level in the next few years, in the central region in 2023 and the western region in 2025. It is also worth noting that in 2025, the ecological protection system level and poverty alleviation system level in the eastern and central regions would be similar.

4.3.2. Estimation of the Coupling Coordination Degree. Based on the CCD model, we estimate the coupling coordination degree of the three systems by using the development level indices of the poverty alleviation system, energy conservation system and ecological protection system of the four regions in China from 2020 to 2025. The estimated results are shown in Figure 7.

Figure 7 shows the coupling coordination degree distribution in the sample area. From 2020 to 2025, the coupling coordination degree will be 37.78%, 47.78%, and 14.44%, corresponding to the stages of superior coordination (V1), moderate coordination (V2) and slight coordination (V3), respectively. The order of proportion from large to small would be moderate coordination (V2), superior

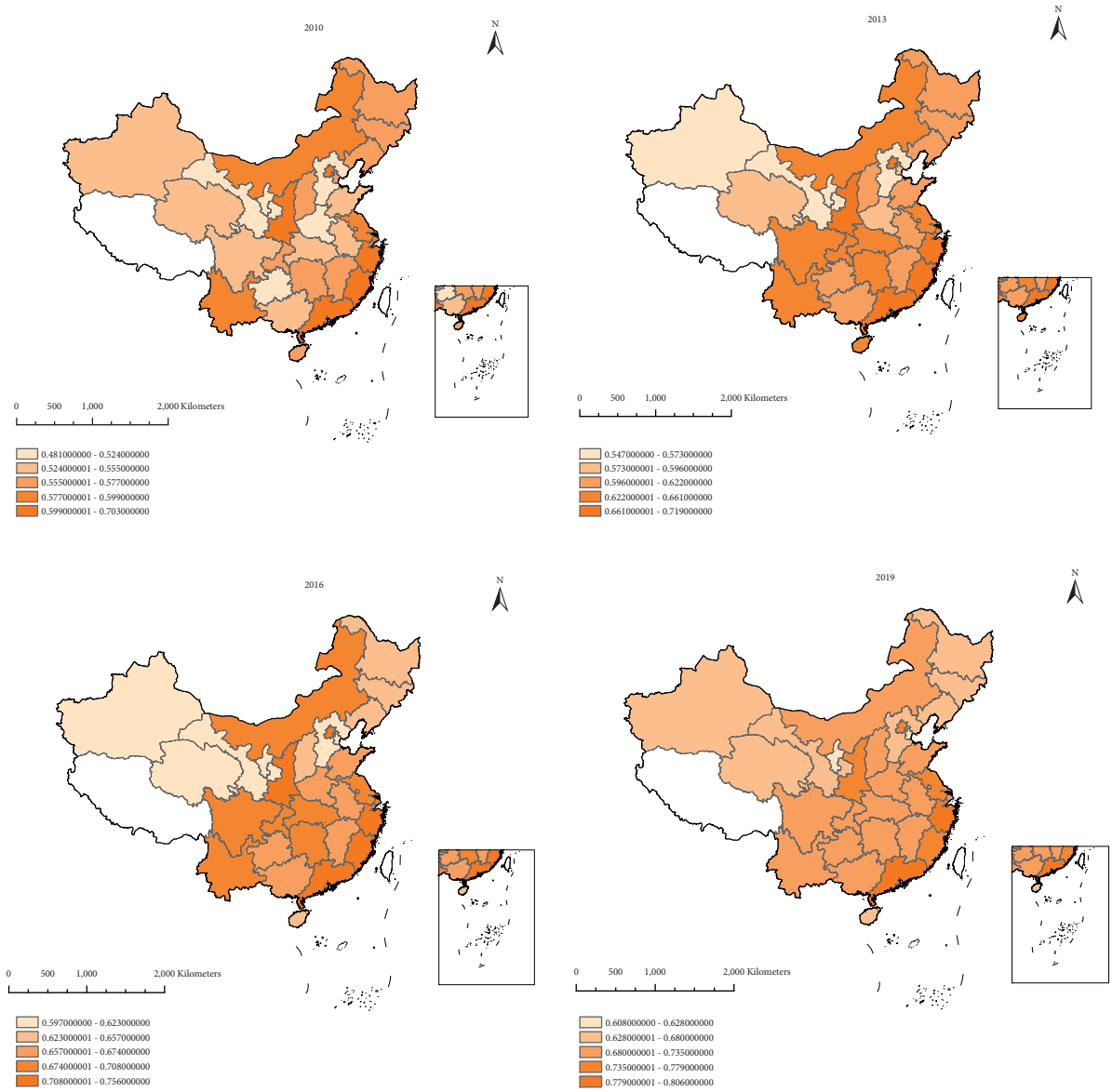

Figure 5: Spatial distribution of the coupling coordination degree.

coordination (V1), and slight coordination (V3). By 2025, the coupling coordination degree of 30 provinces (cities) in China would be mainly in the stage of superior coordination (V1), and there would be 22 provinces (cities) in this stage. Six provinces (cities) would be in the stage of moderate coordination (V2), among which all three provinces in the northeast region would be in this stage. Tianjin and Ningxia would be in the stage of slight coordination (V3). The poverty alleviation system, energy conservation system and environmental protection system in most provinces will be further coordinated in the coming years.

The spatial distribution of the coupling coordination degree stage in China from 2020 to 2025 is shown in Figure 8. First, the spatial difference in the coupling coordination degree among the four regions in China will gradually decrease in the following years. In 2022, the coupling coordination degree of more than half of China's provinces (cities) would be moderate coordinated (V2) and exceed 50% in each region. In the eastern region, 40% of provinces (cities) would be in the stage of superior coordination (V1), 50% in the stage of moderate coordination (V2), and 10% in the stage of slight coordination (V3). All three provinces in the northeast region would be moderate coordinated (V2). In the central region, 33% of provinces (cities) would be in the superior coordination stage (V1), and 67% would be in the moderate coordination stage (V2). In the western region, 27% of the provinces (cities) would be in superior coordination (V1), 55% would be in the stage of moderate coordination (V2), and 18% would be in slight coordination (V3). In 2025, the coupling coordination stage of most provinces (cities) in China would be superior coordination (V1). Among the provinces, 80% are in the eastern region, 100% are in the central region and 73% are in the western region. However, the coupling coordination degree of all three provinces in the northeast region would be moderate coordinated (V2), unlike the other three regions in China.

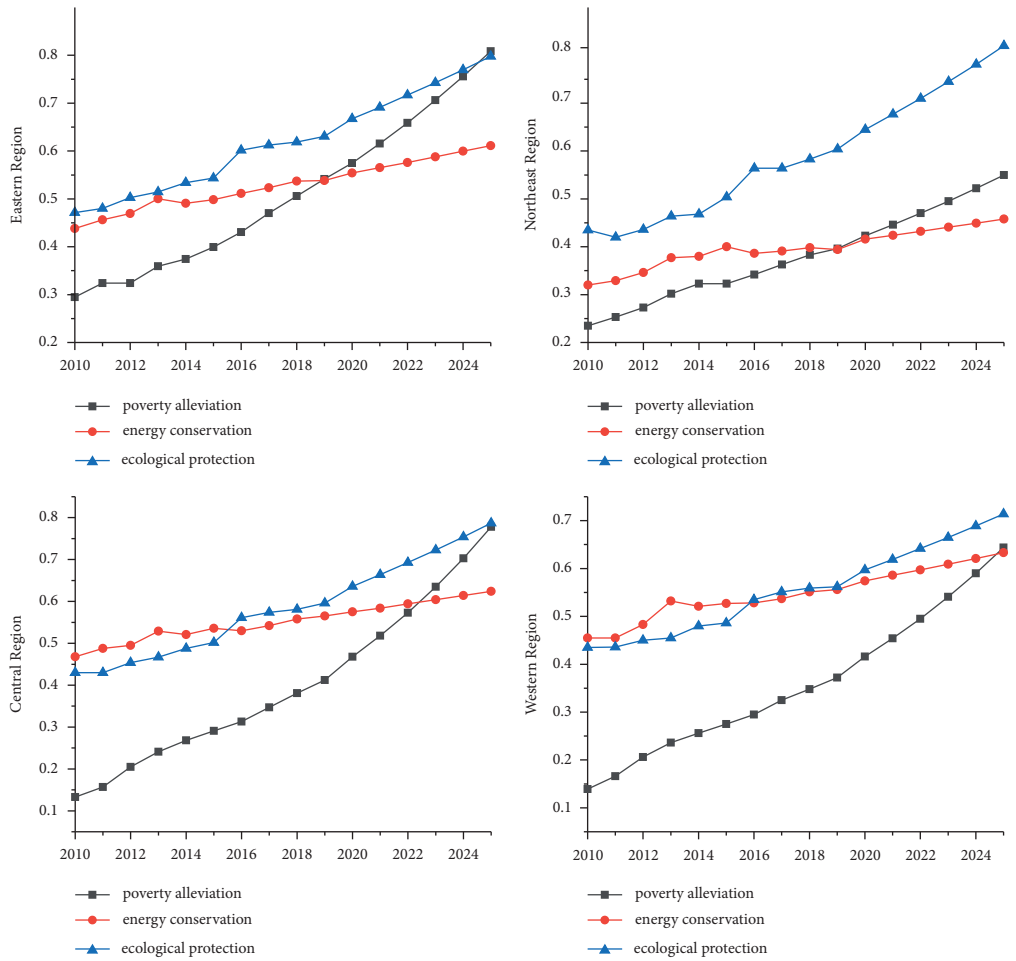

Figure 6: Estimation of the development level.

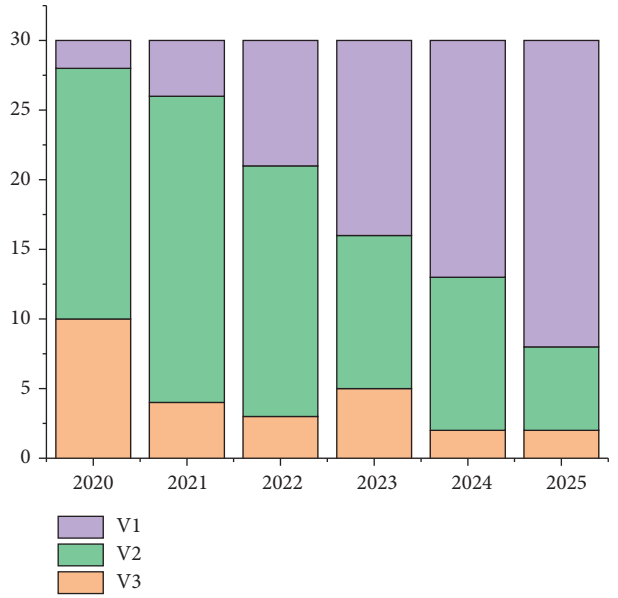

Figure 7: Estimation of the coupling coordination degree stage distribution.

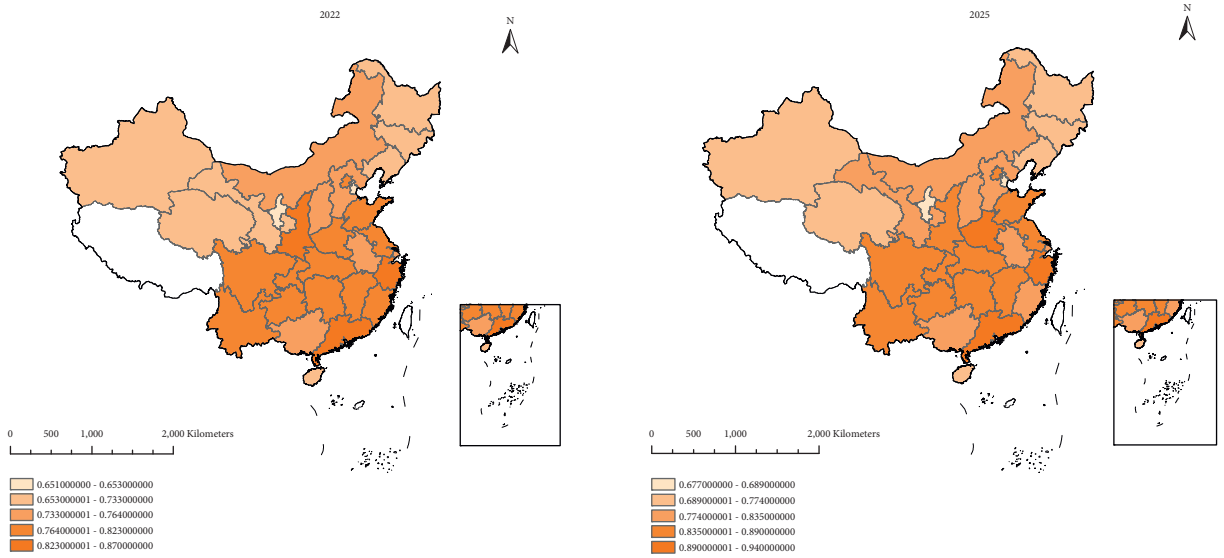

Figure 8: Estimation of the spatial distribution of the coupling coordination degree.

5. Conclusion and Discussion

5.1. Conclusion. This paper constructs the coupling coordination model of poverty alleviation, energy conservation and ecological protection among the four major regions of China through coupling theory, calculates the poverty alleviation system development level, energy conservation system development level and ecological protection system development level of 30 provinces (cities) in China, and analyses and studies the spatial and temporal distribution and changing trend of the coupling coordination degree. In addition, the tendency of the poverty alleviation system level, energy conservation system level, ecological protection system level and coupling coordination degree of the three systems and the tendency of the spatial and temporal distribution in China in the following years are estimated by the GM (1, 1) model.

The results show that first, from 2010 to 2019, the development level of China's poverty alleviation system, energy conservation system and ecological protection system presented upward trends. Regional differences could be seen through the development trends of the development level indices; that of the eastern region was similar to that of the northeast region, and that of the western region was similar to that of the central region. Second, the coupling coordination degree of the three systems in China showed an upward trend. The average coupling coordination degree of 30 provinces (cities) rose from slightly incoordination (V4) in 2010 to moderate coordination (V2) in 2019. However, differences in spatial distribution could also be seen in the study. The average coupling coordination degree of the eastern region was the highest among the four regions in 2019, with the central and western regions ranking second and third, respectively, and the northeast region ranking last. Third, the coupling coordination degree stage distribution in China has improved. In 2010, the coupling coordination degree of more than half of China's provinces (cities) was in the slightly incoordination stage (V4), while by 2019, more than half of China's provinces (cities) were in the moderate coordination stage (V2). Among them, the provinces (cities) with high values were concentrated in the eastern and central regions, while the regions with low values were concentrated in the western and northeast regions. Fourth, the GM (1, 1) model predicted that in the following years, the development level of these three systems in China will increase. However, the poverty alleviation system level in western and central China would exceed the energy conservation system level, while the eastern and northeast regions would not show this trend. Fifth, the coupling coordination degree index of 30 provinces (cities) in China would rise significantly in the following years, and the coupling coordination degree of more than half of the provinces (cities) would be in the stage of superior coordination (V1). Among them, in 2025, 80% will be in the eastern region, 100% in the central region and 73% in the western region. However, the coupling coordination degree of all three provinces in the northeast region would be moderate coordinated (V2), unlike the other three regions in China.

6. Discussion

According to the outline of China's 14th Five-Year Plan, China will step up the implementation of the country's regional development strategies and continue to promote large-scale development in the western region, the full revitalization of the northeast region, the rise of the central region, and the trailblazing development of the eastern region. The conclusion of this paper supports China's regional development strategy. The results show that there will be differences in the development of the poverty alleviation system, energy conservation system and ecological protection system in different regions of China, and the synergy of the three systems is also obviously different. The coupling coordination degree will be the highest in the eastern region in the next few years. The coupling coordination degree in

the central region and western region will increase rapidly. The coupling coordination degree in the northeast region will be lower than that in the other three regions of China. Therefore, corresponding policies need to be formulated according to the situation of different regions in China.

The main contributions of this paper are as follows: first, China's poverty alleviation task in the following years will be to reduce relative poverty; therefore, this paper reflects the poverty alleviation system of different provinces (cities) by introducing indicators of income, education, medical and health care, and public services and studies the relationship among the poverty alleviation system, energy conservation system and ecological protection system, thus expanding the research on the 3E system. Second, based on the CCD model and the GM (1, 1) model, this paper calculates the comprehensive development level of the three systems of poverty alleviation, energy conservation and ecological protection of 30 provinces (cities) in China, showing the development status of each of the three systems. Third, this paper shows the tendency of the development level of the poverty alleviation system, energy conservation system and ecological protection system and the synergy of the three systems in the following years. Last, this paper analyses the internal causes of the development differences among regions, which will be helpful in recommending a strategy for future development.

The link between this paper and existing theories is that the discussion of the relationship among poverty alleviation, energy conservation and ecological protection is a further study on the research of the 3E system. China has achieved remarkable achievements in economic development and poverty alleviation and has contributed to the achievement of global poverty alleviation goals [44]. However, unbalanced development among the regional economy, education, medical and health and public services persists in China, leading to regional relative poverty [45, 46]. Exploring the relationship among the poverty alleviation system, energy conservation system and ecological protection system is in line with the research of the 3E system. Thus, this paper expands upon the field of study of the 3E system relationship.

This paper presents some shortcomings, which are as follows. First, this paper uses the CCD model to study the relationship among poverty alleviation systems, energy conservation systems and ecological protection systems, and there are other methods that can be used in future studies. Second, due to the complexity of the poverty alleviation system, energy conservation system, and ecological protection system, the selection of the indicators needs to be further improved. Third, in view of the lack of Tibetan data, the data for the western region may lead to biased results.

Data Availability

The original 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

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Retraction

Retracted: Empirical Research on Seasoned Equity Offerings, Board Member Characteristics, and Corporate Investment Efficiency

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] 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.

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RETRACTED

Research Article

Empirical Research on Seasoned Equity Offerings, Board Member Characteristics, and Corporate Investment Efficiency

Dapeng Zhu [1] **and Yongli Li** [2]

[1]*School of Accounting, Harbin University of Commerce, Harbin 150028, China*
[2]*School of Economics and Management, Harbin Institute of Technology, Harbin 150001, China*

Correspondence should be addressed to Yongli Li; liyongli@hit.edu.cn

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Seasoned equity offerings (SEO) are an important approach for listed companies to obtain funds after an initial public offering (IPO), which plays a major role in enterprises' demand for funds. However, due to agency conflicts, information asymmetry, tunneling by major shareholders, and other behaviors, listed companies sometimes fail to make proper use of the refinancing funds. In this study, the impact of SEO on corporate investment efficiency is tested. Furthermore, the impact of board member characteristics on investment efficiency of refinancing companies is tested. Refinancing listed companies in Shenzhen and Shanghai Exchange Stock from 2009 to 2020 form the research samples. The research shows that SEO reduces the corporate investment efficiency. According to the impact analysis of the board member characteristics on the investment efficiency of refinancing companies, age heterogeneity of the board inhibits investment efficiency. The older the mean age of directors, the higher the investment efficiency. Furthermore, sex heterogeneity also inhibits investment efficiency. The more female directors, the lower the investment efficiency. Moreover, overseas backgrounds and experiences of directors also inhibit investment efficiency. These findings not only extend the research on the consequences of SEO in China, but also provide reference points and guidance for listed companies to adopt a scientific and reasonable refinancing method, give full play to the advantages, and overcome disadvantages of board members.

1. Introduction

Seasoned equity offering (SEO) refers to the behavior of listed enterprises to refinance through equity, including the issuing of rights (i.e., private and public placements), new shares, and convertible bonds. As an important direct financing approach of listed companies, SEO plays a significant role in boosting high-quality economic development. Ever since the issuance of the Provisional Regulations on the Administration of Share Issuance and Trading of April 22, 1993, SEO has promoted the high-quality development of numerous enterprises for almost three decades. The refinancing amount in China's A-share market was as high as 13 trillion Yuan, which is 3.5 times that of the initial public offering (IPO) fundraising amount. On February 14, 2020, the China Securities Regulatory Commission officially issued a series of supporting policies (the New Refinancing Regulation) to optimize the refinancing on the main board and GEM. The new refinancing regulation is more flexible and broader, relaxing the regulation on the issue price, issue scale, and restricted period of private placement, which favors activating the refinancing market and giving full play to the financing functions of the capital market. The adjustment of refinancing policy has remarkably revitalized the market. Throughout 2020, the issue scale of the market evidently increased. There were a total of 390 companies releasing the SEO plan, and the fund raised was over 910 billion Yuan, which far exceeded the number and amount of

2019. It is estimated that the refinancing market will grow steadily, complement IPO issuance effectively, and jointly give full play to financing for excellent enterprises.

SEO of listed companies is an important means to replenish funds after IPO, and the purpose of some enterprises' refinancing is to expand their business scale, extend the upstream or downstream of industrial chains, or improve their market share. It can create technological innovation or raise money for research and development. To improve the enterprise's financial situation, the acquisition of the target company improves the company's profitability and asset quality. As a major decision of the enterprise, refinancing should be proposed by the board of directors, approved by the general meeting of shareholders, and submitted to the regulatory authorities for examination and approval. Only after the examination and approval of the China Securities Regulatory Commission can it be implemented. Refinancing expands the share capital of listed companies, and refinancing participants will generally obtain discount subscriptions, which cause large fluctuations in the stock price during the refinancing process. After the completion of SEO, there is a decline in performance of certain companies.

SEO can create cash flow, meet the capital demand, and support the development of listed companies. However, due to the agency conflicts and information asymmetry, some companies may be caught in overinvestment after the rights offering. Whether listed companies will rationally use these refinancing funds to increase corporate value and shareholder interests have become a concern in public and academic circle.

The top management team is a key leader of the company's daily operations and strategic decisions. SEO decision is important and hence would certainly be impacted by the top management team, especially the board of directors of listed companies. If they can effectively resolve principal-agent problems arising between shareholders and the management team and reduce the information asymmetry, it would solve the problem of under investment, guarantee the interests of shareholders and other stakeholders more thoroughly, and ensure steady development of the enterprise after SEO. This study can measure the variable of board heterogeneity to a certain degree, and observe its effect on the relationship between SEO and corporate investment efficiency.

In this study, the effect of board member characteristics on the investment efficiency of listed companies after SEO is studied, which provides a basis of decisions for the use of fund by listed companies after SEO. Furthermore, the role of the board of directors in the satisfaction of capital demand and proper use of refinancing funds after the SEO is discussed, which regards certain guiding significance for optimizing the structure of the board of directors and giving full play to their role in listed companies. In this study, the effect of characteristics for refinancing decision makers on the drive and restriction of investment efficiency after SEO is analyzed from an internal viewpoint, which provides capital market investors with references for investment decisions, enables them to understand the impacts of the top management teams' characteristics on SEO, allows them to select more suitable refinancing listed companies for investment, and improves the investment efficiency and rate of return.

2. Literature Review

2.1. Literature on SEO and Investment Efficiency. SEO is an important approach for Chinese listed companies to replenish the fund, and features inter alia a large financing scale and positive signal to the market. However, due to the imperfect market order, incomplete regulatory system, and characteristics of the capital market, owners are usually concerned about whether management can make proper use of the refinancing fund. Scholars have explored the impact of SEO on the investment efficiency of enterprises, but the research mainly focuses on overinvestment. According to the analysis based on the information asymmetry and principal-agent theories, it is insisted that information asymmetry and agency problems are the primary causes of overinvestment.

For instance, Jensen and William had integrated the elements of the agency, property right, and financial theories to develop the enterprise ownership structure theory. They studied the nature of agent costs arising from debt and external equity. It was insisted that the refinancing of listed companies was the decision of operators based on their own interests. For shareholders, refinancing is disadvantageous. Such a behavior enlarges the agency conflict and contributes to the phenomenon of overinvestment [1]. Myers and Majluf not only lay the theoretical foundation for the negative effect of refinancing announcement, but also raise doubts about insiders' established intention of expected capital inflow and whether the project investment is carried out in a value-added way [2]. Jensen argued that the payment to shareholders reduced the power of managers, and when the company must acquire new capital, it would more likely be supervised by the capital market. He proposed the free cash flow hypothesis, insisting that when the company lacked opportunities for growth, if the cash flow of the existing asset exceeds the scale of moderate investment, managers may have the motivation of over investment with the free cash flow [3]. Cronqvista and Nilssonb examine how firms choose between a right offering and private equity placement. Family controlled firms avoid issue methods that dilute control benefits, or subject them to more monitoring. Control considerations also affect security designs. Private placements reduce contracting and ex post holdup costs in new product market relationships [4]. Walker and Yost indicate that, regardless of the stated use of funds, firms increase capital expenditure, research, and development following SEO. In addition, firms increase their long-term debt following SEO, even when the stated reason for the capital was to pay down debt [5]. Harford et al. found that enterprise tended to reduce the refinancing risks by increasing cash holdings and saving cash from the cash flow. The increase of cash reserves could reduce under-investment, while refinancing enterprises may tend to over-invest after holding a large amount of cash [6].

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2.2. Literature on the Influence of the Top Management Teams' Characteristics on Investment Efficiency. The management, as top managers of the enterprise, refers primarily to members of the board of directors and board of supervisors, and the chief executive officer (CEO), who possess the resource allocation and decision-making power, with a major impact on the operation, fundraising, and investment activities of the enterprise. Hambrick and Masons proposed the high-tier team theory from the "top management view," insisting that top managers would make a highly individualized interpretation and decision, according to the organizational context. Top managers decide on the formation of organizational strategies and affect the behaviors of other members of the organization, as a significant influencing factor of corporate performance [7]. Thereafter, much literature appeared on the impacts of individual manager characteristics, including gender, age, and educational, functional, overseas, and financial backgrounds regarding the financial decision-making activities of enterprises in the academic circle.

The sex difference of top managers is usually reflected by different values, attitudes, risk preferences, etc. Some scholars insist that female top managers can effectively inhibit the overinvestment of enterprises. For instance, Carter et al. find significant positive relationships between the fraction of women on the board and firm value [8]. Lückerath-Rovers finds that firms with women directors perform better than those without women on their boards [9]. Isidro and Sobral find that greater female representation on corporate boards of large European firms can increase firm value indirectly [10]. Shin et al. find that female directors show a positive correlation with investment efficiency, based on the same data of listed companies from 2006 to 2014 in South Korea, and female directors were risk-averting, conservative, and discrete, so they can influence the investment efficiency by reducing overinvestment [11]. Hoang et al. finds that female-managed firms are less likely to operate in industries with high levels of risk [12]. Ullah et al. finds that female directors on corporate boards are positively associated with firm value [13]. Some scholars propose opposite viewpoints. For instance, David insisted that there is no explicit and unified relationship between sex diversity and corporate performance for service/wholesale/retail sectors [14]; Adams and Ferreira argued that for companies who excel at corporate governance, sex diversity of directors may lead to overregulation, and have a negative impact on corporate performance [15]; Hussein and Kiwia also found that sex diversity of directors may fail to improve corporate performance, based on the sample data of 250 American companies from 2000 to 2006 [16]. Darmadi finds that both accounting and market performance have significant negative associations with gender diversity [17]. Zhi Jin et al. find that the association between female directors and investment efficiency is negative and significant in examining the role of female directors in board governance [18]. Midavaine finds that gender diversity encourages firms invest more. The findings also illustrate that female CEOs (FCEOs) enhance firm value [19].

The age of top managers usually impacts their attitude towards risks. Vroom and Pahl [20] and Wiersema and Bantel [21] argue that the cognitive views of top managers (reflected by the demographic characteristics of the team) were related to the team's tendency to change the corporate strategy. There was a significant negative correlation between age and risk bearing/value. Younger top managers would look at new opportunities with a more positive attitude, have stronger adaptability, and a creative spirit. Older top managers are more conservative with investment risks and have a declining understanding of new technology and awareness of decision-making projects, as they prefer a steady working environment as opposed to changes. Vincent and Mueller finds that research and development (R&D) spending is greater at firms where CEOs are younger and have greater wealth invested in firm stock [22]. Chowdhury and Fink find that not only do older CEOs invest in less R&D, they also do so suboptimally [23]. Andreou et al. find that firms with younger CEOs are more likely to experience stock price crashes [24].

Educational background usually reflects on the decision-making power of top managers. Bantel and Jackson insist that the higher the education level of top manager, the richer the knowledge reserve, and the stronger the adaptability to the environment and ability to obtain and analyze information, which is conducive to strategic change and performance of the company [25]. Tihanyi et al. demonstrated that a higher mean of elite education and international experience were related to the international diversification of the company, and emphasized the importance of top management teams in international decision-making [26]. Giannetti et al. studied the influence of directors with foreign experience on the corporate performance in the emerging market, and found that top managers with foreign experience usually possessed a strong learning ability, high professional knowledge levels, and high business operation levels. Which could create more advanced management approaches, further alleviate agency conflicts, and improve innovation [27]; Filatotchev et al. insists that export orientation and performance relied not only on the development of R&D and technology transferability but also on the founder's international background, global network, and other entrepreneurial characteristics. Both export orientation and performance are positively correlated to the existence of "returned" entrepreneurs [28]. Walt and Ingley explored the appointment of directors of various professional backgrounds, levels of independence, age, gender, and ethnicity. This study develops a taxonomy describing what is meant by diversity on the board and its implications for decision-making [29].

The abovementioned literature research also shows that the investment efficiency of enterprises is impacted by the inherent problems of corporate system, such as principal-agent relationships, corporate operations (e.g., cash holdings), and governance-level factors (e.g., board member characteristics).

Existing literature proves that scholars have conducted numerous studies on the impact of equity refinancing for investment efficiency, especially regarding different

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refinancing methods. However, due to the differences in refinancing systems of various countries, its impact on investment efficiency is also inconsistent. The characteristics of senior executives have a greater impact on investment efficiency, while board member characteristics have less impact on investment efficiency after refinancing. What is the role of SEO, as an important decision of listed companies? What are the functions of the board of directors' characteristics when refinancing listed companies? Further discussion is carried out in this study.

3. Theoretical Analysis and Hypotheses

Due to the principal-agent problem, shareholders, and operators, as rational and economical, would pursue maximum profits and make self-benefiting investment decisions. To seek extrabenefits, top managers may make investment decisions that harm the interest of investors with their power. In the case of highly centralized equity, controlling the shareholders of refinancing companies can transfer the raised fund or profits to major shareholders, by way of asset restructuring, related party transactions, occupation of listed funds, and so forth, through their power of control. Thus, the capital for investment may be reduced and listed companies may also reduce the capital investment. Agency conflict may force shareholders or top managers to choose projects that may increase their own value but reduce the value of the enterprise or abandon projects that may increase the value of the enterprise but reduce their own value, which may result in inefficient investments. According to the free cash flow theory, the uneven benefit distribution of the company may also urge managers to remake investments with the excess free cash flow to seek profits or take up position-related consumption, which would lead to the improper use of fund and underinvestment. Thus, the large cash flow brought about by SEO may not be utilized completely and rationally.

Since most objects of equity refinancing are major shareholders, the shareholding ratio of major shareholders is further increased after equity refinancing, and the phenomenon of "one dominant share" is more serious, resulting in ignoring the voice of minority shareholders; this aggravates the tunneling behavior of major shareholders. In addition, the SEO review process is lengthy. After the review and approval process is completed, some investment opportunities are missed and the investment of raised funds lags, resulting in the failure of investment projects to meet expectations and the decline of investment efficiency. Therefore, hypothesis 1 is put forward, as follows:

H1: SEO reduces corporate investment efficiency.

Upper Echelons Theory holds that due to the complexity of internal and external environments, managers cannot have a comprehensive understanding of all its aspects. Even within the scope of the manager's field of vision, they can only selectively observe the phenomenon. Thus, managers' existing cognitive structure and values determine their ability to interpret the relevant information. The heterogeneity of the board of directors reflects the corporate governance level. Different characteristics of board members, such as *inter alia* their sex, age, and educational, overseas, and functional background, may influence their decision-making for investments. The influence mechanism is shown in Figure 1.

Therefore, hypothesis 2 is put forward, as follows:

H2: characteristics of the board of directors influence the investment efficiency of refinancing companies.

The age of board members usually means an increase in experience. The older a board member, the more experience, which may help improve the management ability. However, the growth in age also means a more conservative board. Elders may not be as ambitious as youngsters, which may influence the corporate operation. After SEO, the enterprise obtains a large amount of money and must invest in major projects. Concurrently, the pre-investment decision-making has already been made before SEO, and the post-investment management is still necessary. The management's experience is more important than brevity, but the high age heterogeneity of board members would also slow down investment progress and impact investment efficiency. Therefore, the following hypotheses are proposed:

H2a1: the age heterogeneity of board members inhibits the investment efficiency of refinancing enterprises.

H2a2: the older the mean age of board members, the higher the investment efficiency of refinancing enterprises.

Sex diversity of the board of directors may increase disagreements in major investment projects and impact investment efficiency. Females are more risk-averse than males, which is beneficial for risk control, but may lower efficiency. In terms of investment, slow progress may be made in investment decision-making due to cautiousness, and females may tend to avert conflicts and be less proficient in monitoring the tunneling by major shareholders and duty encroachment.

Moreover, due to China's vast territory and complex social structure, the influence of the gender equality ideology also varies significantly in different regions. There are also obvious differences in the concept of gender equality in different regions, resulting in the role of female board members being disadvantaged in some companies.

Therefore, the following hypotheses are proposed:

H2b1: sex heterogeneity of the board of directors inhibits the investment efficiency.

H2b2: female directors inhibit the investment efficiency of refinancing enterprises.

The overseas experience of board members would create overseas experience, but may be unable to adapt to the Chinese conditions and lower the investment efficiency. Thus, the following hypothesis is proposed:

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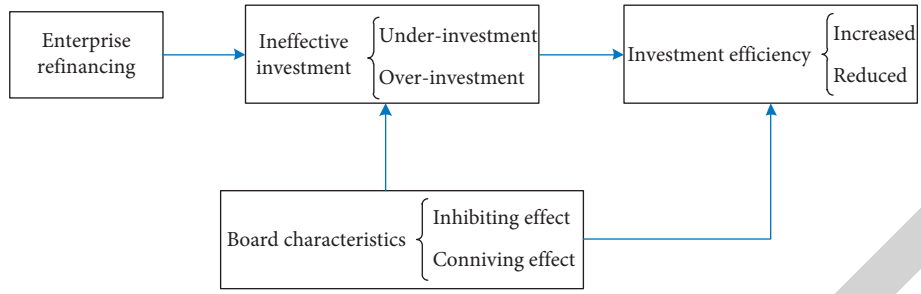

Figure 1: Influence mechanism of board of directors' characteristics for refinancing companies based on investment efficiency.

H2c: the overseas background of board members has a negative impact on the investment efficiency of refinancing enterprises.

4. Research Design

4.1. Data Source and Sample Selection. The data mainly consists of personal characteristics of top managers, which is taken from the CSMAR database, and of company characteristics, which is taken from the CSMAR and Choice databases. The research samples are A-shares from 2009 to 2020, excluding ST and *ST, financial enterprise, and private placement samples of back-door listings. After combination with the data of personal characteristics of top managers, 22,660 observed items are obtained. Considering the impact of extreme value, 1% and 99% winsorization is carried out for major continuous variables.

4.2. Variable Definition

4.2.1. Explained Variable. Investment efficiency (Inveffi): currently, there are three types of predominant models for the measurement of corporate investment efficiency: the investment—cash flow sensitivity model, cash flow—investment opportunity cross-sectional discriminant model, and residual measurement model. As explained by Richardson [30], the residual measurement model can directly measure whether the enterprise launches over- or underinvestment, with relatively robust results. Therefore, it has been widely applied to the measurement of investment efficiency by both domestic and foreign scholars.

Richardson's model is applied as follows:

$$\begin{aligned}\text{Inveff}i_{i,t} &= \alpha + \beta_1 \text{Growsh}_{i,t-1} + \beta_2 \text{Lev}_{i,t-1} + \beta_3 \text{Cash}_{i,t-1} \\ &+ \beta_4 \text{Age}_{i,t-1} + \beta_5 \text{Size}_{i,t-1} + \beta_6 \text{Return}_{i,t-1} \\ &+ \beta_7 \text{Inevest}_{i,t-1} + \sum \text{Year} + \sum \text{Industry} + \varepsilon_{i,t}.\end{aligned} \quad (1)$$

The investment efficiency is judged by the sign of the residual of the investment model. If it is positive, it shows overinvestment (OverInv), and the actual investment level of the enterprise is greater than expected, or it shows underinvestment (UnderInv). Investment efficiency (Inveffi): the absolute value of the residual is taken. The greater the absolute value of the residual, the lower the investment efficiency.

4.2.2. Explaining Variable

SEO: this has three forms: rights offering, issuing new shares, and convertible bonds. If the company chooses any of the three refinancing methods within a year, it will be defined as a refinancing company, and in terms of the measurement of refinancing behavior, it is valued as 1 in this paper, with a nonrefinancing company as 0.

Characteristics of board members: in this study, board members are defined as members of the board, disclosed in the annual report of listed companies. In terms of board heterogeneity, research is conducted on five variables (i.e., age heterogeneity, mean age, sex heterogeneity, women, and overseas background).

4.2.3. Control Variable. In this study, enterprise size, financial leverage, return on investment (*ROA*), cash holdings, sales growth rate, and establishment year are selected as the control variables from the company level, while major shareholder shareholding ratio, board size, and director's pay are selected as the control variables from the governance level. In addition, the impact of the year and industry on the regression results is controlled. The variable definition is shown in Table 1.

4.3. Modelling. Considering the possible endogeneity problem between SEO and overinvestment, the explained variables are lagged by one period in this study; thus, the influence of refinancing behavior on the following year's investment tendency of the enterprise is observed.

To verify hypothesis 1: SEO would lower the investment efficiency of the enterprise. Model (1) is established in this study, and regression analysis is conducted on the full sample.

$$\begin{aligned}\text{Inveff}i_{i,t} &= \alpha_0 + \alpha_1 SEO_{i,t-1} + \alpha_2 \text{Size}_{i,t} + \alpha_3 \text{Lev}_{i,t} \\ &+ \alpha_4 ROA_{i,t} + \alpha_5 \text{Cash}_{i,t} + \alpha_6 \text{Growsh}_{i,t} + \\ &+ \alpha_7 \text{Estage}_{i,t} + \alpha_8 Shrcr_{i,t} + \alpha_9 \text{BoardSize}_{i,t} \\ &+ \alpha_{10} \text{BoardPay}_{i,t} + \alpha_{11} \text{In}du + \alpha_{12} \text{Year} + \varepsilon,\end{aligned} \quad (2)$$

where α is a constant, α_i is the regression coefficient. If SEOt$_{-1}$ regression coefficient is positive, the investment efficiency of refinancing companies decreases.

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Table 1: Variable definition.

Variable type	Variable name	Variable symbol	Variable definition
Dependent variable	Ineffective investment	Inveffi	Absolute residual value of OLS regression based on the richardson model
Independent variable	Seasoned equity offering	SEO	If rights offering, secondary public offering, or a convertible bond is adopted within the year, the value is 1, otherwise 0
	Issuing new shares	NS	If issuing new shares (including private and public placements) is adopted within the year, it is 1, otherwise 0
	Rights offering	RO	If rights offering is adopted within the year, it is 1, otherwise 0
	Convertible bond	CB	If convertible bond is adopted within the year, it is 1, otherwise 0
	Age heterogeneity	Age*H*	Coefficient of variation is adopted (i.e., the specific value of the standard deviation to the mean value)
	Mean age	Age*M*	Mean age of all board members
	Sex heterogeneity	Sex	Calculated with herfindahl index
	Female ratio	Women	Ratio of female directors to all directors
	Overseas background heterogeneity	Oversea	Calculated with herfindahl index
	Company size	Size	The company's size is expressed by the natural logarithm of the company's total assets at the end of the period
	Financial leverage	Lev	Financial leverage is expressed as total liabilities divided by total assets
	Return on assets	ROA	Net profit/average balance of shareholders' equity
	Cash holdings	Cash	Ratio of monetary capital to total assets
	Sales growth rate	Growth	Current amount of operating revenue—amount of operating revenue in the same period of the previous year)/(amount of operating revenue in the same period of the previous year)
Control variable	Years of establishment	Estage	Years of establishment of the company
	Shareholding ratio of major shareholders	Shrcr	Shareholding of the largest shareholder divided by the total share capital
	Board size	BoardSize	Number of board members
	Director's pay	BoardPay	Taking the natural logarithm of the total remuneration of the top three directors
	Year	Year	Dummy variables for the year
	Industry	Industry	According to the *industry classification guidelines for listed companies,* issued by China securities regulatory commission in 2012, the value of the dummy variable is 1 if the sample enterprise belongs to the industry, and 0 otherwise

To verify hypothesis 2: the board heterogeneity of refinancing companies would impact the investment efficiency. Refinancing companies are selected for analysis, and model 2 is established. Board represents the characteristics of board members, and five variables, including AgeH, AgeM, Sex, Women and Oversea, are substituted in model equation (3) for regression analysis.

$$\begin{aligned} \text{Inveff}i_{i,t} &= \beta_0 + \beta_1 \text{Board}_{i,t} + \beta_2 \text{Size}_{i,t} + \beta_3 \text{Lev}_{i,t} \\ &\quad + \beta_4 ROA_{i,t} + \beta_5 \text{Cash}_{i,t} + \beta_6 \text{Growsh}_{i,t} + \\ &\quad \beta_7 \text{Estage}_{i,t} + \beta_8 Shrcr_{i,t} + \beta_9 \text{BoardSize}_{i,t} \\ &\quad + \beta_{10} \text{BoardPay}_{i,t} + \beta_{11} \text{In}du + \beta_{12} \text{Year} + \varepsilon. \end{aligned} \tag{3}$$

5. Empirical Analysis

5.1. Descriptive Statistics and Correlation Analysis. Samples are screened according to the requirements stated previously, and 23,963 samples from 2009 to 2020 are obtained. To eliminate the interference of outliers, 1% and 99% winsorization has been conducted for all continuous variables. First, basic descriptive statistics are conducted for related variables involved in model I. These results are shown in Table 2.

SEO companies account for 14.4%, mainly in the form of issuing new shares. Issuing new shares accounts for 12.9%. Rights offering accounts for 5%. Issuing convertible bonds accounts for 1.1%. Issuing new shares, especially private placement, makes it easier to obtain funds than rights offering, and is becoming more favored by the capital market. Convertible bonds also play a role in the refinancing market because of their flexibility in combining equity and debt. Since rights offering can only possess original shareholders, according to the shareholding proportion allotment, they lead to more restrictions and are used less by companies.

SEO listed companies from 2009 to 2020 are studied in model 2, and 6,034 variables are obtained. Refer to variable statistics in Table 3.

5.2. Regression Results and Analysis. The regression results of model 1 are shown in Table 4, which empirically tests the impact of SEO on the investment efficiency of enterprises. The correlation between SEO (1) and investment efficiency

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Table 2: Descriptive statistics of model 1.

Variable	Mean	Std. dev.	Min	Max
Inveffi	0.041	0.051	0.001	0.324
SEO	0.144	0.351	0	1
NS	0.129	0.335	0	1
RO	0.005	0.069	0	1
CB	0.011	0.103	0	1
Size	22.341	1.278	19.83	26.207
Lev	0.454	0.201	0.06	0.898
ROA	0.035	0.064	−0.255	0.211
Cash	0.166	0.112	0.014	0.585
Growth	0.158	0.43	−0.592	2.783
Estage	2.885	0.319	1.792	3.497
Shrcr	33.937	14.785	8.538	74.095
BoardSize	8.684	1.752	5	15
BoardPay	14.014	1.904	0	16.3

Table 3: Descriptive statistics of model 2.

Variable	Mean	Std. dev.	Min	Max
Inveffi	0.051	0.055	0.001	0.317
Age*H*	0.154	0.051	0.052	0.283
Age*M*	50.888	3.61	42.429	60
Sex	0.218	0.161	0	0.494
Women	0.147	0.128	0	0.556
Oversea	0.147	0.16	0	0.494
Size	22.173	1.254	19.826	25.971
Lev	0.418	0.199	0.056	0.876
ROA	0.044	0.058	−0.217	0.199
Cash	0.185	0.125	0.017	0.621
Growth	0.223	0.416	−0.535	2.439
Estage	2.785	0.378	1.609	3.466
Shrcr	34.391	14.833	8.544	74.976
BoardSize	8.581	1.658	5	15
BoardPay	14.199	0.848	10.309	16.217

variables is positive and significant at the 1% level, indicating that refinancing inhibits investment efficiency, which verifies H1. Among the three SEO methods, the relationship between issuing new shares (2) and investment efficiency variables is positive and significant at the 1% level, indicating that issuing new shares inhibits the SEO. The correlation between rights offering (3) and investment efficiency variables is positive, suggesting that it inhibits investment efficiency, but not significantly. The correlation between the convertible bond (4) and investment efficiency variables is negative, indicating that it promotes the investment efficiency, but not significantly.

The regression results of the verification of H2a by model 2 are shown in Table 5, which empirically verifies the impact of the age characteristics of board members on the investment efficiency of refinancing companies. According to the empirical results, the correlation between age heterogeneity and investment efficiency variables is positive and significant at the 1% level, suggesting that the higher the age heterogeneity of refinancing companies, the lower the investment efficiency. This verifies H2a1. The correlation between the mean age and investment efficiency variables is negative and significant at the 1% level, indicating that the older the age of directors in refinancing companies, the higher the investment efficiency. This verifies H2a2.

The regression results of the verification of H2b by model 2 are shown in Table 6 and empirically verify the impact of sex characteristics of board members on the investment efficiency of refinancing companies. They suggest that the correlation between sex heterogeneity of the board and investment efficiency of refinancing companies is positive and significant at the 5% level. This means that sex heterogeneity of the board inhibits investment efficiency of refinancing companies, which proves H2b1. The correlation between females and investment efficiency variables is positive and significant at the 5% level, suggesting that the more females, the lower the investment efficiency. This proves H2b2.

Regression results of the verification of H2c by model 2 are shown in Table 7, which verify the impact of overseas background of board members on the investment efficiency of refinancing companies. According to the empirical results, the correlation between overseas background heterogeneity and investment efficiency of invested companies is positive and significant at the 10% level, suggesting that the overseas background of directors inhibits investment efficiency of refinancing companies. This verifies H2c.

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Table 4: Regression results of the relationship between SEO and investment efficiency.

	(1) Inveffi	(2) Inveffi	(3) Inveffi	(4) Inveffi
SEO	0.006***			
	(0.001)			
NS		0.006***		
		(0.001)		
RO			0.008	
			(0.006)	
CB				−0.002
				(0.002)
Size	−0.001***	−0.001***	−0.001***	−0.001***
	(0)	(0)	(0)	(0)
Lev	−0.005**	−0.004*	−0.005**	−0.005**
	(0.002)	(0.002)	(0.002)	(0.002)
ROA	−0.001	−0.001	−0.001	−0.001
	(0.006)	(0.006)	(0.006)	(0.006)
Cash	−0.009***	−0.009***	−0.01***	−0.01***
	(0.003)	(0.003)	(0.003)	(0.003)
Growth	0.031***	0.031***	0.031***	0.031***
	(0.002)	(0.002)	(0.002)	(0.002)
Estage	−0.008***	−0.008***	−0.008***	−0.008***
	(0.001)	(0.001)	(0.001)	(0.001)
Shrcr	0***	0***	0***	0***
	(0)	(0)	(0)	(0)
BoardSize	−0.001***	−0.001***	−0.001***	−0.001***
	(0)	(0)	(0)	(0)
BoardPay	0	0	0	0
	(0)	(0)	(0)	(0)
Year	Controlled	Controlled	Controlled	Controlled
Industry	Controlled	Controlled	Controlled	Controlled
_cons	0.08***	0.08***	0.077***	0.076***
	(0.011)	(0.011)	(0.011)	(0.011)
Observations	23963	23963	23963	23963
R − squared	0.116	0.116	0.115	0.114

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

Table 5: Regression results of the relationship between age characteristics of board members and investment efficiency of refinancing companies.

	(1) Inveffi	(2) Inveffi
Age$H$	0.052***	
	(0.014)	
Age$M$		−0.001***
		(0)
Size	−0.001	0
	(0.001)	(0.001)
Lev	−0.006	−0.006
	(0.005)	(0.005)
ROA	0.008	0.013
	(0.015)	(0.015)
Cash	−0.026***	−0.023***
	(0.006)	(0.006)
Growth	0.034***	0.034***
	(0.003)	(0.003)
Estage	−0.002	−0.005**
	(0.002)	(0.002)
Shrcr	0	0
	(0)	(0)

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Table 5: Continued.

	(1) Inveffi	(2) Inveffi
BoardSize	−0.001***	−0.001**
	(0)	(0)
BoardPay	0.002*	0.001
Year	Controlled	Controlled
Industry	Controlled	Controlled
_cons	0.076***	0.121***
	(0.019)	(0.019)
Observations	6034	6034
R − squared	0.115	0.106

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

Table 6: Regression results of the relationship between sex characteristics of board members and investment efficiency of refinancing companies.

	(1) Inveffi	(2) Inveffi
Sex	0.009**	
	(0.004)	
Women		0.012**
		(0.006)
Size	−0.001	−0.001
	(0.001)	(0.001)
Lev	−0.007	−0.007
	(0.005)	(0.005)
ROA	0.007	0.007
	(0.015)	(0.015)
Cash	−0.026***	−0.026***
	(0.006)	(0.006)
Growth	0.034***	0.034***
	(0.003)	(0.003)
Estage	−0.001	−0.001
	(0.002)	(0.002)
Shrcr	0	0
	(0)	(0)
BoardSize	−0.001***	−0.001***
	(0)	(0)
BoardPay	0.002**	0.002**
	(0.001)	(0.001)
Year	Controlled	Controlled
Industry	Controlled	Controlled
_cons	0.082***	0.082***
	(0.019)	(0.019)
Observations	6034	6034
R − squared	0.114	0.114

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

6. Robustness Test

In this study, a variable substitution method is used to conduct the robustness test. The measurement method of investment efficiency (Inveffi) is consistent with model (1). The growth indicator is replaced with the Tobin Q value. Thereafter, the obtained investment efficiency index (Inveffi) replaces the original explained variable for the robustness test to be conducted. After the substitution of variables, the regression coefficient and its significance show no significant change, and the results are still robust.

The test results verifying the robustness of hypothesis 1 are shown in Table 8.

The correlation between SEO (1) and investment efficiency variables is positive and significant at the 1% level, indicating that SEO inhibits investment efficiency. This verifies H1 and is consistent with previous results. Therefore, the Robustness test passed.

The test results verifying the robustness of hypothesis 2 are shown in Table 9. The correlation between age heterogeneity and investment efficiency variables is positive and significant at the 1% level. This suggests that the higher the

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Table 7: Regression results of the relationship between overseas background of board members and investment efficiency of refinancing companies.

Inveffi	Coef.	St. err.	*t*-value	*p* value	95% conf interval		Sig
Oversea	0.009	0.005	1.95	0.051	0	0.018	*
Size	−0.001	0.001	−1.61	0.108	−0.003	0	
Lev	−0.006	0.005	−1.22	0.224	−0.017	0.004	
ROA	0.008	0.015	0.53	0.593	−0.022	0.038	
Cash	−0.026	0.006	−4.45	0	−0.038	−0.015	***
Growth	0.034	0.003	11.58	0	0.028	0.04	***
Estage	−0.001	0.002	−0.60	0.546	−0.006	0.003	
Shrcr	0	0	0.64	0.521	0	0	
BoardSize	−0.001	0	−2.86	0.004	−0.002	0	***
BoardPay	0.002	0.001	1.93	0.054	0	0.004	*
Year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	
Industry	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	
Constant	0.092	0.019	4.86	0	0.055	0.129	***
Mean dependent var		0.051		SD dependent var		0.055	
R-squared		0.114		Number of obs		6034	
F-test		8.329		Prob > *F*		0.000	
Akaike crit. (AIC)		−18424.098		Bayesian crit. (BIC)		−17974.852	

$^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

Table 8: Regression results of the relationship between SEO and investment efficiency (robustness test).

	(1) Inveffi	(2) Inveffi	(3) Inveffi	(4) Inveffi
SEO	0.008***			
	(0.001)			
NS		0.009***		
		(0.001)		
RO			0.007	
			(0.006)	
CB				−0.001
				(0.003)
Size	−0.001***	−0.001***	−0.001**	−0.001**
	(0)	(0)	(0)	(0)
Lev	0.007***	0.007***	0.007***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
ROA	0.055***	0.055***	0.055***	0.055***
	(0.006)	(0.006)	(0.006)	(0.006)
Cash	−0.009***	−0.009***	−0.009***	−0.009***
	(0.003)	(0.003)	(0.003)	(0.003)
Growth	0.002***	0.002***	0.002***	0.002***
	(0)	(0)	(0)	(0)
Estage	−0.009***	−0.009***	−0.009***	−0.009***
	(0.001)	(0.001)	(0.001)	(0.001)
Shrcr	0***	0***	0***	0***
	(0)	(0)	(0)	(0)
BoardSize	−0.001***	−0.001***	−0.001***	−0.001***
	(0)	(0)	(0)	(0)
BoardPay	0*	0*	0*	0*
	(0)	(0)	(0)	(0)
_cons	0.116***	0.115***	0.111***	0.111***
	(0.02)	(0.02)	(0.021)	(0.021)
Observations	22472	22472	22472	22472
R − squared	0.057	0.057	0.054	0.054

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

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Table 9: Regression results of the relationship between board members' characteristics and investment efficiency of refinancing companies (robustness test).

	(1) Inveffi	(2) Inveffi	(3) Inveffi	(4) Inveffi	(5) Inveffi
Age*H*	0.058***				
	(0.014)				
Age*M*		−0.001***			
		(0)			
Sex			0.009**		
			(0.004)		
Women				0.011**	
				(0.005)	
Oversea					0.013***
					(0.005)
Size	−0.001	0	−0.001	−0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Lev	0.004	0.002	0.003	0.003	0.004
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
ROA	0.077***	0.076***	0.076***	0.076***	0.077***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Cash	−0.031***	−0.031***	−0.031***	−0.031***	−0.032***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Growth	0	0	0	0	0
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Estage	−0.004*	−0.003	−0.004*	−0.004*	−0.004*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Shrcr	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)
BoardSize	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***
	(0)	(0)	(0)	(0)	(0)
BoardPay	0.001	0.001	0.001*	0.001*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
_cons	0.082***	0.126***	0.091***	0.091***	0.103***
	(0.02)	(0.02)	(0.019)	(0.019)	(0.019)
Observations	6139	6139	6139	6139	6139
R − squared	0.056	0.057	0.054	0.054	0.055

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

age heterogeneity in refinancing companies, the lower the investment efficiency, which verifies H2a1. The correlation between the mean age and investment efficiency variables is negative and significant at the 1% level. This indicates that the older the age of directors in refinancing companies, the higher the investment efficiency. This verifies H2a2. The correlation between sex heterogeneity of the board and investment efficiency of refinancing companies is positive and significant at the 5% level. This means that sex heterogeneity of the board inhibits the investment efficiency of refinancing companies, which proves H2b1. The correlation between females and investment efficiency variables is positive and significant at the 5% level, suggesting that the more females, the lower the investment efficiency. This proves H2b2. The correlation between overseas background heterogeneity and investment efficiency for invested companies is positive and significant at the 1% level, suggesting that the overseas background of directors inhibits the investment efficiency of refinancing companies. This verifies H2c and is consistent with the previous results. The Robustness test is passed.

7. Conclusion

With the state's encouragement of direct financing by enterprises and the development of the capital market in China, SEO has become an important approach for listed companies to obtain the development fund. With an in-depth application of the modern enterprise management philosophy in China, extensive attention has been paid to the governance ability of company management. In this study, SEO listed companies in China's A-share market from 2009 to 2020 are selected as the research sample, the influence of SEO on the investment efficiency of enterprises is verified,

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and the effect of board characteristics on investment efficiency of refinancing companies is studied further. The empirical results have shown that the following:

(1) SEO lowers investment efficiency. Among the three SEO methods, rights offering lowers investment efficiency, and so does the secondary public offering. However, the effect is not remarkable. Convertible bonds can enhance the investment efficiency unremarkably. Conversely, for obtaining fund through SEO, listed companies can compare the three methods to improve the investment efficiency of SEO.

(2) Age heterogeneity of board members inhibits the investment efficiency of refinancing companies. The older the mean age, the better the investment efficiency. This reflects the "experience" effect. While applying the SEO fund, younger directors shall listen to elder directors more often, to improve investment efficiency.

(3) Sex heterogeneity of board members inhibits the investment efficiency of refinancing companies. Female executives lower investment efficiency. They must give full play to their roles more actively, supervise the tunneling by major shareholders, and observe duty encroachment, to enhance the investment efficiency of refinancing companies.

(4) Overseas heterogeneity of board members inhibits the investment efficiency of refinancing companies. An overseas background broadens the horizon, but attention should be paid to whether the investment decisions adapt to the Chinese conditions. Strengths must be developed and weaknesses avoided, to give full play to their overseas experience.

Implications of the conclusion: firstly, among the three refinancing methods, additional issuance often leads to the decline of investment efficiency. Under the same conditions, from the perspective of investment efficiency, a better choice is to preferentially choose convertible bonds for SEO. Secondly, the age difference of the board of directors is too large, which sometimes creates more conflicts. Reducing such a difference appropriately and listening to the opinions of more experienced board members can improve investment efficiency. Thirdly, despite the continuous improvement of women's status in China, there is still room for improvement in the role of female members within the board of directors, which requires an improvement in their ability to perform duties, rather than increasing their numbers. Finally, board members with overseas backgrounds have many roles to play within the company, but their role in the company's investment efficiency is not satisfactory. The role of independent directors with overseas backgrounds is still worthy of in-depth consideration.

Data Availability

The data were collected from CSMAR database. Anyone who has registered in CSMAR can download the data we use in this work.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Retraction

Retracted: Reconstruction Design of Existing Residential Buildings Based on 3D Simulation Method

Discrete Dynamics in Nature and Society

Received 19 December 2023; Accepted 19 December 2023; Published 20 December 2023

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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) Manipulated or compromised peer review

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.

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[1] W. Bo and C. Mengjia, "Reconstruction Design of Existing Residential Buildings Based on 3D Simulation Method," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 8159213, 11 pages, 2022.

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Research Article

Reconstruction Design of Existing Residential Buildings Based on 3D Simulation Method

Wang Bo[1] and Chen Mengjia[2]

1Hunan Zhongda Design Institute Co., Ltd., Changsha, Hunan, China
2School of Architecture, Central South University, Changsha, Hunan, China

Correspondence should be addressed to Chen Mengjia; 171301011@csu.edu.cn

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The existing building reconstruction methods exist after three-dimensional building modeling information is not complete, and the wall insulation performance improvement effect is not obvious. Therefore, a reconstruction method of existing residential buildings based on 3D simulation is proposed. This paper analyzes the present situation of energy consumption of existing residential buildings, analyzes the fuzziness characteristic in the process of testing the thermal performance of existing residential buildings by the method of spatially distributed fusion and feature extraction, uses the fuzzy equilibrium scheduling method to decompose the fuzziness characteristic scale of the thermal performance of the thermal insulation of existing residential buildings, and optimizes the design of the thermal performance of the thermal insulation transformation of existing residential buildings. The 3D simulation software is a 3D modeling tool named 3DS Max. The real-time simulation software Unity3D engine is used to reconstruct the building scene and complete the reconstruction of existing residential buildings. The experimental results show that the information integrity of the building model reconstructed by 3D simulation technique is nearly 100%, and the insulation performance of the building wall is better.

1. Introduction

A large number of unrenovated existing residential communities are experiencing material aging and social decline, causing the decline of the old city as a whole, thus affecting the development of the whole city. Residential community occupies the largest proportion of land in the urban built-up area, and residential building occupies the highest proportion in the urban building stock. The old urban residential community is formed gradually in the long-term historical development process, and it is the epitome of urban development in each historical period. Judging from the current state of the city, most of the older existing houses are concentrated in the urban central area [1]. There are some problems in the existing residential communities, such as small scale of urban pattern, high density of population, high proportion of low-income population, obsolete infrastructure, and poor housing quality. Today, information technology has already become the production tool of the new era. In any industry, the application of information exchange and processing relying on computer technology has been popularized in most industries, among which the manufacturing industry and the electronic industry can be regarded as revolutionary changes, but the impact on the construction industry is still relatively low, the application of computer and digital technology in the construction industry is still immature, and the competition in the construction industry is becoming increasingly fierce. It is necessary to enhance the competitiveness and drive the modernization of the design industry by using information technology in this period. At the same time, with the construction industry low energy consumption, green and sustainable development requirements, strengthening the construction of information technology has become the future direction of construction [2, 3]. With the development of computer software and hardware, the emergence of

building information model provides a new solution to the above problems. It is a revolutionary technology from traditional 2D drawing to 3D design and construction. It is called the second technological revolution of the building industry. Three-dimensional simulation not only realizes the rapid development and upgrading of existing technology but also affects the change of design organization and management and will affect the change of people's thinking mode in the long run. From the design point of view, 3D simulation application is not only to improve the design efficiency and shorten the design cycle but also to improve the design quality and core competitiveness.

Reference [4] proposes a virtual space reconstruction method based on the principle of visual space orientation. Firstly, the spatial orientation is based on vision, and the geometric structure of visual spatial orientation is determined. Secondly, combined with the principle of VR technology, visual perception interaction is carried out. In order to maintain symmetry, the left and right viewing angles of the target are determined, and the target is fixed. Finally, in order to solve the conflict between VR system and users, the virtual space is corrected based on the central eye principle, including three processes, 3D image acquisition, image presentation, and virtual space perception, and the virtual space reconstruction is realized combined with the conflict derivation formula. Reference [5] carries out three-dimensional scene simulation and reconstruction based on the refinement of air ground integration and octree theory. The measurement data of the building scene is obtained by tilt photography, and the feature points are extracted. The error mathematical model of regional network is constructed between GCP, connection points, and connection lines, acquiring all image location elements and generating dense point clouds. According to the position of point cloud, texture mapping is carried out by combining virtual reality with matching the best viewing angle image so as to complete 3D modeling. Reference [6] proposes the energy-saving design of small buildings in summer with an intelligent cooling system and studies a new refrigeration control strategy. As a part of an intelligent energy system, this strategy balances thermal comfort and building energy consumption by using sensing and machine programming technology. In order to achieve this goal, the intelligent cooling system couples the general form of the building with energy consumption and personnel thermal comfort cooling simulated using EnergyPlus software and compares it with similar buildings without SCS. At the beginning of the study, using the data of hundreds of randomly selected survey groups, by analyzing and verifying the specific relationship between different groups in the statistical society, the body mass index and its thermal comfort temperature were obtained, and the sample buildings were modeled by EnergyPlus software. The results show that if the intelligent ventilation system which can calculate the thermal comfort temperature according to human BMI is adopted, the cooling load of buildings can be saved by 35% every year. Reference [7] proposes that, based on the example of public building projects in cold areas, the thermal insulation characteristic parameters of the enclosure structure are tested, and the results show that there is a large gap with the requirements of the current energy-saving standard. By reasonably setting parameters and using energy consumption simulation, the annual energy consumption difference of the enclosure structure before and after reaching the standard is compared. This paper deeply analyzes the energy-saving potential of different transformation schemes and the energy-saving sensitivity of different envelope structures, estimates the transformation costs of different schemes, takes into account the energy-saving effect and economic benefit, and determines the final energy-saving transformation scheme of maintenance structure.

However, the above literature methods have incomplete building information after three-dimensional modeling, and the improvement effect of wall insulation performance is not obvious. Therefore, a building reconstruction method of existing residential community based on a three-dimensional simulation method is proposed. Firstly, this method analyzes the current situation of building energy consumption in the existing residential community and uses the fuzzy equilibrium scheduling method to decompose the fuzzy characteristic scale of the thermal insulation performance of the building wall in the existing residential community under the limit search. The innovation of the research method is to optimize the thermal performance of thermal insulation transformation of existing residential community buildings. The information integrity of the reconstructed building model by three-dimensional simulation technology is close, and the thermal insulation performance of the reconstructed building wall is better.

2. Reconstruction of Existing Residential Community Buildings Based on Three-Dimensional Simulation Method

2.1. Current Situation of Building Energy Consumption in Existing Residential Communities. Before the research of the key technology of the wall structure rebuilding, the actual building energy consumption status in hot summer and cold winter areas is briefly understood.

The total energy consumption of buildings includes the energy consumption of public buildings, residential buildings, and other buildings, and the energy consumption of residential buildings includes the existing residential community buildings and dormitories, among which the existing residential community buildings account for about 93%. Therefore, the energy consumption of residential buildings is the key component of the energy consumption of buildings [8].

Heat loss in existing residential buildings is an important factor of energy loss at this stage, which is caused by heat transfer of wall structure and heat infiltration of air in windows and doors. According to the related data, the heat consumption of the wall structure is about 70 ~ 81%. Thus, in the green residential energy-saving planning, the first is to solve the wall structure thermal insulation function [9, 10].

In order to deeply study the energy consumption situation of existing residential buildings in hot summer and

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cold winter areas, it is envisaged that no hot water system shall be used indoors, gas shall be turned off, the exterior of the buildings shall include landscape lighting, the exterior lighting load shall not enter indoors, the windows shall use 3.0 mm thick low-radiation single-layer glass, and there shall be no external shading facilities [11, 12]. Common tile is laid on the ground, the roof has better heat insulation performance, and the wall is 220 mm heavy wall. According to the above reference conditions, input summer hot winter cold climate factors and other required parameters, to air conditioning power consumption as a criterion, the specific results as shown in Figure 1.

Figure 1 simulates the air conditioning power consumption from January to December in winter and summer. It can be seen that the highest energy consumption of air conditioning is in July and August, no matter which building wall insulation scheme is used. Taking July as an example, the air conditioning energy consumption in winter and summer is 18.5 kWh/m^2 and 19.9 kWh/m^2.

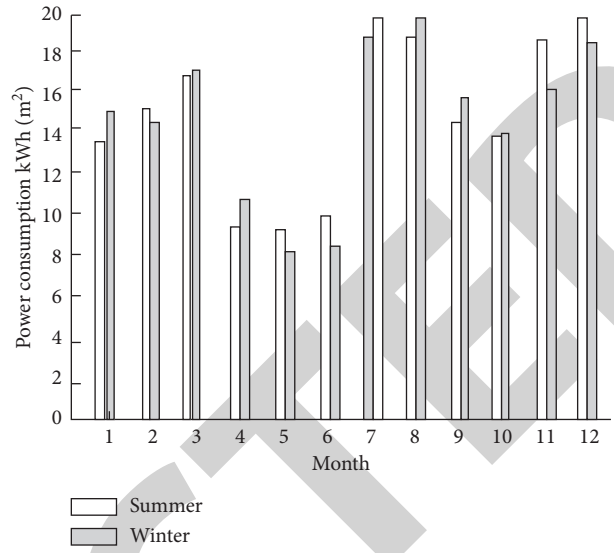

Figure 1: Schematic diagram of building energy consumption in the existing residential community.

2.2. Calculation and Fusion of Thermal Performance Parameters. The fuzziness characteristic of the heat preservation and transformation of the wall of the existing residential community is analyzed by the method of spatially distributed fusion and feature extraction, the fuzziness characteristic scale decomposition of the heat preservation and transformation of the wall of the existing residential community is decomposed by the fuzzy equilibrium scheduling method under the extreme search, and the optimization design of the test model of the heat preservation and transformation of the wall of the existing residential community is conducted [13–16].

The characteristic quantities of thermal performance distribution of wall insulation transformation of existing residential community buildings are $\widehat{R}_{r1}(T_{r1}^0) \le \overline{R}_{2r}(W_2^0)$ and $\widehat{R}_{r2}(T_{r2}^0) \le \overline{R}_{1r}(W_1^0)$. Transform the thermal performance test problem of thermal insulation transformation of building walls in existing residential communities into an optimization problem:

$$\min_{\{W_1, W_2\}} = \mathrm{Tr}\left\{W_1 W_1^H + W_2 W_2^H\right\}. \tag{1}$$

Combined with the method of space ambiguity detection, the operation and maintenance parameters of the thermal performance test of the wall insulation rebuilding in the existing residential community are analyzed, the correlation eigenvalues of the thermal performance test of the wall insulation rebuilding in the existing residential community are extracted to obtain the optimal parameters T_{r1}^0 and T_{r2}^0, the convergence constraint method is adopted to control the process of the thermal performance test of the wall insulation rebuilding in the existing residential community, and all the characteristic solutions are satisfied with $R^{\mathrm{mac}}(W_1, W_2) \ge R^{bc}(T_{r1}^0, T_{r2}^0)$.

Using the adaptive parameter fusion method, the in-depth learning function of thermal performance test of wall insulation transformation of existing residential community buildings is obtained as follows:

$$\begin{aligned} &\min_{\{\mathbf{T}_{r1}, \mathbf{T}_{r2}\}} \mathrm{Tr}\left\{T_{r1} T_{r1}^H + T_{r2} T_{r2}^H\right\}, \\ &\text{s.t. } \widehat{R}_{r1}(T_{r1}) + \widehat{R}_{r2}(T_{r2}) > R^{\mathrm{mac}}\left(W_1^0, W_2^0\right). \end{aligned} \tag{2}$$

The optimal solution to the problem has a closed form. The optimal characteristic of the thermal performance test of the wall insulation transformation of existing residential community buildings is T_{rj}. The fuzzy control method can be used to test the thermal performance of the wall insulation transformation of existing residential community buildings. Combined with the fuzzy parameter optimization method, the structural design of the wall insulation parameter optimization fusion model is carried out.

2.3. Reconstruction of Exterior Wall Based on Heat Transfer Performance Coefficient. The nontransparent wall structure is to change the thickness of the insulation layer to obtain the design heat transfer performance coefficient. If the insulation thickness is too small, the heat transfer performance coefficient will become larger, resulting in more building heat loss [17]. If the thickness of insulation layer is too small, the economic investment will become more. Using the technology for reference to meet the requirements of heat transfer performance coefficient of inner wall structure, the thickness of insulation layer is 120 ~ 340 mm, the step size of simulation variable is 30 mm, the relative heat transfer performance coefficient of the outer wall is 0.198 ~ 0.084 W/(m^2·K), and the heat transfer performance coefficient of the roof is 0.175 ~ 0.063 W/(m^2·K).

In cooler climates, the key is to ensure that the building is well insulated [18–20]. Enhanced insulation level can not only reduce energy consumption but also achieve a higher indoor temperature in winter and improve residential comfort in summer at a lower surface temperature. The process of energy consumption with the thickness of insulation layer is shown in Figure 2.

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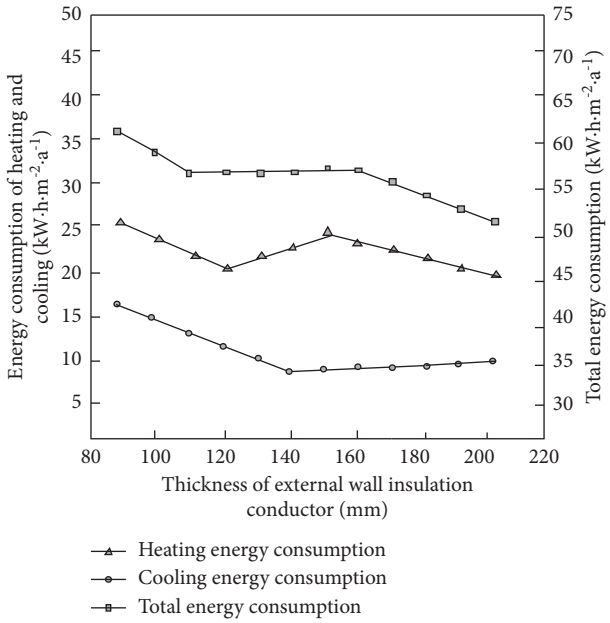

Figure 2: Variation of energy consumption with a thickness of external wall insulation layer.

It can be seen from Figure 2 that the thickness of the insulation layer of the wall structure increases from 120 to 340 mm, the heat transfer performance coefficient decreases significantly, the heating energy consumption and total energy are decreasing, and the change range of cooling energy consumption is not high. The reason for this phenomenon is that the heat transfer performance coefficient of the wall structure decreases, reducing the heat consumption of the foundation of the wall structure [8, 21]. If the insulation thickness is less than 230 mm, the energy consumption for heat supply shall exceed the annual heating demand criteria for buildings with near-zero energy consumption in cold areas set forth in the technical guidelines; if the thickness of the insulation layer of the external wall is more than 280, the energy consumption shall be changed slightly, the effect of energy conservation is not obvious, and then the increase of the thickness of the insulation layer will cause the increase of the construction cost. Therefore, on the basis of considering the reference value of the technical guideline planning, real energy-saving achievements, and economic cost, the exterior wall insulation materials of near-zero energy consumption buildings in hot summer and cold winter areas are transformed into thick graphite polystyrene insulation panels [6, 22].

From the perspective of energy-saving rate, the correlation among heat transfer performance coefficient, energy-saving rate, and sensitivity coefficient of exterior wall is shown in Figure 3. Sensitivity coefficient is the change of the influence elements in the possible values. This paper explores and evaluates the influence of the change of the influence elements on a certain or a group of evaluation indexes.

It can be seen from Figure 3 that when the heat transfer performance coefficient of the outer wall is between 0.198 and 0.06 W/(m^2·K), the energy-saving effect decreases with the decrease of the heat transfer coefficient [23, 24].

2.4. 3D Simulation System Settings. Generally, the range of indoor 3D simulation scene is large, the number of simulation models in the scene is large, the scene is complex, and the amount of data is large. The system not only needs to realize the fidelity of the simulation environment but also needs to obtain good real-time and interactive performance. Therefore, the hardware configuration is CPU 2.99 GHz; main memory is 3.63 GB; graphics display card is E8400. The operating system is based on Microsoft's Windows XP Professional 2002. Windows 2002 is based on an NT technology framework; the kernel is powerful and stable, with a friendly human-computer interaction interface, is the mainstream operating system, supporting multithreading technology, and is conducive to real-time simulation to ensure friendly and timely human-computer interaction.

2.4.1. 3D Modeling Tool 3DS Max. 3DS Max is a 3D model and animation rendering software developed by Autodesk Company. It is widely used in advertising, film and television, industrial design, architectural design, multimedia production, games, auxiliary teaching, and engineering visualization. Compared to the same type of 3D modeling software, SketchUp, 3DS Max has many advantages in model optimization, texture rendering, and finesse. Its advantages include the following:

(i) Powerful function and good expansibility. 3DS Max has the formidable modeling ability, has the formidable superiority in the role modeling and the animation manufacture aspect, and has many plug-ins to be able to help the user to carry on the work conveniently.

(ii) Simple operation and convenient use. 3DS Max is arguably the easiest 3D software to get started with.

(iii) The stability of the software is high; compatibility is good.

(iv) The effect is very realistic. So this system uses 3DS Max as the tool for making indoor 3D models.

3DS Max is mainly used for modeling objects, environment scenes, and roles in 3D display and can export models in other file formats through related plug-ins, such as *osgb files by using OSG -for-3 ds Max plug-ins, which allow plug-ins to extend the features of the model to provide a lot of convenience for expansion and application. In 3DS Max software, we can use different kinds of modeling methods to choose the appropriate modeling methods according to the structure characteristics of modeling objects. The common modeling methods include basic geometry modeling, surface raster modeling, composite object modeling, and graphical modeling. 3DS Max has powerful functions in animation rendering, polygon processing, mesh smoothing generation, material parameter design, and so on. In the process of modeling, it is very important to choose different modeling methods according to the characteristics of objects. Using the way of changing view angle, we can visually and intuitively observe the concrete shape of the object and improve the efficiency of model design.

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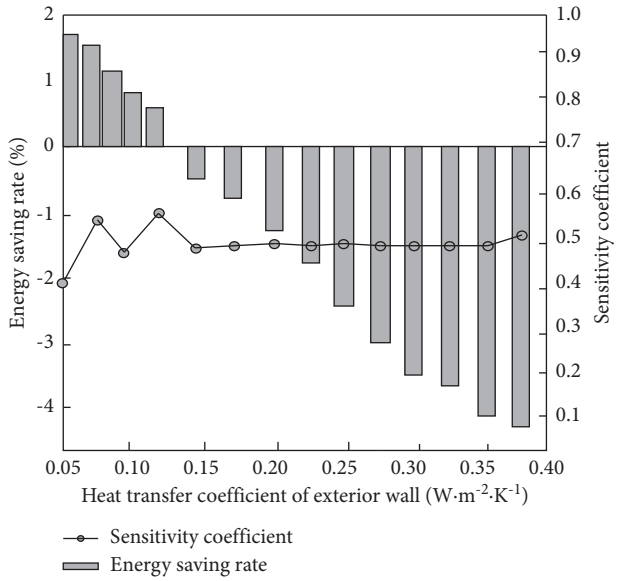

Figure 3: Correlation between heat transfer performance coefficient of exterior wall and energy-saving rate and sensitivity coefficient.

2.4.2. Real-Time Simulation Software Unity 3D Engine. Unity 3D is a multiplatform game development engine developed by Danish Unity Technologies. It is a fully integrated professional game production tool. Unity engine is very powerful. One of its most remarkable features is cross-platform development. Game software or simulated reality system made with Unity 3D can be released on PC, MAC, Android, and mainstream home game console platforms launched by Microsoft, Nintendo, and Sony. Once launched, it is favored by game and simulated reality developers; it has become a 3D production engine with rapid development in recent years.

Unity 3D engine is a hierarchical development environment, which can provide users with a very perfect graphical interface, with visual editing, detailed attribute editing, and dynamic scene preview functions. Unity 3D engine integrates rich development resources, mainly including terrain making tools, common scripts, physical engines, particle systems, lighting modules, rendering modules, collision detection components, and processing methods for setting images. More importantly, Unity 3D engine also provides users with a powerful class library: mono behavior. In this class library, developers can easily call these methods for function development through various defined methods. Unity3D is not only widely used in the game field but also widely used in 3D simulation, 3D product display, 3D simulation exhibition, and 3D scene navigation. Unity3D is a unique 3D engine. The rendering, scheduling management, and simulation driving of the simulation scene adopt the graphical user interface that can operate flexibly in the Unity 3D engine environment to complete the configuration and driving graphics and use mono behavior class library and C# language application program interface API to flexibly realize system functions.

2.4.3. Auxiliary Software. In addition to the modeling software and driver software, AutoCAD software/Photoshop image processing software is also used in the auxiliary aspect. AutoCAD software is used to receive and process the CAD drawings of the indoor plane.

In the indoor 3D simulation interactive system, the core content is to build a 3D simulation environment to reflect the real scene. In the process of modeling, different modeling methods are selected for different types of entities, which can reduce the complexity of the model and improve the lifelike effect. In this paper, we choose geometric modeling technology to construct an indoor simulation environment. Firstly, we obtain the vector data and texture data based on the indoor environment plane diagram and photographic photos. Secondly, we use geometric modeling technology to construct the entity scene and indoor objects model and then process the model by texturing, hiding, and transparent culling. Figure 4 shows a flowchart for modeling an indoor simulated environment.

2.5. Building Scene Reconstruction Based on 3D Simulation Method. The three-dimensional simulation method is used to match the feature points of the building simulation scene [25]. The traditional 3D simulation reconstruction method needs to calculate the mapping matrix ζ of the view; that is,

$$\lambda_j \cdot x_j = \zeta \cdot X_j. \tag{3}$$

In the formula, x_j represents a plane image point, X_j represents a three-dimensional point opposite it, and λ_j represents a depth parameter. However, in practical applications, it cannot achieve the effect of error-free shooting, angle, and depth, other conditions between the captured images cannot be unified, and these defects will interfere with the reconstruction effect [26].

Aiming at the above problems, this paper uses the iterative factorization method to match the feature points of multiple views. The iterative results of rotation matrix R, shift vector T, and depth matrix λ, instead of the mapping matrix in the traditional method, can be used in the spherical coordinates to reduce the error caused by calculating the depths of two graphs [27].

The factorization algorithm is proposed according to the orthogonal projection environment. Based on this idea, a large number of affine and photographic models are proposed [28]. Based on the characteristics of spherical coordinate system, the relative motion parameters of image sequences are obtained according to the following algorithms in the environment of known matching points, but no camera parameters. Assume that the expression for the position of the plane point is

$$\lambda_j^i \cdot x_j^i = \lambda_j^i \cdot R_i \cdot x_1^i + T_j. \tag{4}$$

In the formula, $i = 1, 2, \ldots, n$ represents the feature points, $j = 1, 2, \ldots, m$ represents the number of images, λ represents the scaling parameters relative to the feature points, R and T represent the rotation matrix and translation vector, respectively, and R_j and T_j represent the changes in

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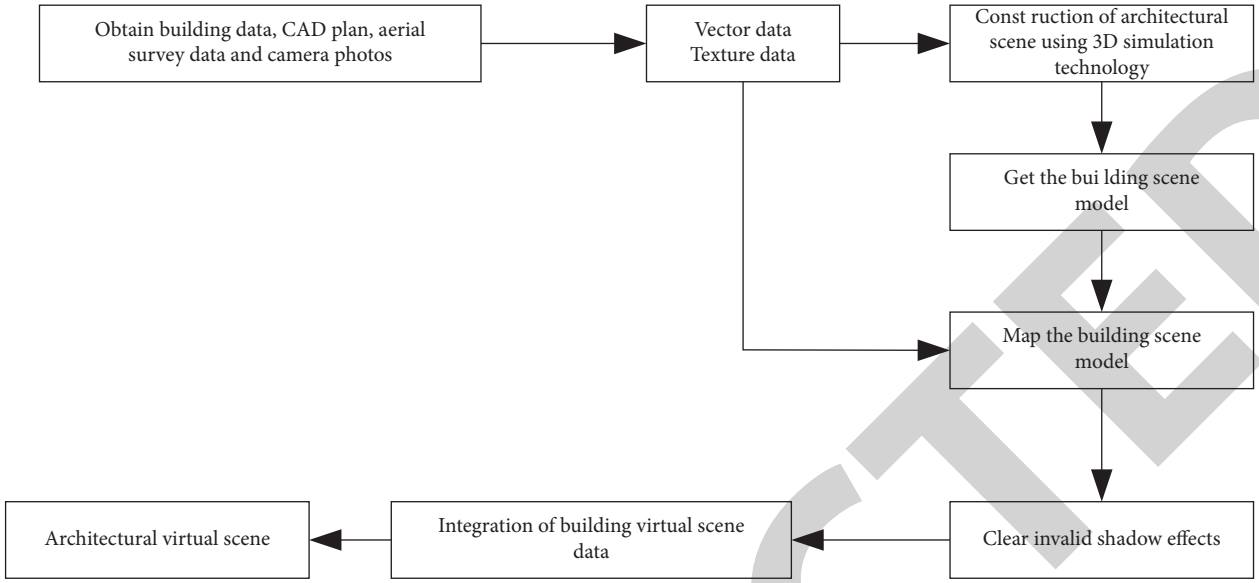

Figure 4: Flowchart of simulation environment modeling.

the comparison between the j frame image and the first frame image.

According to the set of feature points, P_i is assumed to be a feature point on image I_i^{new}, and this point corresponds to point P_{i+1} on image I_{i+1}^{new}. If their corresponding points in 3D space are represented as X, the aim of reconstruction is to calculate X. Through the process of polar correction, it is determined that the relative points of p_i and p_{i+1} in the initial coordinate system are H and J, respectively.

$$\begin{aligned} T_{i+1}^{-1} \cdot p_1^h &= P_i \cdot X^h, \\ T_{i+1}^{-1} \cdot p_{i+1}^h &= P_{i+1} \cdot X^h. \end{aligned} \tag{5}$$

2.6. Construction of Index System. Drainage system, building planning, lighting and electrical system, heating and refrigeration system, and enclosure structure are selected as the criterion layer of the index system. The energy-saving renovation technology of existing residential buildings uses positive and negative ideal points to deal with the indicators. Converting the low optimal index into the high optimal index, the structure energy consumption evaluation index is treated by the same chemotaxis.

$$x_{ij}' = \begin{cases} x_{ij}, & \text{optimal index,} \\ \dfrac{1}{x_{ij}}, & \text{worst indicator,} \\ \dfrac{F}{F + \left| x_{ij} - F \right|} & \text{general indicators.} \end{cases} \tag{6}$$

In the formula, x_{ij} represents the indicator value, x_{ij}' represents the value of the indicator after convergent processing, and F represents the set of samples.

Set normalized matrix $B = (b_{ij})_{n \times m}$ with the following expression:

$$B = \left(b_{ij}\right)_{n \times m} = \begin{bmatrix} b_{11} & \cdots & b_{1m} \\ \cdots & \cdots & \cdots \\ b_{n1} & \cdots & b_{nm} \end{bmatrix}, \tag{7}$$

where element b_{ij} can be calculated by the following formula:

$$b_{ij} = a_{ij} \div \sqrt{\sum_{i=1}^{n} a_{ij}^2}. \tag{8}$$

Because of different units, energy consumption evaluation indexes of the building envelope cannot be unified, and the influence on index weight is not considered. It is necessary to standardize energy consumption evaluation indexes. The proposed method uses the vector normalization method to deal with the evaluation index of energy consumption of building envelope structure. A is used to describe the evaluation index matrix of energy consumption of building envelope structure, which is composed of N samples, and its expression is as follows:

$$A = \left(a_{ij}\right)_{n \times m}. \tag{9}$$

In the formula, a_{ij} represents matrix elements. After the normalization of the above formula, the index values are taken in the [0, 1] interval.

Let d_i^+ represent the Euclidean distance from the positive ideal solution to scheme x_i, and d_i^- represent the distance between the negative ideal solution and scheme x_i, which can be calculated by the following formula:

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$$\begin{cases} d_i^+ = \sqrt{\sum_{j=1}^{m} \left(b_{ij} - b_j^+\right)^4} \\ d_i^- = \sqrt{\sum_{j=1}^{m} \left(b_{ij} - b_j^-\right)^4} \end{cases} \quad (10)$$

Let f_i represent the closeness between the positive ideal solution and each sample case, and its calculation formula is as follows:

$$f_i = \frac{d_i^-}{d_i^- + d_i^+}. \quad (11)$$

2.7. Transformation Measures

2.7.1. Building Structure Optimization. Due to the economic and technical reasons, the layout, shape, and orientation of the existing residential buildings are "facts achieved," which greatly restrict the creativity of architects and engineers, but can only be "reconstructed" on the original basis, and it is difficult to make great changes to the original architectural shape. Therefore, the original shape and structure shall be faithfully followed in the renovation, the existing residential buildings shall not be dismantled or altered arbitrarily, and some necessary improvements shall be made prudently so as to meet the required functional and aesthetic requirements. Complete and meticulous design, quality materials, correct construction methods, and good sense of scale are the necessary conditions for creating a livable environment. The original building for additional or partial reconstruction, so that the existing residential building has a rich sense of hierarchy, is the architectural designer in the transformation of common practices.

The renovation and transformation of the existing single residential buildings shall be based on the principle of being as close as possible to the existing living standards; that is, the area standards and equipment standards shall meet the requirements of modern house types as much as possible, and at the same time, the specific housing needs and payment capacity of each family shall be taken into consideration, and the corresponding schemes and standards shall be formulated according to the specific conditions of specific objects.

The adjustment and reconstruction of the interior space of a single dwelling house is the focal point of the renewal and reconstruction of the interior space of the single dwelling house. Key measures include (vertical and horizontal) expansion.

On the basis of basically reserving the existing buildings, the extension is to build new entities on the basis of the structure of the original buildings or within the close space scope through certain technical measures to supplement and expand the space of the original buildings, which can be divided into longitudinal extension and horizontal extension. The Longitudinal Method of Adaptability and Reuse In the Reconstruction of Existing Residential Buildings, Scale Reconstruction is a common method [29]. The scale characteristics of the building can make the building show the proper expected effect, change the original building scale sense, and make the reconstruction of the building look new. Usually, after the existing residential buildings are used for a period of time, it is often found that the space cannot meet the needs. When the original structure and sunshine spacing allow, it can develop to the upper space. This addition form can not only increase the use area of the building but also improve the use function of the building. In addition, it can also reinforce the existing structural hidden dangers. Through the storey addition and reconstruction of existing residential buildings, the land use rate is improved. Under the condition of unchanged floor area, the building area is increased, the plot ratio is improved, the project cost is reduced, and the service life of buildings is prolonged. Therefore, the storey addition and reconstruction of existing buildings has obvious social and economic benefits [30]. Strictly speaking, there are two kinds of vertical storey adding reconstruction methods: one is to directly add a slope roof with certain utilization space on the flat roof of existing residential buildings, that is, the common flat to slope transformation; the other is to directly add a flat floor with a net height of more than 2.2 m on the flat roof of the existing residential building and add a slope roof on the newly added flat floor. Here, the two reconstruction methods are defined as adding sloping roof reconstruction method and adding storey reconstruction method.

2.7.2. Energy Consumption Technology Optimization. Solar energy is a clean, efficient, and never depleted new energy with safe, reliable, noiseless, pollution-free advantages; the use of solar energy can generally be divided into passive solar energy technology, active solar energy technology, and solar photovoltaic technology (natural lighting is not discussed here).

(1) Utilization of passive solar energy in the transformation of existing residential construction. In the transformation, designers should not only understand the amount of solar radiation in the area where the building is located. For example, Taiyuan City has sufficient light, abundant light, energy and heat. The annual total sunshine hours are 2360 to 2796 hours, and the annual total solar radiation is 5442.8 megajoules per square meter to 5652.18 megajoules per square meter, which belongs to the scope of the national high illumination rate. Moreover, possible occlusions of surrounding buildings and plants (to be avoided by lighting surfaces or collectors during the heating season) should be obtained through site surveys, which should be used as the basis for the design of passive solar buildings [31,32]. Usually, the lighting surface or collector should face south as far as possible but needs to be analyzed in specific circumstances. For example, public buildings that need heating early in the morning and do not need heating in the evening and in the evening, orientations to the south and east are better; in areas where there is morning fog and cloudy, and buildings used mainly at night, orientations to the west can be used. The area of the

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window opening should be determined according to the heat balance of the heating and refrigeration season.

(2) Active solar energy utilization and solar photovoltaic technology.

In order to avoid shielding, solar collectors are often combined on the roof of buildings, and their inclination has some empirical values to refer to: when used to prepare hot water, the empirical value of the inclination angle (the angle between the collector and the horizontal line) is equal to the latitude value of the area where the device is located; when used for heating, the empirical value is latitude plus 15° (with a slight deviation from these optimized angles, the effect is good). How to integrate solar collector with architecture has been a hot issue in recent years. Discussions in Taiyuan are currently focused on how to integrate the collector of the water heater with the building [33,34]. In recent years, other big cities have developed some heat collection systems that can be perfectly combined with exterior walls and windows. Because these devices can be considered together with the building structure, they have a strong overall feeling with the building.

3. Experimental Test and Analysis

In order to verify the functionality and practical significance of the reconstruction of existing residential community buildings based on the three-dimensional simulation method, experiments are carried out to verify it. Taking a typical city with hot summer and cold winter as an example, an existing residential community building in an area of the city is selected to verify the practicability of the reconstruction technology in this paper and the wall structure optimization method defined in the above research is integrated, Research on energy consumption simulation of model buildings. Existing residential community building room internal structure set for the master bedroom, second bedroom, balcony, bathroom, kitchen, and so on. The heat disturbance in a room is the default value of the system, the maximum power for adjusting lights is 10 W, and the "definition of ventilation scope" is selected for indoor ventilation. The minimum number of ventilation times in a room and outside is 2/h when the air conditioner is turned on in winter and summer, the number of ventilation times is set to 5/h when the air conditioner is not turned on in summer, the maximum number of ventilation times in an indoor and outside is 5/h, and then the calculation result of the building load of the existing residential community is shown in Table 1.

According to Table 1, through tape measure, vibration excitation equipment, vibration pickup (sensor), coupling agent, foundation pile dynamic tester, and so on, build the on-site test environment for the detection technology of building reconstruction in existing residential communities. In the on-site layout, the excitation equipment is made of iron, with a mass of 6.13 kg and a pulse width of 1.35 ms; the main frequency is 1480 Hz; the force value is greater than 8 kN; the percussion method is vertical percussion; the percussion frequency is once in 2S. The sensor used is a piezoelectric acceleration sensor. The sensor has high acquisition accuracy and strong anti-interference. It is suitable for on-site industrial measurement, laboratory testing, and instruments. Sensor operation: at least 2 measuring points shall be arranged, and the reflected wave signal shall be collected at the sampling frequency of 0.2 Hz/s. The adopted pile dynamic tester is RS-1616W(L), which has a high-performance processor, main frequency of 1.5 GHz, and running memory of 1 GB; Android operating system and simple and convenient touch screen operation; on-site multihammer superposition and average signal to realize real-time upload of the waveform of each hammer; multihammer waveform that is displayed in the same box to automatically screen invalid data; data files that can be uploaded to the cloud server to realize remote real-time transmission and management of field data; professional data processing and analysis software with comprehensive functions, flexible print settings, rapid analysis of test data, and generation of the test report.

The three-dimensional simulation modeling results of 3DS MAX software are shown in Figure 5. The building after simulation modeling is used to simulate and test the energy consumption improvement effect of building wall.

In order to verify the thermal performance of thermal insulation transformation of the existing residential community building wall, the experimental sample wall is taken to test the thermal insulation performance of the existing residential community building wall.

The reconstruction integrity of different methods is compared, and the results are shown in Figure 6. Among them, the reconstruction integrity of 3D simulation building is expressed by 0% ~ 100%. The larger the value, the higher the 3D simulation building integrity, and vice versa.

It can be seen from the analysis that the integrity of the building simulation scene reconstructed by the method in this paper is significantly higher than the three-dimensional simulation building reconstruction method based on the octree theory proposed in reference [5] and the building structure energy-saving reconstruction method based on public building engineering in cold areas proposed in reference [6], and its maximum value is close to 100% The maximum value of the proposed three-dimensional simulation building reconstruction method based on the octree theory and reference [6] building structure energy-saving reconstruction method based on public building projects in cold areas is less than 50%. This is because this method calculates the depth confidence values of all sampling points and sorts the calculation results, which avoids the repeated fusion of multiview 3D sampling points, and improves the integrity of image 3D simulation.

To sum up, the reconstruction method of existing residential community buildings based on the three-dimensional simulation method has better thermal insulation performance of external walls, which can effectively complete the reconstruction of building scenes and realize the reconstruction of existing residential community buildings.

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Table 1: Building load of the existing residential community.

Statistical items	Company	Statistical value
Building air conditioning area	m^2	236.54
Annual maximum heat load	kW	22.02
Maximum cooling load of the whole year	kW	45.56
Annual cumulative heat load	kWh	5714.22
Annual cumulative cooling load	kWh	1589.33
Annual maximum heat load	W/m^2	90.13
Maximum cooling load of the whole year	W/m^2	667.09
Annual cumulative heat load	kWh/m^2	12.34
Annual cumulative cooling load	kWh/m^2	8.36
Heat load index in heating season	W/m^2	9.12
Air conditioning seasonal cooling load index	W/m^2	1.45

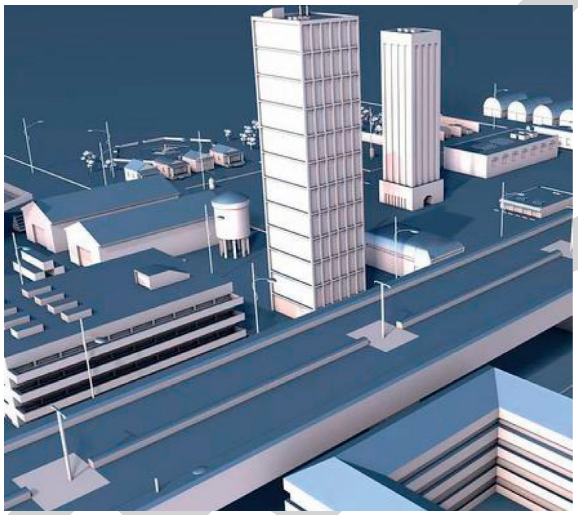

Figure 5: 3D simulation modeling results of 3DS MAX software.

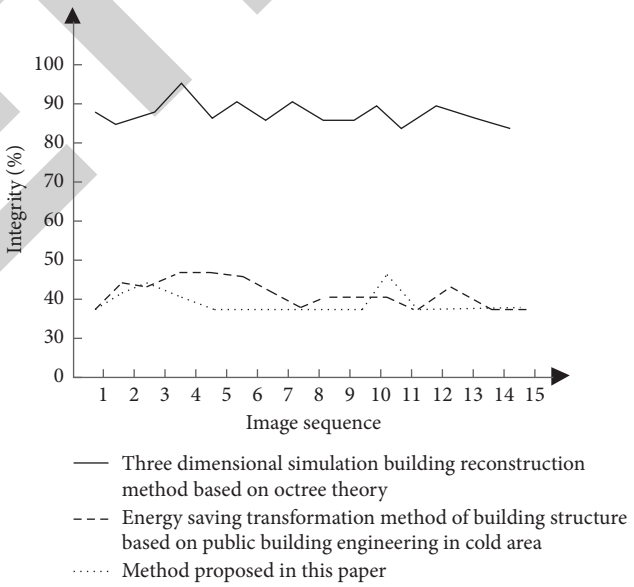

Figure 6: Comparison of reconstruction integrity by different methods.

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4. Conclusion

In order to solve the problems of incomplete building information after 3D modeling and ineffective improvement of wall insulation performance, a new reconstruction method of existing residential buildings based on 3D simulation is proposed. The fuzzy degree of thermal performance of the wall insulation retrofit is analyzed, and the fuzzy equilibrium scheduling method is used to decompose the wall insulation feature scale. The 3D modeling tool 3DS Max is used as the 3D simulation method, and the real-time simulation software UNITY3D engine is used to complete the reconstruction of building scenes and the transformation of existing residential buildings. The experimental results show that the information integrity of 3D simulation technology is higher, and the thermal insulation performance of the reconstructed wall is better, which can provide a reliable research basis.

Data Availability

The raw data supporting the conclusions of this paper will be made available by the authors, without undue reservation.

Conflicts of Interest

The authors declared that they have no conflicts of interest regarding this work.

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Retraction

Retracted: Digital Service Model of Red Educational Resources from the Perspective of Excellent Traditional Culture

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] D. Liu, "Digital Service Model of Red Educational Resources from the Perspective of Excellent Traditional Culture," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7899809, 9 pages, 2022.

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Research Article

Digital Service Model of Red Educational Resources from the Perspective of Excellent Traditional Culture

Dan Liu

School of Law, Shangqiu Normal University, Shangqiu, Henan 475000, China

Correspondence should be addressed to Dan Liu; liudan@sqnu.edu.cn

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In view of the poor service effect caused by the incomplete index base of the traditional red education resources digital service model, this paper puts forward the red education resources digital service model from the perspective of excellent traditional culture. Determine the influencing factors of red education resources in the integration process, integrate the remote scheduling principle of teaching information into the feature vector extraction of red education resources, extract the number of main factors of the feature vector, decompose the feature vector of red education resources, take the wavelet entropy of red education resources as the fusion weight, and integrate the obtained coefficients through wavelet transformation. Get the integration results of red education resources. Build the architecture of digital service model, grab all web pages on the Internet with indexer, and create forward index and reverse index. Use the controller to search web pages and control all web pages to be searched. Restrict query conditions through user interface. Establish a red education resource data index database, query and process documents, and build a digital service model. The experimental results show that the designed service model has good goodness of fit and high performance.

1. Introduction

In the process of building the digital service model, attention to the digital service of the revolutionary and traditional red education resources in education is put on the agenda [1, 2]. In order to meet the digital needs of civic education, reflect the personalized services of characteristic education resources from the perspective of excellent traditional culture in civic education, and give play to the application of information technology in the "moral education first" strategy of main education; the digital construction and application of red education resources have gradually attracted the attention of schools and society [3]. Red education resources refer to the great revolutionary spirit and its carrier formed by the Communist Party of China leading the Chinese people to struggle for many years during the revolutionary period, and are precious resources for the education of loving the party, patriotism, and socialism in the new period [4, 5]. However, due to the influence and limitation of geographical environment and other technical factors for a long time, red education resources cannot be comprehensively applied and shared [6]. Whether the Internet can be used to share the red education resources publicly to the society, so that more people can use modern media technology to share the red education resources, is a new subject facing ideological education and educational technology workers [7]. Therefore, it is necessary to systematically analyze and study the digital construction and effective application of red educational resources, in order to promote the maximum range and maximum degree of open sharing of high-quality characteristic educational resources. Reference [8] proposed open educational resources in a global context. Reference [9] puts forward the path of integrating red cultural resources into socialist core values education of college students under the "micro" background. Based on the above research, the digital service model of red education resources from the perspective of excellent traditional culture is proposed to promote the maximum range and maximum openness and sharing of high-quality characteristic red education resources.

2. Red Education Resource Integration Technology Design

2.1. Determine the Factors Affecting the Integration of Red Education Resources. During the integration of red education resources, from the perspective of excellent traditional culture, based on the remote scheduling theory of teaching information, different quantitative values existing in the integration of red education resources are obtained, and the factors affecting the integration of red education resources are extracted. These factors mainly include the effect of red education, students' subjective will to learn, teaching effect, subjective action, and teaching methods.

Determine the factors affecting the integration of red education resources, and the specific process is as follows:

Assuming that s represents the factors that various conflicting events affect the integration of red education resources, x represents the abnormal measurement value of red education resources in the integration process, n represents the time limit of red education resources in the integration process, and j represents the quantitative value of the integration performance of red education resources. Combined with the remote scheduling theory of teaching information [10], the red education resources are obtained in the integration process. Due to the gap of educational resources, the quantitative value of red educational resources integration is calculated as follows:

$$O_h = \sum_{j=1}^{n} \frac{c_{kh} \times \nu_s}{x}. \tag{1}$$

In the formula, c_{kh} represents the conventional performance of red education resources in the integration process, and ν_s represents the adaptability of red education resources in the integration process. Then the integration probability of red education resources can be calculated by using formula (2), which is

$$\vartheta\left(V_y\right) = \frac{\mu_b \times \kappa_r}{O_h} \times c_{kh}. \tag{2}$$

In the formula, κ_r represents the integration status of red education resources, and μ_b represents the change characteristics of red education resources in the process of integration. Let h_r indicate the characteristics of red education resources and determine the influencing factors of red education resources in the process of integration. The formula is

$$K_v = \frac{h_r \times z_o}{\tau_m} \times \frac{F^D}{\iota(i) \times a_d}. \tag{3}$$

Among them, $\iota(i)$ represents the attributes of red education resources, i represents the factor attribute vector affecting the integration of red education resources, F^D represents the selected characteristics, z_o represents the time required for the integration of red education resources, τ_m represents the failure probability of red education resources in the integration, and a_d represents the integration cycle of red education resources.

The result of determining the factors affecting the integration of red education resources is to obtain the quantitative value of the integration of red education resources based on the remote scheduling theory of teaching information and determine the influencing factors formed in the integration process of red education resources by calculating the integration probability of red education resources.

2.2. Extracting Feature Vectors of Red Education Resources. In the process of integrating red education resources, the remote scheduling principle of teaching information is integrated into the feature vector extraction of red education resources [11, 12], the feature variance contribution rate of red education resources is calculated, the observable random vector of the features of red education resources is given, and the feature vector of red education resources is decomposed by extracting the number of main factors of the feature vector of red education resources [13]. The specific process is as follows:

Assuming that n represents the number of characteristic variables of the original red education resources, X represents the n characteristic variables in the original red education resources samples, which need to meet the conditions of $X = x_1, x_2 \ldots x_n$, the red education resources are processed by orthogonal transformation, and u' characteristic variables (y_1, y_2, y_3) and R represent the correlation coefficient matrix of the red education resources samples. Using the teaching information remote scheduling theory, establish the characteristic equation of red education resources, expressed as

$$\lambda^n(i) = \frac{\{R \times X\}^n}{\{(y_1, y_2, y_3)\}} \times \frac{(x_1, x_2 \ldots x_n)}{u'}. \tag{4}$$

Assuming λ_i represents the number of nonnegative eigenvalues of the correlation coefficient matrix of the red education resource samples, and λ_i is sorted under the condition of $\lambda_1 \geq \lambda_2 \geq \lambda_n \geq 0$, the first m red education resource features can be extracted, namely,

$$\Phi(p) = \frac{m \times (\lambda_i)}{\xi(e)} \times \eta(r). \tag{5}$$

In the formula, $\xi(e)$ represents the noise interference of the characteristics of red educational resources, and $\eta(r)$ represents the uncertainty of the characteristic vector of red educational resources. Let α represent the variance of the characteristics of the first m red education resources, and the calculation formula is

$$\beta(p) = \frac{m \times \alpha}{\mu(R)} \times \nu(e)(\sigma \times \kappa). \tag{6}$$

In the formula, $\mu(R)$ represents the weight of characteristic samples of red education resources, $\nu(e)$ represents the information entropy of different characteristics of red education resources, σ represents the optimal threshold of characteristic variables of red education resources, and κ represents the observation variables of student characteristics.

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$X = x_1, x_2 \ldots x_n$ is defined as the random vector of the characteristics of red education resources, a_{ij} represents the factor load of the characteristic vector of red education resources, and the observable random vector of the characteristics of red education resources is calculated, that is,

$$\partial(X) = \frac{X \times F}{\left(a_{ij}\right)_{n \mp m}} \times c_i \times \varepsilon_i \times X_i. \tag{7}$$

In the formula, F represents the unobservable vector of red education resources, c_i represents the factor load of special red education resources, and ε_i represents the unique factor affecting factor load c_i. Measure the uncertainty degree of red education resource information source X^*, and the calculation formula is

$$H\left(X^*\right) = \frac{p_i \log\ p_i}{H\left(p_1, p_2, \cdots, p_n\right)} I\left(a_i\right). \tag{8}$$

In the formula, $I(a_i)$ represents the space of red education resource information source X^*, p_i represents the probability of occurrence of red education resource integration strategy, and $H(p_1, p_2, \ldots, p_n)$ represents the probability of occurrence of discrete random variables. Let $I(\lambda_i)$ represent the information function of red education resource integration, and the feature vector of red education resource integration behavior class can be defined as

$$\xi(w) = \frac{I\left(\lambda_i\right) \times H\left(X^*\right)}{\zeta(k)} \times \vartheta(R). \tag{9}$$

In the formula, $\zeta(k)$ represents the information amount of red education resources and $\vartheta(R)$ represents the cumulative information contribution rate of red education resources integration.

The result of extracting the feature vector of red education resources is to integrate the remote scheduling principle of teaching information into the feature vector of red education resources, calculate the feature variance contribution rate of red education resources, extract the number of main factors of the feature vector of red education resources, decompose the feature vector of red education resources, and lay a foundation for the integration of red education resources.

2.3. Integrating Red Education Resources. According to the extraction results of red education resource feature vector, a complete red education resource data set is established. Through the data fusion algorithm [14, 15], all the red education resource features in the red education resource data set are reconstructed [16], and the reconstructed red education resource data set is decomposed. According to the decomposition results, the wavelet variance of red education resources is calculated [17]; take it as the weight fusion wavelet coefficient to obtain the integration result of red education resources. The specific process is as follows:

Step 1: Assuming q resource managers manage multiple red education resources X at the same time, the red education resource reserve value in each resource manager can be expressed as

$$Z_i = X + V_i,\ i = 1, 2, \ldots, m. \tag{10}$$

In the formula, V_i represents the red education resource parameter in the resource manager. Suppose δ_i represents the weight in each resource manager and σ_i represents the variance of red education resource parameters. Finally, the integration value of red education resources is $Z = \sum_{i=1}^{q} \delta_i Z_i$, and the total mean square error of red education resource integration is

$$\begin{aligned} \sigma^2 &= E\left[(X - Z)^2\right] \\ &= \sum_{i=1}^{q} \delta_i^2 \sigma_i^2. \end{aligned} \tag{11}$$

Step 2: According to the extreme value theory of multivariate function, it can be calculated that the minimum value of formula (11) is $(1/\sum_{i=1}^{q}(1/\sigma_i^2))$, and the weighting factor corresponding to the minimum value is

$$\delta_i = \frac{\left(1/\sigma_i^2\right)}{\sum_{i=1}^{q}\left(1/\sigma_i^2\right)}. \tag{12}$$

Step 3: The weighting factor obtained by formula (12) is used to reconstruct the characteristics of red education resources. The formula is

$$Z_J = \sum_{k} h_n(J,k)\varphi_{J,k} + \sum_{J}\sum_{k} g_n(J,k)\psi_{J,k}. \tag{13}$$

In the formula, Z_J represents the reconstructed red education resources, $\varphi_{J,k}$ represents the scale function of the red education resources in the J layer, $h_n(J,k)$ represents the k approximation coefficient of the red education resources, $\psi_{J,k}$ represents the wavelet resource function of the red education resources in the J layer, and $g_n(J,k)$ represents the k detail resource function of the red education resources. Assuming that $W_{h,i}$ represents the weighting factor of the approximation parameter of red education resources and $W_{g,i}$ represents the weighting factor of the detail parameter of red education resources, the following is obtained:

$$\begin{aligned} \sigma^2 &= \sigma_h^2 + \sigma_g^2 \\ &= E\left[Z_V^2 - \sum_{i=1}^{q} W_{h,i}^2 \frac{1}{2}\eta_i \varphi_{J,k}\right]. \end{aligned} \tag{14}$$

Step 4: According to formula (14), the mean square deviation of the weighted result of the integration of red education resources is less than or equal to the mean square deviation of the optimal weighting of red education resources in time domain. Through the remote scheduling of online teaching resources through teaching information [18, 19], the mean square deviation of red education resources becomes smaller and smaller with the decomposition of scale. The final conclusion provides a theoretical basis for the integration of red education resources [20–22].

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Step 5: The wavelet entropy of red education resources is obtained by using the distribution of energy series of red education resources [23–25]. The specific process is as follows:

$$H_{we} = H\left(p_1(E), p_2(E), \ldots, p_J(E)\right). \quad (15)$$

In the formula, $p_J(E)$ represents the normalized energy sequence of red education resources. To sum up, the wavelet entropy of red education resources is taken as the fusion weight of red education resources, and the coefficient obtained is integrated. After wavelet transformation, the integration result of red education resources is obtained, and the red education and teaching resources are integrated to build a harmonious campus, so as to create a good environment for the healthy growth of college students, all-round, multilevel shape and cultivate college students' correct outlook on life, world outlook, and values with high taste, vigorously carry forward the positive, healthy, and upward red spirit, highlight the red melody representing the development direction of the times and reflecting the requirements of social progress, enhance the effectiveness of red education resources teaching, and realize the integration of red education resources.

3. Red Education Resources Digital Service Model Architecture

3.1. Digital Service Model Architecture. The basis for establishing the architecture of digital service model is that the system is the core of the construction of teaching environment. It is based on digitization, takes disciplines and majors as the main line, takes courses as the center, and integrates teaching document information such as teaching plan, curriculum, and syllabus, as well as various types of teaching resources such as teachers' lectures, courseware, reference materials, and multimedia resources. The integrated resources are organically run through the teaching process to provide teachers and students with all-round and practical teaching information and teaching reference resources services. In the view of students, a large amount of redundant information brought by search engines wastes a lot of students' time. At the same time, due to the huge amount of information, it also adds a lot of inconvenience to software developers to find relevant information [26, 27]. In order to make better use of the existing red education resources and meet people's needs for information retrieval, there is an urgent need for a digital basic education search engine. The architecture of digital service model is shown in Figure 1.

According to Figure 1, the structure of digital service model is mainly composed of indexer, controller, user interface, and other key parts. The architecture of digital service model takes digital technology as the core and digital industrialization as the main line. According to the requirements of colleges and universities for large databases, a systematic, more applicable data platform that can provide accurate data information is gradually established to promote front-end application and promote the all-round development of students. The contents of each component are described in detail below.

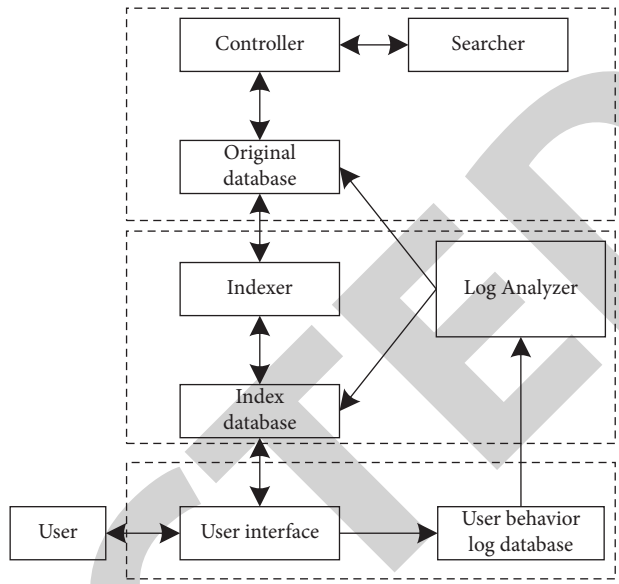

Figure 1: Architecture of digital service model.

3.1.1. Indexer. It is a web spider that searches for web page link addresses in a web page, reads the content of the web page from a page of the website (usually the home page), looks for other link addresses in the web page, and then finds that the next page enters through these link addresses. This cycle will continue until all pages of the site are crawled [28]. Taking the whole Internet as a site, web spiders can use this principle to grab all web pages on the Internet. The main function of the indexer is to obtain the information of teaching materials, extract the index items, use them to represent the digital documents of red educational resources, and generate the index table. For search engines, selecting index words and keywords is a more core problem [29]. When common words are selected as index words in search engines, although the storage required for retrieval is small, the frequency of each index word is high. Because there are many unregistered words, it is obviously not suitable to introduce them into the index vocabulary. Therefore, use statistical methods to filter unregistered words.

Statistical vocabulary acquisition is another method to identify unregistered words. In large corpora, words with certain expression ability often do not appear in isolation but have certain statistical rules. The statistical method is used to automatically obtain vocabulary by using the cooccurrence information between words. Formally, a word is a stable combination of words. Therefore, the more the adjacent words appear at the same time in the context, the more likely it is to form a word [30]. Therefore, the frequency or possibility of word combination can better reflect the reliability of word formation [31, 32]. The combination frequency of adjacent cooccurrence symbols and their mutual occurrence information are calculated in the corpus. The mutual information between two Chinese characters is determined, and their adjacent cooccurrence probability is calculated.

Reciprocal information is the embodiment of the compact combination of Chinese characters. If the tightness

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exceeds a certain threshold, it can be considered that this phrase constitutes a word. After analyzing web pages and word segmentation, we need to use inverse indexing technology to index word segmentation. Establishing reverse indexes includes establishing forward and reverse indexes, as shown in Figure 2.

As shown in Figure 2, after analyzing the web page, you get a forward index table with the page number as the primary key. To speed up the recombination process, the whole process must be done in memory. In the case of large data volumes, there is enough memory to ensure that the creation process is completed in one go. After increasing the amount of data, you can group data and then merge data. The index module's strategy is to divide the index into K groups, depending on the memory size of the computer system, so that each set of operations requires less memory than the maximum memory size that the system can provide. The inverted index of group K is generated by using the inverted index generation algorithm. The inverted index of group K is merged, and the data corresponding to the same index is merged together. Finally, the inverted file index with the index as the primary key is obtained, that is, the inverted index.

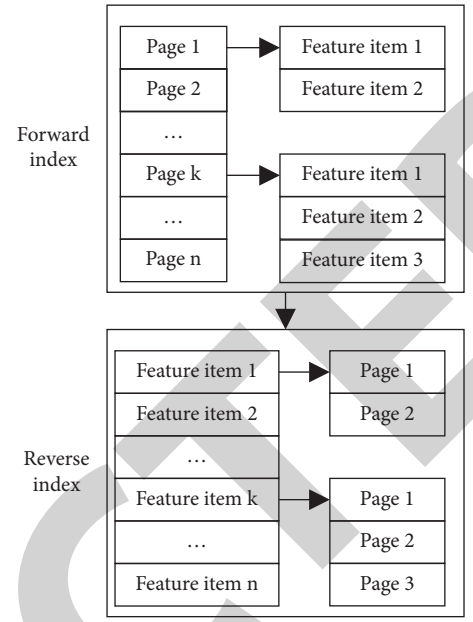

Figure 2: Establishing reverse index from forward index.

3.1.2. Controller. The controller focuses on solving the overall efficiency and quality problems. The so-called efficiency is to collect predetermined web pages with as few resources, computer equipment, network bandwidth, and time as possible [33, 34]. Even when using computers to collect web pages, we should also pay attention to parallel development and utilization. While arranging to use multiple computers to form a cluster, share the exported network bandwidth. With the increase of the number of devices, the network bandwidth domain quickly becomes the bottleneck of the environment. In addition, it may be too late to provide the required web pages on the server side, so do not let the crawling process started by the collector focus on a few sites. If you pay too much attention to the collection activities of some websites, or grab too many pages from a website in a short time, it may lead to quality problems. Web crawler can not grab web pages too frequently, which will affect the normal access of website users. Because the number of web pages collected in a certain period of time is limited, search as many important web pages as possible and do not miss important web pages [35]. Identifying the importance of web pages is also the key to structure mining. Using the home page as much as possible and then conducting the first round of search on the home page can improve the overall search efficiency.

3.1.3. User Interface. The function of user interface is to input user query, display query results, and provide user relevance feedback mechanism. Its main goal is to facilitate users to use search engine and obtain efficient and timely information through various ways, so as to improve efficiency. The design and implementation of users adopt the theory and method of human-computer interaction, which is fully in line with human thinking habits. Through the user interface of intelligent search engine, users can submit query requests in natural language. The system will decompose the word segmentation system according to the needs of users to obtain the words to be queried [36]. The user input interface can be divided into simple interface and complex interface. A simple interface provides a text box for users to input query strings, while a complex interface allows users to limit query conditions, such as logical operation, similarity, domain name range, location, information display time, length, etc.

3.2. Service Process Design

3.2.1. Construction of Red Education Resource Data Index Database. The process of establishing the data index database of red education resources in the query system is as follows (Figure 3).

Step 1: First, the user gives the query conditions.

Step 2: The index system searches the document subset related to the query requirements according to the query requirements of excellent traditional culture.

Step 3: According to the subset of red education resource documents, check whether the obtained digital documents of red education resources are related to the query criteria.

Step 4: If the document is not related to the query criteria, return to Step 2. If the document is related to the query criteria, the relevance is sorted.

Step 5: Finally return the red education resource document and the document sorted by query criteria to the user. Figure 3 shows a data index database of red education resources.

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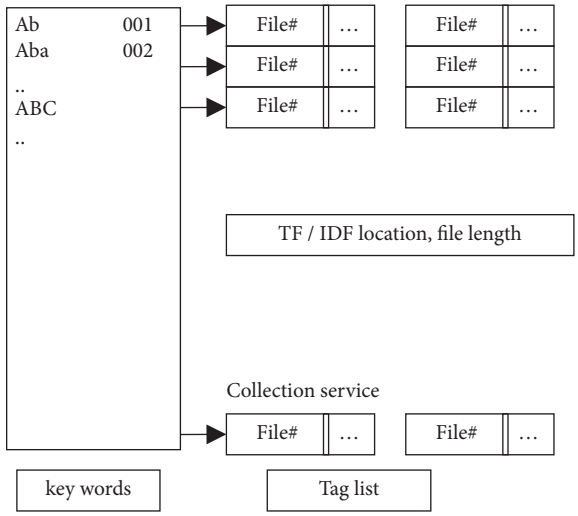

Figure 3: Red education resource data index database.

With the support of the red educational resource data index library shown in Figure 3, determine the factors affecting the index and query the number of keywords, connection operation fields, and values in the range. Probability distribution of values in the value field, field update frequency, index maintenance cost, and database insert and delete operation frequency. Based on these factors, it is determined to build index on the field, so as to complete the construction of red education resource database index.

3.2.2. Query and Processing of Digital Documents of Red Education Resources. Before creating the index, the statistical component of the digital document of red education resources needs to summarize and record the statistical data corresponding to the text features and then use these data to calculate the score of the digital document of red education resources. According to the sorting algorithm and retrieval model, determine the data users want to obtain. The specific process is shown in Figure 4.

According to Figure 4, the specific steps of querying and analyzing the digital documents of red education resources are as follows.

(1) Analyze and query digital documents of red education resources. Firstly, the analysis and processing of the query correspond to the processing steps of the digital document of red education resources; that is, the words in the query are converted into the same form as the words generated when processing the text of the digital document of red education resources. Otherwise, an error will occur when sorting. Text analysis mainly includes lexical analysis, that is, to identify the morpheme information, vocabulary information, and phrase information contained in the text content. The result of file analysis is the representation of the corresponding structure and related content of the file.

(2) Remove stop words. Stop words are high-frequency words or text information, such as prepositions used in digital documents of red education resources. These two function

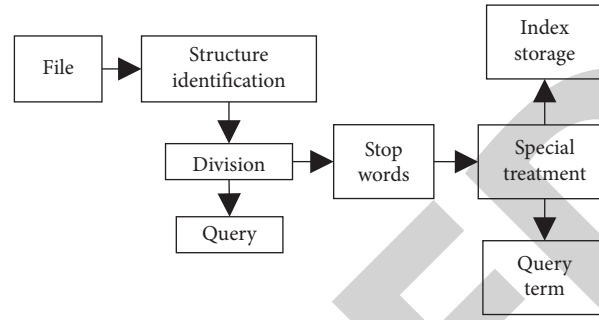

Figure 4: Query and analysis of digital documents of red education resources.

words are helpful to sentence structure but also help to describe the topic in the article. Removing these two words can not only reduce the size of the index, but also reduce the occupation of corresponding memory space and improve the speed and effect of the index.

(3) Extract stem. In the process of retrieval, stem extraction can match information retrieval with related semantics. If a word is deformed or derived from multiple forms, it can be simplified to the same stem.

3.2.3. Construction of Digital Service Model. To save space, use the smallest integer data possible. In larger tables, the number of bytes grows very fast. On the other hand, once a field is created, it is very difficult to modify it. Therefore, for security reasons, you should predict the maximum value of the field that may need to be stored and then select the appropriate data type. To better control the data stored in the field, numerical data can be used to represent the integer part and decimal part of the number, and a service model is established based on this.

Let the sample set be $X = \{x_1, x_2, x_3, \ldots\ldots, x_n\}$ and the estimated parameter be α, so as to determine the implied variable. The likelihood function formula is

$$L(\alpha) = L(x_1, x_2, x_3, \ldots, \ldots, x_n; \alpha). \tag{16}$$

In formula (16), $L(\alpha)$ represents the likelihood function of parameter α relative to sample set X, and the mathematical expression is

$$\alpha = \arg\max l(\alpha). \tag{17}$$

In formula (17), the logarithm of $l(\alpha)$ function is transformed into logarithm summation calculation method to obtain the expression of log likelihood function:

$$H(\alpha) = \sum_{i=1}^{n} \ln\ p(x_i; \alpha). \tag{18}$$

The digital service model is obtained according to the expression of log likelihood function:

$$\mathrm{P} = \frac{\left|R_{H(\alpha)} \cap T\right|}{\left|R_{H(\alpha)}\right|} \times 100\%. \tag{19}$$

In formula (19): R_a represents the service result of required red education resources; T represents the required

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sample set. The higher the value, the more accurate the service results will be. The database index service will be completed, so as to complete the construction of the digital service model of red education resources from the perspective of excellent traditional culture.

4. Experimental Analysis

The experiment of the digital service model of red education resources from the perspective of excellent traditional culture is verified on the basis of the file archiving and file retrieval performance of the prototype system, which involves each specific functional module. The model is developed in Java language and the operating system is Windows 10. According to the actual application, the resource digital service model is tested in a university laboratory, and four hosts are selected to set the network environment. The specific settings are shown in Table 1.

The experimental data mainly use text and video files, and about 80000 different kinds of files are collected. Different file compression methods are adopted for different file types, which is one of the most effective methods to improve compression efficiency. It can be seen that the decompression time is significantly less than the file compression time. It is precisely because multiple sliding windows are involved in file compression in the digital service model of red education resources, and the internal resources of the window need to be matched with the dictionary. String matching is the most time-consuming, and string matching is not required when decompressing the file.

According to the above design ideas, the model is applied to the real digital service environment of red education resources. The architecture of the model is divided into two phases, and the content of phase I is selected as the research object. The specific work arrangements for the functional requirements investigation, *R*&*D*, testing, joint commissioning, functional verification and training, and online trial operation stages are as follows:

(1) Demand research stage: complete demand research, study business model, conduct demand research and analysis, and prepare demand description scheme according to the needs of customers.

(2) Function *R* and *D* stage: Design front-end UE interface prototype and data dictionary, system integration interface design and *R* & *D*, and function *R* and *D*.

(3) Test and joint commissioning stage: test environment deployment, interface joint commissioning test, and business function joint commissioning test.

(4) Function verification and training stage: training preparation, user operation training, and gray environment for system function verification.

(5) Online trial operation stage: online trial operation scheme preparation, online trial operation application, production environment deployment, and online trial operation.

In combination with the specific contents of the phase I function implementation arrangement of the above red education resources digital service model, from the perspective of excellent traditional culture and according to the construction of grid support tools in the urban area, we choose to popularize and try out the digital service model of red education resources and analyze its trial effect. After completing the construction of the model, the time consumed to complete various businesses and the response time for providing digital services will be recorded, as shown in Figure 5.

From the implementation results obtained in Figure 5, it can be seen that, before and after the application of the model constructed in this paper, both the time consumed to complete various businesses and the service response time are significantly less than before the application of the model. At the same time, before the application of the model, the increase of business volume will affect the service response time and business consumption time to a certain extent. However, after the application of the model, with the increase of business volume, neither of the two parameters shows an obvious trend of increasing, indicating that the problem that the service response time and business consumption time before the application of the model are affected by business volume is solved. At the same time, the above implementation results further prove that, in the perspective of excellent traditional culture, we can further strengthen the digital service quality of red education resources and improve service experience and satisfaction.

In order to further prove the rationality of the digital service model of red education resources from the perspective of excellent traditional culture, the goodness of fit of the technology is judged by relevant test residuals. The calculation formula of goodness of fit is

$$R^{\text{new}} = 1 - \frac{Q}{2\sum \widehat{y}_2} \times 100\%. \tag{20}$$

In the formula, new represents the determination coefficient, $\widehat{y}_2$ represents the fitting degree, and Q represents the sum of squares of residuals. By comparing the model of [8] and the model of [9], the goodness of fit test results of red education resource integration analysis under three different models are shown in Figure 6.

It can be seen from the results in Figure 6 that the goodness of fit of the red education resources digital service model for red education resources integration from the perspective of excellent traditional culture is better than the other two methods. The reason is that the model gives the correlation between the factors affecting the integration of red education resources and the integration of red education resources by obtaining the quantitative value of the integration characteristics of red education resources, making the goodness of fit of red education resource integration better.

To sum up, after the application of the digital service model of red education resources designed from the perspective of excellent traditional culture, with the increase in business volume, neither of the two parameters shows an obvious increase trend, indicating that the problems existing

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Table 1: Experimental environment settings.

Test tool	Memory size/G	Hard disk size/G	Control system	Set up quantity
The server	4	500	Linux	1
Host A	2	250	Win10	1
Host B	4	300	Win8	1
Host C	4	300	Win8	1

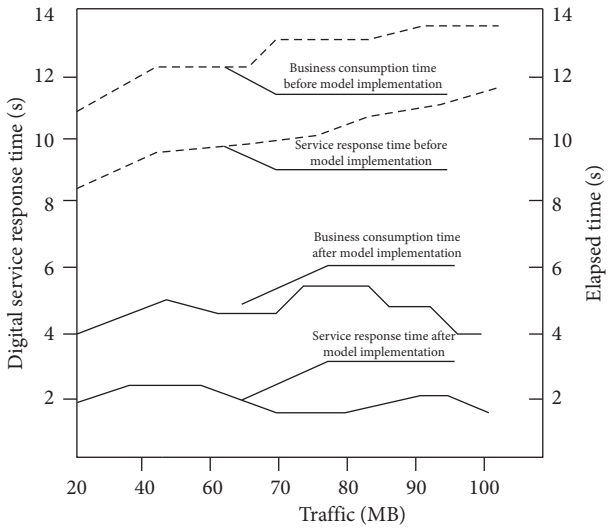

Figure 5: Implementation effect of digital service model of red education resources.

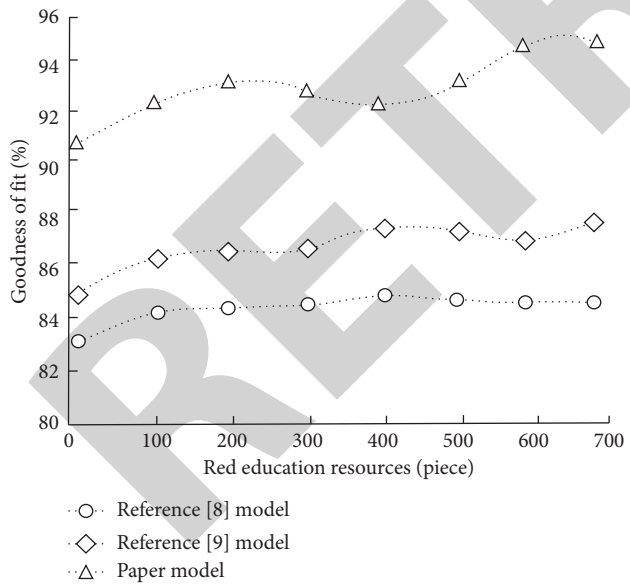

Figure 6: Goodness of fit test results of red education resource integration analysis.

before the use of the model are solved and the quality of digital service of red education resources is further strengthened. To improve service experience and satisfaction, the goodness of fit of red education resource integration is better.

5. Conclusion

Convenience also provides opportunities and challenges for the digitization and sharing of red education resources. The digital service model of red education resources designed from the perspective of excellent traditional culture consumes significantly less time to complete various businesses and provides service response time. Moreover, the goodness of fit effect of the integration of red education resources is better after the application of the digital service model. There are some deficiencies in the research on the mining and value evaluation of red educational resources, which need to be further improved.

Due to the lack of research level and the limitations of objective conditions, it is necessary to increase research efforts in the future, strengthen communication with relevant local departments, conduct in-depth research on red education resources, and establish a complete library of red education and culture resources. On the other hand, the sample size of index screening and index scoring can be expanded to obtain more objective data as far as possible to ensure scientific research results.

Data Availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding this work.

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Retraction

Retracted: Empirical Research on the Relationship between Industry Working Capital Shortfall and Company Cash Holding in the Same Industry

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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Research Article

Empirical Research on the Relationship between Industry Working Capital Shortfall and Company Cash Holding in the Same Industry

Zhaohua Li,[1] Junyi Jiang,[2] Lijuan Xia,[3] and Chien-Chi Chu[4]

[1]*School of Accountancy, Harbin University of Commerce, Harbin 150028, China*
[2]*Center for Science Communication and Achievement Transformation, National Natural Science Foundation of China, Beijing 100085, China*
[3]*School of Economics and Management, Harbin Institute of Technology, Harbin 150001, China*
[4]*School of Economics and Management, Foshan University, Guangdong, 528000, China*

Correspondence should be addressed to Lijuan Xia; lijuanx@163.com

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Affected by the fluctuation of the market and economic environment during the epidemic period, the capital pressure of companies has increased sharply, which increases the possibility of risk transmission in the same industry and poses new challenges to the operation and financing of companies. From the perspective of preventive motivation of corporate cash holding, we creatively use the industry working capital shortfall as the explanatory variable to construct an Extended Cash Holding Model and a Cash Holding Value Regression Model. Taking the panel data of A-share listed companies in Shanghai and Shenzhen as samples, this paper uses the Classical Linear Regression Model and Fixed Effects Regression Model to study the relationship between industry working capital shortfall and cash holdings in the same industry, as well as the relationship between industry working capital shortfall and cash holding value. The empirical results show that industry working capital shortfall has an important impact on the cash holding level within the same industry, and the cash holding level is significantly and positively correlated with industry working capital shortfall. Moreover, this study also reveals that the industry working capital shortfall has a dual impact on cash holdings. Specifically, the higher the risk of industry working capital shortfall, the lower the value of company cash holdings. The conclusions of this paper not only extend the research on cash holding but also provide support and reference for companies to optimize the cash holding value.

1. Introduction

The epidemic outbreak in 2019 spread all over the world. Policies, such as staying at home and maintaining social distance, have created new challenges to the global economy. Oxford Economics predicts that the impact of the epidemic will lead to the lowest growth rate of the global economy this year since the 2008 financial crisis. Simultaneously, due to the restrictions on production and operation during the epidemic, the daily operation of companies is abnormal and the capital turnover is difficult. Capital holdings have become a decisive source of capitals to support the operation of companies. For instance, once the revenue exceeded 100 million, the ITXDL listed on the new third board failed to resist the break of the capital chain caused by the epidemic and went bankrupt. Cash is an important economic resource in business operation, and a large number of empirical research studies have indicated that listed corporations prefer substantial cash holdings regardless of the countries [1, 2]. Sufficient cash holding not only meets the company's day-to-day operations such as paying wages, purchasing raw materials, and paying interests but also plays a critical role in the company's investment, financing decisions, dividend payout policy, dealing with emergencies, and so on. Thus, "cash is king" is gradually accepted by financial managers. Especially after the outbreak of the global economic crisis in

2008, all social sectors are more concerned about cash holdings. The collapse of Lehman Brothers and Chrysler have demonstrated the importance of cash assets to the company. In this paper, the cash holding level is the company's cash and cash equivalents. The cash holding value is measured by the excess return of the difference between the company's annual return and the average market return of the total market value.

The world economy has gradually recovered from the international financial crisis in 2008. One experience learned from the global economic crisis in 2008 is that the capital shortfall in an industry may cause serious negative externalities, as Brownlees and Engle documented that capital shortfall of large financial institutions will weaken their functions and have adverse effects on the economy [3], and Zheng and Song revealed that the stock market crisis will cause more damage on the system [4]. The industry, as the external environment most closely related to companies, has a direct and significant impact on the operation of the enterprise in the industry [5]. Problems in the industry, such as industry capital shortfall, not only limit the development of the entire industry but also affect the profits of companies in the industry. Therefore, the industry capital is also closely concerned by the company and its investors. Now, under the outbreak of novel coronavirus pneumonia, the companies' cash holding once again becomes the decisive factor for the development of companies. Demary et al. found that similar to the pattern observed after the financial crisis, companies affected by the COVID-19 will strengthen capital corporate saving to better cope with future shocks [6]. Some scholars proposed that companies with abundant cash holdings can buffer against the outbreak of the COVID-19 epidemic [7], and Wieczorek-Kosmala took the tourism industry as an example and proved the importance of cash holding in resisting risks [8].

Considering the impact of emergencies on enterprises, it has extraordinarily practical significance to study cash holding of companies under crisis, which is helpful for companies to solve the emergency quickly and effectively. However, the cash holding level, the amount of cash held by a company, is a double-edged sword for the company. Oler and Picconi pointed out that the deviation of cash holdings from the optimal level, i.e., exceeding the optimal level and insufficient cash holdings, has adverse effects on the income of companies [9]. On the one hand, excessive cash holdings may trigger a high level of idle funds, which can further cause higher opportunity costs for the company. On the other hand, insufficient cash holdings may cause loss of investment opportunities, unaffordable business expense, and increase in financing cost. Brealey et al. also pointed out that one of the most important research issues in the financial sector is the determination of company's cash holdings [10]. Thakur and Kannadhasan further confirmed the increase of cash holdings will increase the value of companies but also may cause greater corruption [11]. The above research shows that the value of cash holdings of companies is variant and affected by many factors, for instance, quality of corporate governance and corporate financial policy, etc. This reflects that the real value of cash holding value under specific circumstances is an important aspect that companies need to consider when making cash holding decisions. Therefore, it is urgent to investigate relevant factors that may affect cash holding level and cash holding value. In terms of the industry working capital shortfall, we wonder that how will the industry working capital shortfall affect the cash holding level in the same industry corporations? Furthermore, how will the working capital shortfall affect the value of cash holdings in the same industry?

Since the 1990s, a myriad of research has studied the decision-making of cash holding. Both theoretical and empirical research have yielded fruitful results. There are several mature theoretical models, and these theories can be divided into two broad categories: capital structure theories and agency conflict theories. First, the capital structure theories also include trade-off theory [12] and pecking-order theory [13]. The main characteristics of trade-off theory are to determine the financing structure of a company by weighing costs and benefits. Different from the trade-off theory, pecking-order theory determines the factors that affect cash holding level and value from the information asymmetry perspective. The second category theory is agency conflicts, in which there are four types: flexibility hypothesis [14], spending hypothesis [15], shareholder power hypothesis [16, 17], and costly contracting theory [18]. The research on the influence of agency conflict on corporate decision making is widely used. Agency conflict theory is applied to study the complex relationship between directors and managers in corporate governance [19]. Risk management based on agency conflict proposes that the methods commonly used to motivate managers exacerbate the institutional challenges associated with risk [20]. Besides, in terms of taxation, Tang et al. using conflict theory explored the role of local government. Empirical research mainly focuses on two aspects [21]. One aspect is the factors that affect the cash of companies (see Harford et al. [22] and Chen et al. [23]). The other research aspect is the influence of cash holdings on economic consequences (see Denis and Sibilkov [24] and Almeida et al. [25]). However, most studies are explored based on the developed capital market environment and corporate governance environment. The applicability of these conclusions in Chinese listed companies needs to be further verified. In particular, China is in the economic transition period, where the level of corporate governance in China is relatively low, and the capital market is inadequate.

As far as we know, there is no formal study to explore the relationship between cash holdings and working capital shortfall in China's market environment. Therefore, it is of great significance to study how the industry working capital shortfall affects cash holdings from the perspective of industry characteristics and market environment in China. The contribution of this study is threefold.

First, we introduce working capital shortfall to study cash holdings in the same industry which enriches the existing research results related to cash holdings and provides empirical support for cash holding theory based on precautionary motivation. According to the motivation of

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cash holding, most of the existing research studies on cash holding are from the transaction motivation, while the research from the perspective of precautionary is still limited. Consequently, inspired by the study of Opler et al. [27] and Faulkender and Wang [26], we research the impact of working capital shortfall about the cash holdings within the same industry under the background of financial crisis based on the theory of precautionary motivation of cash holdings.

Second, this study enriches the research results of cash holding value and provides a new insight into the economic consequences caused by the industry working capital shortfall. This study considers industry working capital shortfall in the same industry as a new research perspective and illustrates the impact of working capital shortfall on cash holding value from agency theory, which also enriches the research results of agency theory. More importantly, based on the economic consequences caused by the shortfall of working capital in the same industry, the research conclusions of this paper can also guide managers to make scientific cash holding decisions.

Third, the development of the companies in the same industry has certain common characters. This study provides support for cash holding decisions by companies in the same industry, especially in the major emergency prevention motivation. Industries and companies are closely linked, and the development of companies largely depends on industry trends. The bankruptcy of a company cannot be absorbed by more powerful competitors when the industry is in recession or economic recession, which may release more negative signals to the market and even affect the stability of the overall market economy. Therefore, the research of this paper can provide a decision-making reference for the management of the industry and the overall economy.

To better clarify the research problem, the rest of this paper is organized as follows. The reminder of this paper begins with a description review of cash holding in Section 2. Section 3 puts forward the research hypothesis. Section 4 presents the data used for the empirical and provides a detailed description of the model. Section 5 discusses the empirical results and conducts the robustness test. Section 6 outlines our conclusions and managerial implications.

2. Related Work

This paper is mainly related to two streams of literature: influencing factors of cash holding literature and cash holding value research literature. The first stream focuses on studying the influence factor of cash holdings and is presented in studies by Isshaq et al. [28] and Ozkan and Ozkan [29]. These studies are based on listed companies in developed countries and investigated internal factors that influence the level of cash holdings. These findings suggest that the cash holding level is positively related to these factors including company growth, cash flow, and information asymmetry degree and is negatively related these factors including financial expertise of the board members, company size, credit rating, and debt level. After that, many studies have incorporated financing constraints into the analysis to study the impact of this variable on cash holdings, and representative research included Almeida et al. [25], Arslan et al. [30], and Han and Qiu [31]. Furthermore, Duchin [32] and Subramaniam et al. [33] explored whether the organizational structure of firms affects the cash holdings. Lin investigated the structural factors that affect the cash holdings of listed companies from the perspective of ownership structure [34]. Al-Najjar looked into the impact of dividend policy and capital structure on cash holdings in developing countries [35]. Lim and Lee took Korean companies as an example to investigate how CEO characteristics affect corporate excess cash holdings [36]. Jebran et al. studied the effect of principal-principal conflicts on cash holdings [37]. Among this stream of literature, the following studies are related to ours because they examine the external factors that influence cash holdings. Chen and Chuang pointed out cash holdings of companies depend on the external environment, that is, with the increase of external investment opportunities, companies will increase their cash holdings, and effective corporate governance can promote companies to increase cash holdings [38]. Bugshan et al. firstly explored the relationship between Shariah compliance and corporate cash holdings, as well as the adjustment speed of the optimal cash holding target of trade-off theory [39]. Baum et al. empirically studied the relationship between the macroeconomic volatility and the current asset allocation of non-financial companies [40]. Similarly, Abushammala and Sulaiman further identified the macroeconomic factors that affect corporate cash holdings through empirical research [41]. Taking emerging markets as the research object, Feng et al. further confirmed the increase of policy uncertainty, and the companies' value with more cash holdings is greater [42]. Using a "quasi natural experiment," Doidge and Dyck studied the interactions between tax incentives and corporate policies and found that the company's cash holding policy is adjusted with changes in tax incentives [43]. Magerakis et al. also documented that the tax regime significantly affects the cash holdings of UK corporation [44]. In addition, Gill and Shah discussed in detail the internal and external factors that determine the capital holding of Canadian companies [45]. To deal with the impact of accidents on companies, Qin et al. studied the impact of COVID-19 on enterprise cash holdings by difference-in-differences method and found that COVID-19 has a significant positive impact on industry cash holdings in serious-impact industries [7]. Based on the data of 285 listed companies in Vietnam, Nguyen et al. found that cash holdings had a positive impact on financial stability during the pandemic crisis [46]. The essential difference between this stream of literature and our work is that we incorporate the industry working capital shortfall into the determinants of cash holdings and explore how this factor affects the company's cash holdings.

The second related stream of the literature concentrates on cash holding value, including studies by Denis and Sibilkov [24], Louis et al. [47], Huang et al. [48], and Schauten et al. [49]. Drobetz and Grüninger [50], Bugshan et al. [39], and Kusnadi [51] proposed that the quality of corporate governance has a positive role in promoting cash market value. Tong investigated how corporate

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diversification affects corporate cash holding value. The author documented that with low level of corporate governance in companies, diversification hurts cash value among firms [52]. Aktas et al. considered CEO behavior and showed that the effect of CEO overconfidence on cash holding value depends on the enterprise financial situation [53]. Some studies also documented that the existence of liquidity constraints also helps to improve the cash value. For example, Denis and Sibilkov [24] pointed out that the cash holding value of financially constrained companies is higher than that of unconstrained companies. Almeida et al. [25] also proved that the financially constrained company is more valuable than the financially unconstrained company.

The marginal value of cash was first proposed by Faulkender and Wang [27]. They took stock excess return as the research object and found that the cash marginal value is negatively correlated with the cash holding level. Chou and Feng further discussed how multiple directorships affect the value of cash held by companies and found that the increase of multiple directors will limit the cash holdings and increase the marginal value of cash holdings [54]. Kusnadi studied how political connections influence the cash holdings [55]. Compared with the companies without vertical interlock, Chen and Yang proved that investors tend to value cash holdings in companies with vertical interlock substantially less [56]. Ahmadi et al. studied the effect of product competition and growth opportunity on the cash holding value [57]. Pinkowitz et al. further investigated investment protection policies in different countries [58]. Breuer et al. considered the degree of investors' risk aversion and then proved that the cash holding value decreases with the aversion of investors to information uncertainty [59]. Bharadwaj et al. discussed the cash holdings of companies based on the brand value [60]. Mikkelson and Partch proposed that high cash holdings contribute to the improvement of operating performance [61]. Martínez-Sola et al. documented a concave relation between cash holdings and firm value, verifying the existence of an optimum level of cash holding [62]. Different from these studies above, we analyze cash holdings by incorporating the industry working capital shortfall and further investigate the influence of industry working capital shortfall on the cash holdings.

3. Research Hypotheses

Compared with previous studies, this study not only considers the influence of internal variables on the cash holdings but also introduces an external variable of "industry working capital shortfall" to study cash holdings. This paper defines cash holding level as money and cash equivalents of a company. The cash holding value is defined as the excess return between the company's annual return and the average market return of the total market value. According to the previous section, it is reasonable to adopt working capital shortfall to examine the relationship between cash holdings and working capital shortfall.

First, the research of cash holding level and cash holding value has made considerable achievements from the perspective of the company's features, such as financial behaviors, governance features, and financial constraints. The external environment is also one of the crucial factors that affect the company's cash holdings, such as the macroeconomic factors, degree of economic prosperity, degree of market competition, and so on. Therefore, the influence of external environment factors on cash holdings should be further discussed. However, the existing research on the external environmental factors of cash holdings mainly focuses on macroeconomic factors. Quantifying macroeconomic factors is a challenge, and the quantitative results may not be accurate and cannot be analyzed. So, we choose industry working capital shortfall as an external environment factor to study its impact on cash holdings.

Second, previous studies have laid a solid theoretical and model foundation for the research of this paper. We take Opler et al.'s model [26] as our baseline model and analyze the relationship between industry working capital shortfall and cash holdings. Then, we use the model of the marginal value of cash proposed by Chen et al. [23] to explore the relationship between industry working capital shortfall and the cash holding value. In addition to the model, the variable of industry working capital shortfall used by the two models can be measured based on the idea of value at risk. Industry working capital shortfall is defined as the 95 percentile of working capital gap ratio of all companies in the same industry over the last five years. Specifically, industries are classified according to the Guidelines for Industry Classification of Listed Companies issued by China in 2012 in this paper.

Combining the above analysis and the research questions in this paper, how will the industry working capital shortfall affect the cash holdings in the same industry corporations? Furthermore, how will the working capital shortfall affect the value of cash holdings in the same industry? The following sections analyze the above problems in detail and form two research hypotheses.

The Impact of the Working Capital Shortfall on the Level of Cash Holdings in the Same Industry. The company's investment activities, such as new product development, will be hindered by the shortage of working capitals. Some of the company's objects, such as customer satisfaction, market share, and economic benefit, will also be implicitly affected by the working capitals in the same industry. A succession of events may eventually cause the company to close or even go bankrupt. Jenson and Meckling had indicated that cash works as a buffer against the disadvantage of a liquidity shortage [63]. Therefore, companies can cope with potential working capital shortfall problem through changing the number of cash holdings. Considering the similarity and convergence of companies within the same industry, the company can prevent the shortfall risk based on the reference companies which have already fallen into the working capital shortfall problem.

Hypothesis 1: under the control of other factors, the working capital shortfall is positively correlated with the cash holding level of companies within the same industry. That is, the greater the working capitals shortfall, the more the cash holdings of companies within the same industry.

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The Impact of the Working Capital Shortfall on the Value of Cash Holdings of Corporations within the Same Industry . Based on Hypothesis 1, when the shortfall in working capital is large, firms tend to hold more cash. Liu and Mauer pointed out that cash holdings can effectively avoid the shortage and help to get a positive evaluation of the capital market [18]. The ways to increase cash holdings of listed companies in China mainly include two means which are internal financing and external financing, respectively. On the one hand, the industry shortage of working capital has squeezed the profit margin of the companies in the industry. The decline in profits makes it difficult for companies to increase cash holdings through internal financing and rely on external financing to increase capital holdings. On the other hand, the information asymmetry phenomenon is apparent in China's capital market. Besides, investors are pessimistic about the development of the industry due to the shortfall of working capital, which has been proven by Pinkowitz et al. [58]. These reasons have led to very high external financing cost. Based on the above analysis, this study proposes the following hypothesis.

Hypothesis 2: the industry working capital shortfall is negatively correlated with the cash holding value of corporations within the same industry. That is, the greater the shortfall of working capitals, the lower the cash holding value of corporations within the same industry.

4. Empirical Design

4.1. Data Sources and Sample Selection. Demary et al. proposed that the pattern of companies during COVID-19 was similar to that observed after the financial crisis [6]. Considering the similarity between the epidemic and the 2008 financial crisis, this paper chooses Shanghai and Shenzhen A-share listed corporations from 2007 to 2015 as the initial samples, which can provide some reference for enterprise capital holding decisions under the epidemic situation. The financial data were collected from the Wind database. The corporate governance data were derived from the CSMAR database of GTA Information Technology Co. Ltd.

This paper used the following principles to collect and preprocess the data samples. (1) Financial listed corporations are excluded because their business characteristics are not suitable for our study. (2) All ST and *ST corporations are excluded because the long-term downturn caused by such corporations may lead to frequent changes in cash holdings. (3) Sample corporations in case of missing values are excluded. (4) In this paper, we use the winsorization method to deal with outliers. Sample companies with financial value deviating from the 1% quantile (99% quantile) are set as 1% quantile (99% quantile). According to these sampling criteria, 7775 company samples were obtained. The empirical research was conducted using STATA12.0 software.

4.2. Empirical Model. Following Opler et al. [26], we use working capital shortfall to test the hypothesis between the working capital shortfall and the cash holding level of a company within the same industry; the empirical model is designed. Specifically, the model is represented as follows:

$$\begin{aligned}\text{cashhold}_{i,t} = {} & \beta_0 + \beta_1 \text{shortfall}_{i,t} + \beta_3 \text{nwc}_{i,t} + \beta_4 \text{leverage}_{i,t} \\ & + \beta_5 \text{size}_{i,t} + \beta_6 \text{tobing}_{i,t} + \beta_7 \text{dividend}_{i,t}, \\ & + \beta_8 \text{ce}_{i,t} + \beta_9 \text{cflow}_{i,t} + \beta_{10} \text{dbstr}_{i,t} + \beta_{11} \text{nei}_{i,t} \\ & + \beta_{12} \text{first}_{i,t} + \beta_{13} \text{dir}_{i,t} + \beta_{14} \text{idir}_{i,t} + \beta_{15} \text{jir}_{i,t}, \\ & + \beta_{16} \text{liangzhi}_{i,t} + \varepsilon_{i,t},\end{aligned} \tag{1}$$

where β_0 is a constant term, β_1 represent the regression coefficients of each variable, $\varepsilon_{i,t}$ is a random disturbance term, i denotes the i-th sample observation among the samples, and t represents time dimension. In this model, the explained variable is the corporate cash holding level ($\text{cashhold}_{i,t}$). The explanatory variable is the industry working capital shortfall ($\text{shortfall}_{i,t}$). The rest of the variables are set as control variables; the detailed description of these variables is listed in Part A of Table 1.

There are two widely used methods to measure the value of cash holdings: one is the Classic Company Value Regression Model proposed by Fama and French [64], and the other is the Marginal Value Regression Model proposed by Faulkender and Wang [27]. The Classical Value Regression Model reflects the marginal value of cash by analyzing the relationship between cash holdings and the change in cash and the company's market value, that is, cash holdings and change in cash are independent variables, and the corporate market value is the dependent variable in the regression model. However, the disadvantage of this method is that it is difficult to explain the regression coefficients of the variables obtained in the model. The Marginal Value Regression Model reflects the marginal value of cash by analyzing the relationship between the change in cash and the excess return of the company. This regression model is more intuitive in response to the cash compared with the Classical Value Regression Model. Therefore, we adopted the Marginal Value Regression Model to test the hypotheses between the cash holding value and the working capital shortfall. Specifically, the model is designed as follows:

$$\begin{aligned}r_{i,t} - R_{i,t}^{B} = {} & r_0 + r_1\left(\frac{\Delta C_{i,t}}{M_{i,t-1}}\right) + r_2\left(short\,fall_{i,t}\right) \\ & + r_3\left(short\,fall_{i,t} * \frac{\Delta C_{i,t}}{M_{i,t-1}}\right) + r_4\left(\frac{\Delta E_{i,t}}{M_{i,t-1}}\right) \\ & + r_5\left(\frac{\Delta NA_{i,t}}{M_{i,t-1}}\right) + r_6\left(\frac{\Delta I_{i,t}}{M_{i,t-1}}\right), \\ & + r_7\left(\frac{C_{i,t-1}}{M_{i,t-1}}\right) + r_8\left(\frac{NF_{i,t}}{M_{i,t-1}}\right) + r_9\left(L_{i,t}\right) + \varepsilon_{i,t},\end{aligned} \tag{2}$$

where r_0 is a constant term, r_i represent estimated parameters, and $\varepsilon_{i,t}$ is a random disturbance term. The explanatory variable is excess return ($r_{i,t} - R_{i,t}^{B}$). The model introduces two explanatory variables (one variable is the

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Table 1: Variable name, symbol, and definition.

Variable name	Symbol	Variable definitions
Part A: effect variables of the cash holding levels		
Cash holding level	$\text{cashhold}_{i,t}$	Money and cash equivalents of company i in year t/year-end total assets in year t
95% quantile of industry working capital gap ratio	$\text{shortfall}_{i,t}$	From year *t-5* to year *t-1*, the 95% quantile of the working capitals gap ratio of the same industry, where the working capitals gap ratio is defined as max [0, -EBIT/total assets]
Fixed assets	$\text{fa}_{i,t}$	Year-end fixed assets of company i in year t/year-end total assets in year t
Net-working capitals	$nwc_{i,t}$	Net working capitals of company i in year t/year-end total assets in year t
Financial leverage	$\text{leverage}_{i,t}$	Total liabilities of company i in year t/total assets in year t
Corporation scale	$\text{size}_{i,t}$	Log (total assets) of company i in year t
Growth opportunities	$\text{tobing}_{i,t}$	Asset market value of company i in year t/asset book value in year t , asset market value = total liabilities + non-tradable shares * net assets per share (bps) + circulating a shares * per market price
Dividend payout	$\text{dividend}_{i,t}$	Ordinary dividends paid by company i in year t/total assets of company i in year t
Capital expenditure	$ce_{i,t}$	(Cash received from fixed assets, intangible assets, and other long-term assets-cash received from disposal of fixed assets, intangible assets, and other long-term assets)/ year-end total assets in year t
Cash flow	$\text{cflow}_{i,t}$	(Net profit + depreciation, amortization) of company i in year t/year-end total assets in year t
Debt structure	$\text{dbstr}_{i,t}$	Current liabilities of company$i$inyear t/totalliabilities in year t
Net share issue dumb variable	$\text{nei}_{i,t}$	Company i in year t: if an IPO occurs, the value of rationed shares is 1; otherwise, it is 0
Equity concentration	$\text{first}_{i,t}$	The largest shareholder shareholding ratio of company i in year t
Board size	$\text{dir}_{i,r}$	Log (number of directors) company i in year t
Independent board size	$i\ di\ r_{i,r}$	Company i in year t: number of independent directors/number of directors
The size of the supervisory board	$jir_{i,r}$	Company i in year t: log (number of supervisors)
Two jobs are also dummy variables	$\text{liangzhi}_{i,t}$	Company i in year t: if the chairman or the manager is a concurrent post, the value is 1; otherwise, the value is 0
Part B: effect variables of the cash holding value		
Excess return	$r_{i,t} - R_{i,t}$	$r_{i,t}$ represents the annual return of company i in year t$R_{i,t}$ represents the average market return of total market capitalization of company i in year t
Change in cash holdings	$\Delta C_{i,t}/M_{i,t-1}$	Company i in year t: change in cash holdings/equity market capitalization
95% quantile of the working capital gap	$short\,fall_{i,t}$	From year *t-5* to year *t-1*, the 95% quantile of the working capitals gap ratio of the same industry , where the working capitals gap ratio is defined as max [0, - EBIT/total assets]
Change in earnings	$\Delta E_{i,t}/M_{i,t-1}$	Earnings before interest and tax of company i in year t/equity market capitalization in year *t-1*
Change in non-cash asset	$\Delta NA_{i,t}/M_{i,t-1}$	Change in non-cash assets (total assets - cash holdings) of company i in year t/equity market capitalization in year *t-1*
Change in financial expenses	$\Delta I_{i,t}/M_{i,t-1}$	Changes in financial expenses of company i in year t/equity market capitalization in year *t-1*
Cash holdings of last year	$C_{i,t-1}/M_{i,t-1}$	Cash holdings of company i in year *t-1*/equity market capitalization in year *t-1*
Net cash flow	$NF_{i,t}/M_{i,t-1}$	Net cash flow of financing activities of company i in year t/equity market capitalization in year *t-1*
Asset-liability ratio	$L_{i,t}$	Total liabilities of company i in year t/equity market capitalization in year t

Note. Indicators of Part B (except $L_{i,t}$ and $\text{shortfall}_{i,t}$) are divided by $M_{i,t-1}$ to eliminate the impact of corporation size on the model.

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industry working capital shortfall ($\text{shortfall}_{i,t}$), and the other variable is the product of the working capital shortfall and the change in cash holdings ($\text{shortfall}_{i,t} * \Delta C_{i,t}$)) to test the effect of the working capital shortfall and the cash holdings on excess returns of the company. For the meaning of other variables, see Part B in Table 1. To facilitate analysis, we derive the derivative of the two sides of formula (2), and then the cash holding value V becomes

$$V = r_1 + r_3 \text{shortfall}_{i,t}. \tag{3}$$

5. Empirical Results and Discussion

5.1. Descriptive Statistical Analysis. Table 2 lists the descriptive statistical results of the variables used in the models. These results include the mean, standard deviation, minimum, median, and maximum of these variables. As can be seen from the statistical results in Panel A of Table 2, the mean value of cash holding level is 19.85%, indicating that cash is an important component of the company's total assets. The maximum of cash holdings is 69.23%, the minimum is only 1.49%, and the standard deviation is 14.45%, indicating that the gap between the cash holdings held by different corporations is great. The mean value of the working capital shortfall is 2.59%, which indicates that over the past five years, 5% of companies in the same industry have had a liquidity shortfall that exceeded the average level. The maximum of working capital shortfall is 19.37%, indicating that certain corporations may face huge working capital shortfall at times. The mean value of cash flow in the

Table 2: Descriptive statistics of the main variables.

Variable	N	Average	Standard deviation	Minimum value	Median	Maximum
Part A: variables that affect the level of cash holdings						
cashhold	8153	0.1985	0.1445	0.0149	0.1559	0.6923
shortfall	9300	0.0259	0.0344	0	0.0023	0.1937
size	8153	21.9285	1.2542	19.4698	21.7587	25.7218
leverage	8153	0.4281	0.2065	0.0873	0.4308	0.9720
tobing	8153	2.6463	2.0060	0.8711	1.9771	12.1996
cflow	8151	0.0618	0.0495	−0.1031	0.0578	0.2183
ce	8098	0.0531	0.0488	0.00018	0.0392	0.226
nwc	8151	0.193	0.181	−0.362	0.197	0.627
fa	8147	0.263	0.181	0.00218	0.231	0.756
dividend	8153	0.0122	0.0160	0	0.00687	0.0835
dbstr	8153	0.833	0.172	0.274	0.892	1
nei	9300	0.228	0.419	0	0	1
first	9300	0.355	0.151	0.0893	0.336	0.752
dir	8888	2.161	0.193	1.609	2.197	2.708
idir	8888	0.371	0.0537	0.300	0.333	0.571
jir	8888	1.256	0.255	1.099	1.099	1.946
liangzhi	8832	0.266	0.442	0	0	1
Part B: variables that affect the value of cash holdings						
$r_t - R_t$	8131	0.133	0.502	−1.683	−0.0221	4.198
$\Delta C_t/M_{t-1}$	5729	0.0378	0.260	−1.532	0.0093	1.382
shortfall_t	6790	0.0263	0.352	0	0.00193	0.194
$\Delta E_t/M_{t-1}$	5729	0.0127	0.061	−1.287	0.0637	2.544
$\Delta NA_t/M_{t-1}$	5729	0.149	0.628	−2.906	0.087	13.791
$\Delta I_t/M_{t-1}$	5729	0.00273	0.0177	−0.652	0.0036	0.674
C_{t-1}/M_{t-1}	6790	0.1825	0.192	0.0002	0.312	2.886
NF_t/M_{t-1}	5686	0.0896	0.146	−0.669	0.0548	3.103
L_t	8153	0.360	0.380	0.0037	0.395	0.983

Note. ① The counts N of each variable are different because each variable has different missing values. ②The counts N of Part A and Part B are different because the variables of Part B are the amount of changes per variable, indicating that the sample statistics are one year less than Panel A.

total assets is 6.18%, which is greater than the median value; its statistical result is similar to the cash holding variable. The mean of the financial leverage is 42.81%, and the median is 43.08%, indicating that the distribution of financial is similar to the normal distribution. In corporate governance variables, the mean value of ownership concentration is 35.5%, and the median is 33.6%, indicating that the shares of listed corporations in China are more concentrated. The average size of the board is 2.161. The average proportion of independent directors is 37.1%, and the average size of the board of supervisors is 1.256, indicating that the board of directors and supervisors is relatively small in Chinese listed companies.

The descriptive statistical results listed in Panel B of Table 2 are variables that affect the cash holding value. The maximum of excess returns ($r_{i,t} - R^B_{i,t}$) is 4.198. The minimum is 1.683. Also, the standard deviation is 0.502. The statistical results indicate that the excess returns of different companies are different and unstable. On the other hand, it also shows the instability of A-share market. The mean value of cash holding level ($C_{i,t-1}/M_{i,t-1}$) is 0.1825. The minimum and maximum are 0.002 and 2.886, respectively. They indicate that the level of cash holdings is high in China, and there a big gap in cash holding level between different listed corporations. These results also illustrate that listed corporations in China may have serious agency problems. The maximum of cash holdings ($\Delta C_{i,t}/M_{i,t-1}$) is 1.382. The minimum is −1.532. The mean value is 0.0378. So, the gap between maximum and minimum in cash holding change is very large. The maximum and minimum of revenue changes ($\Delta E_{i,t}/M_{i,t-1}$) are 2.544 and −1.287, respectively, indicating that there is a distinct difference in profitability between listed corporations. The mean of change in non-cash assets ($\Delta NA_{i,t}/M_{i,t-1}$) is 0.129. The maximum and the minimum are 13.791 and 2.906, respectively, so the gap between the maximum in non-cash assets and the minimum in non-cash assets is large, which may be due to the different characteristics between the industries, and the average of the asset-liability ratio ($L_{i,t}$) is 0.36. The median is 0.395. Also, its distribution is similar to the normal distribution. But the maximum and minimum are 0.983 and 0.0037, respectively, indicating that different companies' financial leverage is different.

5.2. Correlation Analysis. Pearson and Spearman correlation coefficients are effective methods to evaluate multicollinearity [65, 66]. To avoid the effect of multicollinearity between variables on the experimental results, in this paper, Pearson and Spearman correlation coefficients are used to test the multicollinearity between variables. The results are shown in Table 3. Generally speaking, there is multicollinearity problem between variables if the correlation coefficient is more than 0.8. From Table 3, we can see that the

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Table 3: Test of correlation coefficients of major variables (Pearson and Spearman).

Part A: variables that affect the level of cash holdings

	cashhold	size	leverage	tobing	cflow	*ce*	*nwc*	*fa*	dividend
cashhold		−0.264***	−0.041***	0.258***	0.215***	0.024***	−0.118***	−0.336***	0.283***
size	−0.268***		−0.053***	−0.598***	−0.066***	−0.077***	−0.093***	0.034***	−0.037***
leverage	−0.049***	−0.037***		0.047***	0.0427***	0.184***	0.084***	−0.027***	0.044***
tobing	0.213***	−0.470***	0.026***		0.297***	0.040	0.032***	−0.140***	0.137***
cflow	0.223***	−0.037***	0.023***	0.228***		0.261***	−0.146***	0.099**	0.501***
ce	−0.038***	−0.074***	0.068***	−0.001	0.180***		−0.178***	0.527***	0.193***
nwc	−0.187***	−0.087***	0.067***	−0.047***	−0.090***	−0.160***		−0.354***	0.024
fa	−0.357***	0.104***	−0.116***	−0.175***	0.024**	0.442***	−0.377***		−0.041***
dividend	0.301***	−0.072***	0.034***	0.112***	0.474***	0.110***	−0.002	−0.057***	
dbstr	0.212***	−0.317***	0.014***	0.160***	0.082***	−0.114***	0.075***	−0.249***	0.113***
shortfall	0.127***	0.063***	−0.097***	−0.004	−0.106***	−0.035***	−0.044***	0.064***	−0.141***
nei	0.063***	0.017**	0.015**	0.159***	0.047***	0.015*	0.026**	−0.054***	−0.074***
first	0.017**	0.256***	−0.043***	−0.126***	0.090***	0.002	−0.016	0.057***	0.108***
dir	0.074***	0.278***	−0.131***	−0.168***	−0.002	0.037***	−0.103***	0.149***	0.008
idir	0.030***	0.033***	0.032***	0.060***	−0.020*	−0.018	0.020*	−0.054***	−0.018
jir	−0.132***	0.288***	−0.163***	−0.016***	−0.038***	−0.045***	−0.129***	0.159***	−0.086***
liangzhi	0.126***	−0.194***	0.150***	0.116***	0.035***	0.096***	0.098***	−0.075***	0.076***

Continuation of part A

	dbstr	shortfall	nei	first	dir	idir	jir	liangzhi
cashhold	0.255***	0.187***	0.052***	0.015**	0.068***	0.030***	−0.120***	0.119***
size	−0.345***	0.102***	0.076**	0.222***	0.266***	−0.004***	0.276***	−0.203***
leverage	0.025***	−0.161***	0.031**	−0.064 ***	−0.156***	0.020***	−0.022***	0.176***
tobing	0.251***	−0.084***	0.124***	−0.154***	−0.199***	0.031***	−0.230***	0.163***
cflow	0.106***	−0.098***	0.019***	0.078***	−0.004	−0.019*	−0.057***	0.055***
ce	−0.093***	−0.029***	0.018*	0.011	0.044***	−0.026	−0.046***	0.101***
nwc	0.085***	−0.049***	−0.003**	−0.030	−0.096***	0.022*	−0.135***	0.104***
fa	−0.202***	0.112***	−0.044***	0.045***	0.127***	−0.053***	0.126***	−0.050***
dividend	0.109***	−0.178***	−0.096***	0.105***	0.014	−0.018	−0.091***	0.087***
dbstr		−0.138***	−0.017	−0.030***	−0.112***	−0.007	−0.170***	0.109***
shortfall	−0.110***		−0.016***	0.042	0.028	0.012**	0.092***	−0.055***
nei	0.016	−0.039***		−0.062***	−0.012**	0.014*	−0.009***	0.012**
first	−0.047***	0.006	−0.044***		0.003**	0.023***	0.047***	−0.045***
dir	−0.122***	−0.002	−0.025**	0.027**		−0.448***	0.287***	−0.168***
idir	−0.010	0.021**	0.008*	0.041***	−0.459***		−0.078***	0.088***
jir	−0.165***	0.067***	−0.028***	0.060***	0.307***	−0.098***		−0.181***
liangzhi	0.108***	−0.064***	0.024**	−0.059***	−0.160***	0.100***	−0.178***	

Part B: variables that affect the value of cash holdings

	$r_t - R_t$	shortfall	$\Delta C_t/M_{t-1}$	$\Delta E_t/M_{t-1}$	$\Delta NA_t/M_{t-1}$	$\Delta I_t/M_{t-1}$	C_{t-1}/M_{t-1}	NF_t/M_{t-1}	L_t
$r_t - R_t$		−0.137**	0.115***	0.311***	0.171***	−0.302**	0.056***	−0.093***	−0.143***
shortfall	−0.131**		0.039***	−0.035***	−0.121***	0.162***	−0.224***	0.036***	0.152***
$\Delta C_t/M_{t-1}$	0.103***	0.026***		0.174***	0.026***	0.113***	−0.229	0.326***	0.176***
$\Delta E_t/M_{t-1}$	0.217***	−0.022***	0.207***		0.275***	0.076***	0.146***	0.157**	0.029***
$\Delta NA_t/M_{t-1}$	0.162***	−0.116***	0.021***	0.311***		0.245***	0.174**	0.533***	0.168***
$\Delta I_t/M_{t-1}$	−0.331**	0.171***	0.123***	0.091***	0.252***		−0.005***	0.244***	0.172**
C_{t-1}/M_{t-1}	0.066***	−0.237***	−0.231***	0.134***	0163***	−0.004***		−0.057***	0.072***
NF_t/M_{t-1}	−0.108***	0.108***	0.329***	0.149**	0.517***	0.247*****	−0.053***		0.137***
L_t	−0.158***	0.170***	0.182***	0.032***	0.163***	0.168**	0.079***	0.142***	

Note: The Pearson coefficient is down the diagonal, and the spearman coefficient is above the diagonal. ***, **, *, respectively represent significant, 0.01, 0.05, 0.10 level.

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correlation coefficients between variables are mostly less than 0.5 and are significant at the 0.1% level, indicating that there is no obvious multicollinearity problem between variables. There is a significant positive correlation between the industrial operating capital shortfall (shortfall$_t$) and cash holding level (cashhold$_t$) at the level of 1%; this result is consistent with Hypothesis 1. Also, there is a significant negative correlation between the industrial operating shortfall (shortfall$_t$) and returns ($r_t - R_t$) at the 1% level. This result indicates that the shortage of working capitals may reduce the company's excess returns, thereby weakening the value of the company cash holdings.

5.3. Regression Fitting Results and Analysis. To test Hypothesis 1, this paper chooses the OLS Model, the Fixed Effect Model, and Random Effect Model to fit the corporate cash holding level with the explanatory variables, and the

results are shown in Table 4. Then, the Hausman test (Hausman test: a method used in the regression analysis of panel data, is applied to the regression of Fixed Effect Model and Random Effect Model Regression) is carried out to test the Fixed Effect Model and Random Effect Model. The test results show that the Random Effect Model is rejected by the test, so the regression results of the Fixed Effect Model and OLS Model are adopted for further use.

From Table 4, the adjusted R square of OLS Regression and Fixed Effect Regression is 0.2531 and 0.2687, respectively. Tested by OLS Regression and Fixed Effect Regression, the model has good reliability, and the coefficients are significant. The significance of the regression coefficient indicates that the design of the model is reasonable. By observing the regression results of each variable, the positive correlation between industrial operating capital shortfall (shortfall_t) and cash holdings (cashhold_t) in OLS and Fixed Effect Models is significant at the level of 0.1%. The result indicates that when the shortage of industrial operating capitals becomes more serious, companies in the same industry tend to hold more cash. From an economic point of view, assuming that other conditions remain unchanged, if there is a standard error (0.0344) change in working capital shortfall, then the proportion of cash holdings in total assets will change by 9.29% (Fixed Effect Model: $0.0344 * 0.27 = 0.00929$). The change in working capital shortfall is equivalent to an increase of 4.68% in the average value of cash holdings. That is, managers are particularly sensitive to the working capital shortfall within five years of other companies in the same industry. Thus, managers incline to hold more cash to deal with the possible shortage of working capitals. Thus, Hypothesis 1 has been supported. For other control variables, the corporation size, financial leverage, net operating capital ratio, and fixed asset ratio are negatively related to cash holdings, and the negative correlations are significant at the level of 0.1%. But the board size is significant at 1% level. The growth opportunities, stock issuance dummy variables, dividend dividends, and the largest shareholder holdings are positively correlated with cash holdings, and the positive correlations are significant at the level of 0.1%. But there is no obvious correlation between the scale of the independent director and corporate cash holdings. This result indicates that the small size of the independent directors' board in China results in weak decision execution over cash holdings.

To test Hypothesis 2, two types of data samples are regressed using the Fixed Effect Model based on considering the individual effects, and the two datasets are data samples considering working capital shortfall and data samples without considering working capital shortfall, respectively. The results are shown in Table 5. In Fixed Effect Regression I, the coefficient of change in cash holding variable ($\Delta C_t/M_{t-1}$) is 0.741, and the results of significance test indicate that cash holding increment has positive effect on excess returns significantly at the level of 0.1%, that is, each additional unit of input cash yields 0.741 unit of excess returns. The operating capital shortfall ($short\,fall_t$) and the product of operating capital shortfall and the change in cash holding ($\text{shortfall}_t * \Delta C_t/M_{t-1}$) are added to Fixed Effect Regression II to test the hypothesis. The coefficient of $short\,fall_t$ is −1.192, and the result indicates that operating capital shortfall has negative correlation on excess returns significantly at the level of 0.1%. The coefficient of $\text{shortfall}_{i,t} * \Delta C_{i,t}/M_{i,t-1}$ is −6.147, and the result indicates that $\text{shortfall}_{i.t} * \Delta C_{i,t}/M_{i,t-1}$ has negative correlation on excess returns significantly at the level of 0.1%. The results show that both of them are negatively correlated with the excess returns, and the greater the gap of operating capitals shortfall, the lower the excess returns of cash. To investigate the relationship of cash holding value and operating capital shortfall more clearly, formula (3) ($V = r_1 + r_3\text{shortfall}_{i,t}$) is also examined. From regression II, we can estimate the cash holding value in the case of a working capital shortfall. Assuming that the average value of working capital shortfall is 0.0263, we can calculate that the cash holding value of the company is 0.61 ($0.773–0.0263 * 6.147$) in the case of a working capital shortfall. In regression model I, formula (3) is used when the working capital shortfall is not considered; we can calculate that the cash holding value of the company is 0.74 ($0.741–0.0263 * 0$). These two regression results show that the cash holding value of listed companies in China is less than the face value. Furthermore, the shortage of working capital further reduces the value of cash holdings, so Hypothesis 2 is validated.

5.4. Robustness Test. To verify the validity of the above empirical study results and enhance the reliability of the results, we perform the following stability test.

Robustness Test 1. The Ordinary Least Square (OLS) Method is used to test the impact of operating capital shortfall on cash holding level in the same industry. To overcome the effect of heteroscedasticity and intra-group residual correlations on the estimation results, we conduct the OLS regression analysis under two conditions, respectively. In the first condition, we perform robust processing of the standard deviation to minimize the heteroscedasticity and residual correlation effect; then, we conduct OLS regression analysis. In the second condition, following Faulkender and Wang [27], we group companies according to their dividend payout ratio and then the OLS regression analysis is conducted after the clustering of companies. As shown in Table 6, the operating capital shortfall expands with the increase of cash holdings in the next year, and the positive relation is significant at the level of 0.1%. This result indicates that the relationship between the operating capital shortfall and the cash holding level is robust. The greater the gap of the operating capital shortfall in the industry is, the more cash the corporations in the same industry tend to hold, and the result is consistent with the empirical results.

Robustness Test 2. The OLS regression analysis of excess return is also conducted under two kinds of robustness test. The test results are shown in Table 7. The coefficient of $short\,fall_t$ is -1.263. The coefficient of $\text{shortfall}_{i,t} * \Delta C_{i,t}/M_{i,t-1}$ is -6.218, and they are all significantly negatively correlated at 0.1%. According to formula

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Table 4: The regression result of validating Hypothesis 1.

Model variables	OLS cashhold_t	Fixed effect regression cashhold_t	Random effect regression cashhold_t
shortfall_t	**0.227*****	**0.270*****	0.206***
	(5.08)	**(8.61)**	(6.39)
size_t	−0.00144***	−0.00126***	−0.00220**
	(−7.17)	(−12.95)	(−2.93)
leverage_t	−0.0146***	−0.0130***	−0.0141***
	(−19.84)	(−26.33)	(−35.15)
tobing_t	0.00678***	0.00870***	0.00898***
	(6.05)	(11.39)	(14.14)
cflow_t	0.0961*	0.0825*	0.0874
	(2.48)	(2.55)	(0.69)
ce_t	−0.0106**	−0.0172*	−0.0261
	(−3.21)	(−2.11)	(−1.57)
nwc_t	−0.412***	−0.491***	−0.400***
	(−21.87)	(−45.79)***	(−49.17)
fa_t	−0.368***	−0.499***	−0.445***
	(−27.08)	(−37.10)	(−45.07)
nei_t	0.0195***	0.0207***	0.0201***
	(5.92)	(8.87)	(9.03)
dividend_t	0.433***	0.394***	0.578***
	(7.26)	(6.61)	(7.50)
dbstr_t	−0.0191**	−0.0215***	−0.0223**
	(−3.11)	(−5.73)	(−2.97)
first_t	0.0490***	0.0380***	0.0931***
	(3.92)	(8.94)	(8.44)
dir_t	0.0368**	0.0383**	0.0462*
	(3.15)	(3.23)	(2.15)
idir_t	−0.0677	−0.0441	0.0785
	(−1.87)	(−1.91.)	(1.99)
jir_t	−0.000986	−0.000921	−0.000344
	(−0.50)	(−0.72)	(−0.44)
liangzhi_t	0.0132**	0.0178**	0.0159**
	(3.13)	(3.29)	(3.25)
cons	1.404***	1.304***	0.600***
	(7.23)	(15.30)	(12.56)
***F* statistic**	127.93***	163.49***	
Adj_R-sq	0.2531	0.2687	0.2717
Observation	7775	7775	7775

Note. The numbers in parentheses are *t*-test values; ***, **, and *, respectively, represent significance at 0.1%, 1%, and 5% levels. The random effect regression in STATA software does not give the F statistic, and it does not affect the study because it does not consider the random effect regression results. The bold values signify the main result.

Table 5: The regression result of validating Hypothesis 2.

Model **Variable**	Fixed effect regression I $r_t - R_t$	Fixed effect regression II $r_t - R_t$
$\Delta C_t/M_{t-1}$	**0.741*****	**0.773*****
	(16.62)	**(15.10)**
$\Delta E_t/M_{t-1}$	1.993***	2.298***
	(24.76)	(22.39)
$\Delta NA_t/M_{t-1}$	0.0295**	0.0103***
	(3.46)	(6.78)
$\Delta I_t/M_{t-1}$	−7.309***	−6.327***
	(−46.46)	(−40.46)
C_{t-1}/M_{t-1}	0.338**	0.131*
	(3.25)	(2.81)
NF_t/M_{t-1}	−0.156*	−0.213
	(−2.46)	(−1.40)

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Table 5: Continued.

Model **Variable**	Fixed effect regression I $r_t - R_t$	Fixed effect regression II $r_t - R_t$
L_t	−0.4844*** (−19.48)	−0.4158*** (−14.53)
shortfall$_t$		**−1.192***** **(−36.55)**
shortfall$_t * \Delta C_t/M_{t-1}$		**−6.147***** **(−12.16)**
cons	0.0615*** (7.58)	0.0647*** (6.01)
F statistic	103.59***	83.79***
Adj_R-sq	0.2426	0.2192
Observation	5677	5677

Note. The numbers in parentheses are t-test values; ***, **, and *, respectively, represent significance at 0.1%, 1%, and 5% levels. The bold values signify the important results explained in the text.

Table 6: Results of robustness test 1.

Model **Variable**	OLS with robust cashhold$_t$	OLS with cluster cashhold$_t$
shortfall$_t$	**0.227***** **(6.22)**	**0.227***** **(7.42)**
size$_t$	−0.00144*** (−8.55)	−0.00144*** (−5.51)
leverage$_t$	−0.0146*** (−5.21)	−0.0146*** (−13.04)
tobing$_t$	0.00678*** (7.53)	0.00678** (2.95)
cflow$_t$	0.0961* (2.13)	0.0961* (2.33)
ce_t	−0.0106** (−3.28)	−0.0106* (−2.41)
nwc_t	−0.412*** (−23.63)	−0.412*** (−16.56)
fa_t	−0.368*** (−24.50)	−0.368*** (−20.26)
nei$_t$	0.0195*** (6.76)	0.0195*** (5.20)
dividend$_t$	0.433*** (7.32)	0.433*** (4.87)
dbstr$_t$	−0.0191* (−2.48)	−0.0191** (−3.09)
first$_t$	0.0490* (2.56)	0.0490* (2.12)
dir$_t$	0.0368* (2.16)	0.0368** (3.21)
idir$_t$	−0.0677 (−1.93)	−0.0677 (−1.23)
jir$_t$	−0.000986 (−0.48)	−0.000986 (−0.34)
liangzhi$_t$	0.0132* (2.34)	0.0132* (2.19)
cons	1.404*** (9.77)	1.404*** (6.51)
F statistic	134.92***	129.70***
Adj_R-sq	0.2531	0.2531
Observation	7775	7775

Note. The numbers in parentheses are t-test values; ***, **, and *, respectively, represent significance at 0.1%, 1%, and 5% levels.

Table 7: Results of robustness test 2.

Model **Variable**	OLS with cluster $r_t - R_t$	OLS with robust $r_t - R_t$
$\Delta C_t/M_{t-1}$	**0.751***** **(6.06)**	**0.751***** **(5.16)**
$\Delta E_t/M_{t-1}$	2.192** (3.75)	2.192*** (21.34)
$\Delta NA_t/M_{t-1}$	0.0111** (3.31)	0.0111* (2.45)
$\Delta I_t/M_{t-1}$	−6.364*** (−4.24)	−6.364*** (−5.34)
C_{t-1}/M_{t-1}	0.134** (3.51)	0.134** (3.24)
NF_t/M_{t-1}	−0.201 (−0.10)	−0.201 (−0.68)
L_t	−0.4249** (−3.47)	−0.4249*** (−6.43)
shortfall$_t$	**−1.263***** **(6.15)**	**−1.263**** **(−3.52)**
shortfall$_t * \Delta C_t/M_{t-1}$	**−6.218***** **(−20.84)**	**−6.218***** **(−17.36)**
cons	0.0591*** (−11.87)	0.0591*** (−8.96)
F statistic	123.19***	105.04***
Adj_R-sq	0.2297	0.2297
Observation	5677	5677

Note. The numbers in parentheses are t-test values; ***, **, and *, respectively, represent significance at 0.1%, 1%, and 5% levels. The bold values signify the main result.

(3), the greater the working capital shortfall, the lower the cash holding value of corporations in the same industry, and this finding is consistent with the above research results which indicate that the regression result is robust.

6. Conclusions and Managerial Implications

Inspired by the impact of major emergencies on enterprise operation, the aim of this paper is to provide empirical evidence for the relationship between industry working capital shortfall and cash holdings. We constructed an

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Extended Cash Holding Model and a Cash Holding Value Regression Model by introducing the industry working capital shortfall as one of the explanatory variables. To study the impact of major emergencies on corporate cash holdings, this paper selects the 2007–2015 panel data after the financial crisis for empirical analysis. A Classical Linear Regression Model and Fixed Effects Regression Model are adopted to explore the impact of industry working capital shortfall on the level and value of cash holdings in the same industry, which reveals the relationship between working capital shortfall and cash holdings.

Different from the existing research results, the major contribution of this paper is to study the effect of industry working capital shortfall on cash holdings of the company. This analysis shows that there is a two sides effect relation between industry working capital shortfall and cash holdings, which implies that industry working capital shortfall is a crucial factor in the determination of cash holdings, especially in case of emergency. The larger the working capital shortfall, the more cash companies in the same industry hold. Meanwhile, the cash holding value of companies within the same industry is depressed due to the shortage of industry working capitals. This is, the working capital shortfall is not only the incentive factor of cash holdings but also the restraining factor of cash holding value. As the working capital shortfall has a dual impact on cash holdings, it is necessary to weigh the working capital shortfall and cash holdings in order to maximize value. This result is also robust to heteroscedasticity test and residual correlation test, respectively.

For companies, the interruption of cash flow is the most fatal factor that directly leads to bankruptcy. Since the outbreak of the COVID-19, due to some social emergency strategies, market imbalance, and other reasons, the operation of some companies has been seriously shocked, which results in an increased risk of capital shortfall. From the perspective of preventive motivation of corporate cash holding, this paper provides direct empirical evidence for companies to deal with crisis events and provides a theoretical basis for companies to make decisions on cash holdings under the influence of major and emergency events. Meanwhile, it also enriches the relevant research on cash holding with preventive motivation. Our research has several implications for managers and industry working capital shortage research. First, the current epidemic situation is still severe. Based on the important buffer role of cash holding in crisis, managers should increase their cash holdings decisions to fully deal with possible risks. Second, due to the "two sides effect" of industry working capital shortfall on the level and value of cash holdings in the same industry, it is not always beneficial for companies to increase their cash holdings during the epidemic. Thus, companies should weigh the relationship between industry working capital shortfall, cash holding level, and cash holding value, so as to resist risks and maximize enterprise value. Finally, to cope with the impact of major events, such as the financial crisis and epidemic on the economy, the government can stabilize the market environment by regulating the industry working capital.

This research is based on the data of Chinese listed companies, and the conclusions drawn are applicable to Chinese market. However, the applicability of this conclusion in other countries needs to be further verified. In addition, as the epidemic continues, relevant data affected by COVID-19 continue to be enriched. In the future, we can consider updating the sample data and exploring more direct evidence [63].

Data Availability

The financial data were collected from the Wind database. The corporate governance data were derived from the CSMAR database of GTA Information Technology Co. Ltd.

Disclosure

Zhaohua Li and Junyi Jiang are Co-first author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Spatial Differentiation and Influencing Factors of the Green Development of Cities along the Yellow River Basin

Yu Chen,[1] Xuyang Su,[1] and Qian Zhou[2]

[1]*School of Economics and Management, Zhengzhou University of Light Industry, Science Avenue 136, Zhengzhou, Henan 450000, China*
[2]*Economics School, Zhongnan University of Economics and Law, Nanhu Avenue 182, Wuhan, Hubei 430073, China*

Correspondence should be addressed to Qian Zhou; z0005072@zuel.edu.cn

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The traditional development model of high consumption and low efficiency approaches the threshold of resource and environmental carrying capacity, bringing a series of severe social and ecological environmental problems, and it is urgent to realize green development transformation. Based on a multidimensional perspective, this paper constructed a comprehensive evaluation system for urban green development along the Yellow River Basin (YRB). Entropy method, exploratory spatial data analysis (ESDA) model, and trend analysis were used to measure and characterize the spatiotemporal evolution of urban green development index (UGDI) along the YRB in 2008, 2013, and 2018, and geographically weighted regression (GWR) model was used to explore the influencing factors of urban green development. The results are as follows: (1) the UGDI along the YRB showed a slow upward trend, but the absolute value was relatively low, mainly concentrated in 0.2699–0.3799. (2) The UGDI had obvious regional differences, and cities such as Baotou and Zibo showed a "high-high" agglomeration, while most cities in the midstream showed a "low-low" agglomeration, and in terms of space, they were "high in the east and west, low in the middle" and "high in the north and low in the south." (3) Influencing factors had different degrees of impact on the UGDI. Economic, industrial, urbanization, and green infrastructure factors played a positive role in promoting the urban green development, while the relationship between governance, technological factors, and green development varies from city to city.

1. Introduction

The city is a highly concentrated area of people's life and production, and it plays the dual role of industrial development carrier and regional economic growth engine. With the continuous advancement of population urbanization and land urbanization, cities have accumulated a lot of material wealth, and the population size, spatial scale, and production scale have also been rapidly expanded, forming a new urbanization development path with distinct characteristics in China [1–3]. In 2020, 56.2% of the world's population lived in urban areas, and it is expected that this proportion will increase to 62.5% by 2035 [4]. Sustained population growth, economic development, and resource consumption approach or exceed the ecological boundary, intensifying the contradiction between human and nature, environmental pollution and ecological destruction are becoming increasingly serious, the contradiction between supply and demand of natural resources is increasing, and human physical and mental health and social harmony are also threatened [5, 6]. In the context of the gradual disappearance of labor factor dividends and the increasingly tense resource and environmental constraints, the development model that relies only on increasing inputs of production factors cannot be sustained [7]. At present, COVID-19 has swept the world and caused serious impact on the economic and social development of various countries. It is imperative to realize the transformation of thinking and economic growth model.

From a long-term perspective, green development is an effective way to cope with climate change and energy resource crises [8, 9]. It is an inevitable choice for future

development models. It can maintain a balance between economic growth, wealth accumulation, social development, and environmental protection and will help create a new situation of social material and ecological civilization and then realize the organic coordination of "production-living-ecology." As an important ecological barrier and economic belt, the YRB is a typical area with rapid economic-society-environmental changes. Its green development is related to regional coordination and linkage and the establishment of a modern social and economic system. However, a series of factors such as long-standing rigid constraints of resources and environment, irrational industrial structure, and unbalanced spatial development have put a lot of pressure on ecological security in the basin, and the coordination among human being, nature, and society is facing huge challenges. In view of this, president Xi Jinping proposed to handle the relationship between ecological protection and high-quality development correctly and pointed out at the conference of the Central Finance and Economics Committee that the YRB must be vigorously protected and governed to take the path of ecological protection and high-quality development. Therefore, based on the research logic of "UGDI measurement-spatial and temporal pattern analysis-influencing factors analysis," this paper uses entropy method to calculate UGDI and then discusses the agglomeration characteristics of green development according to spatial pattern and spatial autocorrelation analysis. Finally, the GWR model is used to analyze the influencing factors of green development. The results are expected to provide reference for ecological protection and high-quality development in the basin. The structure of this paper is as follows: Section 2 is a literature review on the study of green development; Section 3 is a presentation of materials and methods; Section 4 is the results of this paper; and Section 5 is conclusions and suggestions. The research framework of this paper is shown in Figure 1.

2. Literature Review

2.1. Concept Definition. Green development is a critique of traditional development models [10] and also a deepening and improvement of concepts such as green economy, circular economy, and sustainable development [11]. With the development of industrial civilization and the accumulation of material capital, in order to alleviate the contradiction between economic growth and the ecological environment, early green development related ideas pointed out that it is necessary to move from growth fanaticism to a stable state and advocated investing in natural capital and fostering sustainable development of the environment [12]. Steady-state economy, green economy, and ecological economy are considered the original ideas of green development. The academic community widely believes that the research on green development or green economy started with Pierce's "Blueprint for a Green Economy." The book points out that economic development must be bearable by the natural environment and human beings themselves and will not blindly pursue production growth and cause social division and ecological crisis [13]. With the deepening of research, the concept of sustainable development was proposed and showed a certain comprehensiveness. Although sustainable development is a controversial concept, it is usually expressed as the intersection of environment, society, and economy, and the three should be unified on the path of sustainable development [14]. In addition, some scholars also defined green development from the perspective of ecological industry and believed that measures such as adjusting factor prices and differential taxes should be adopted to cultivate low-carbon economy and green economy and establish a sustainable and circular development model [15]. On the whole, the research on green development shows a flourishing situation. Most scholars' understanding of green development mainly focuses on two viewpoints. One view holds that green development is to fully understand the interaction mechanism of economic, social, and natural system under the constraints of resources and environment and finally realize the maximization of the benefits of the three systems [7]. Another view emphasizes that green development is the pursuit of coordination between economic development and ecological environment [16].

2.2. Index System and Evaluation Methods. The establishment of an evaluation index system for green development and quantitative analysis of the status of green development can provide an important basis for government decision-making and improvement of management efficiency. Some organizations and scholars have carried out a large number of studies on green development evaluation index systems and measurement methods [17–19]. In terms of the construction of the indicator system, the OECD places more emphasis on the positive role of economic growth in tackling climate change and environmental protection, defines green development from the perspective of green growth, and then proposes four primary indicators including economy, environment, society, and technology and development, and the corresponding green growth indicator system of 14 secondary indicators. Although UNEP's inclusive green economy measurement indicator system has similarities with the OECD, it places more emphasis on ecological protection [20]. Based on the research theory and practice state of China's green development, some scholars have established a national and regional green development evaluation index system, such as the establishment of the China green development index to evaluate the status of green development in various areas in China [21], and constructed a green development evaluation system according to the connotation of China's green development in the new era [22], and a regional green development evaluation index system was constructed from the dimensions of ecological space optimization, good ecological environment, and ecological economic development [23]. The early evaluation methods were mainly based on the DEA model. For example, Färe et al. [18] measured the environmental efficiency index of OECD countries, and Coli et al. [17] measured the environmental efficiency of Italian provinces in 2004. Since then, TOPSIS model, projection pursuit model, comprehensive index method, spatial measurement model, information entropy model, and dissipative structure theory have also been more and more popular [22].

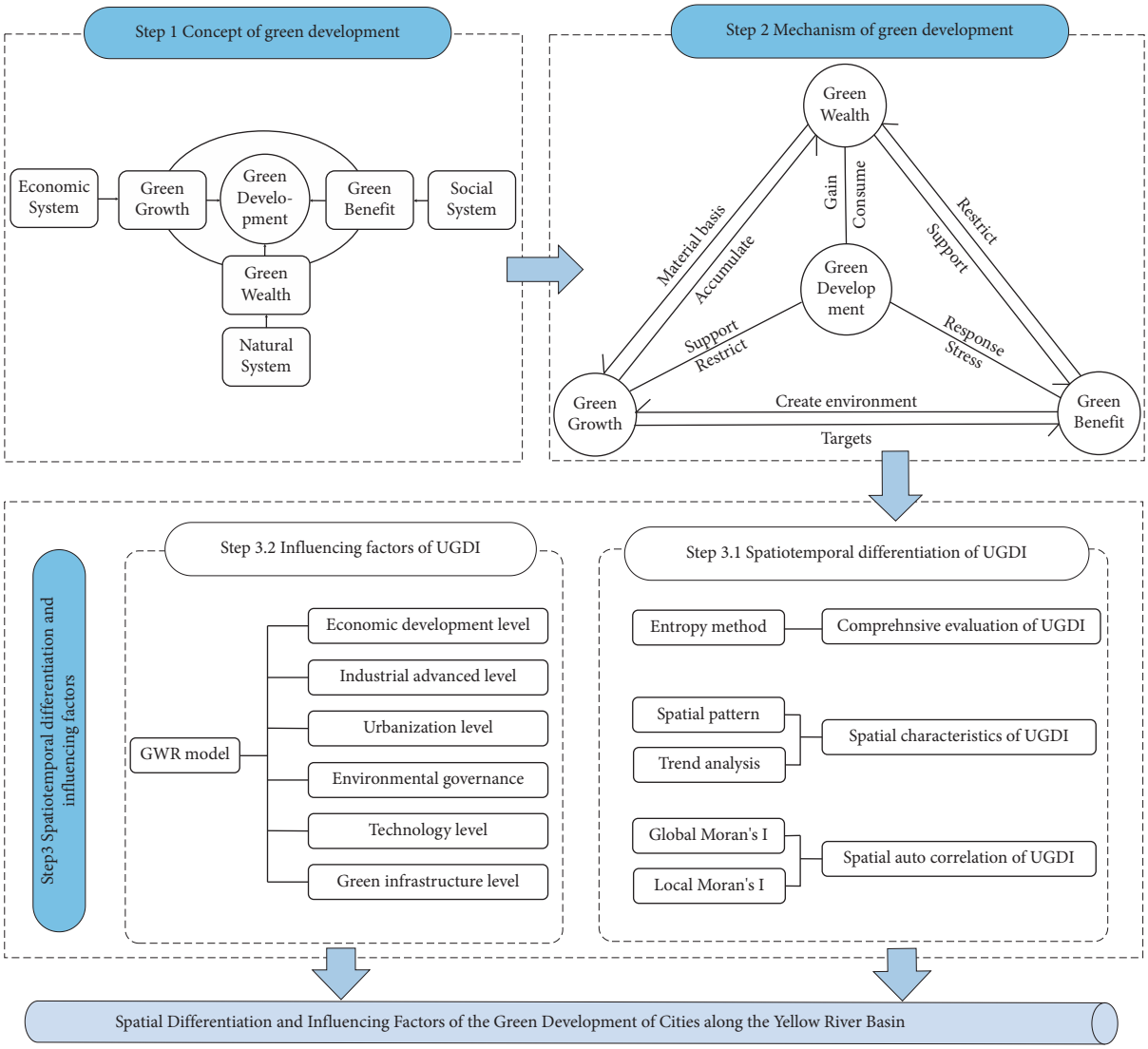

Figure 1: Research framework.

2.3. Factors Affecting Green Development. The research on the influencing factors of green development is helpful to distinguish the degree of influence of each influencing factor, and it can also provide a certain reference for policy making to improve the green development level. Shironitta's inspection and calculation analysis of carbon dioxide emissions from 1995 to 2009 in 40 countries found that the deindustrialization of high-income countries has resulted in lower CO_2 emissions than middle-income countries with heavy industrial and believed that changes in industrial structure are an important factor affecting economic green development [24]. Honma and Hu [25] found that a higher proportion of manufacturing and wholesale and retail will reduce the efficiency of green development. However, the overall industrial development or the improvement of the green development level is affected by technology, and technological progress promotes the continuous development of human society. Whether in traditional OECD countries or newly industrialized countries, general technological innovation and specific technological innovation are conducive to the country's green and sustainable development. Especially with the transition of energy development from the "oil era" to the "low carbon era," how to balance economic development and energy utilization to improve the green development level is a major practical issue facing today. In addition, some scholars have tried to propose a path to achieve green development in terms of key measures, policy support, institutional guarantees, and promotion mechanisms [26] and believe that it is necessary to coordinate interest relationships, regulate the behavior of subjects, improve institutional arrangements, and promote encouragement compatibility and other aspects to promote the green development [27].

To sum up, green development is the focus of attention of all countries in the world today. It has gone through a process from shallow to deep, from single to diversified, and there is a trend of refinement to specific industries and regions, but there are still issues that need to be explored in

depth. In terms of evaluation indicators, the trend of multidisciplinary cross-analysis based on a certain framework structure has emerged. Although the indicator system of green level and efficiency evaluation is relatively comprehensive, there is still room for improvement. For example, tolerance and equity are one of the goals of human development, and it is also the inherent requirement of green development, but the evaluation system of existing research pays little attention to this aspect. In terms of influencing factors, although many scholars have conducted research from a qualitative and quantitative perspective, fewer spatial analysis methods have been used. Therefore, in terms of research content, this paper breaks through the previous single mode of thinking and integrates economic, social, and natural system to carry out multilevel research on green development level; uses entropy method, ESDA model, and other methods to quantitatively study the spatiotemporal pattern of the green development; and seeks a path to achieve green development through the GWR model, to a certain extent to make up for the lack of discussion of regional differences in previous studies.

3. Materials and Methods

3.1. Concept and Theoretical Basis

3.1.1. Concept of Green Development. Under the constraints of resources and environment, green development focuses on maximizing environmental, economic, and social benefits in the development process through policy guidance, innovation-driven, and effective allocation of resources, so as to achieve the symbiosis of economic, social, and natural system and the diversification of development goals. On the basis of the existing research, the economic, social, and natural system are integrated to sort out the theoretical framework of green development (Figure 2). The framework consists of three levels: "core layer-middle layer-outermost layer." (1) The outermost layer is composed of economic system, social system, and natural system. The three systems are supported by different green concepts to form the foundation for green development. For example, in the economic system, the idea of low-carbon and recycling requires optimizing the industrial structure, reducing the consumption of energy resources, and forming a green development pattern of industrial agglomeration and technological innovation. In the social system, emphasis is placed on building green and smart cities and increasing fiscal policy support to increase people's well-being, improve people's living standards and social security, and achieve green social systems. Based on the basic pattern of ecological environment and natural characteristics, the natural system forms a green development benchmark by the interaction and coupling of natural factors such as water resources, land resources, and climate conditions. (2) The middle layer is the green performance of the economic, social, and natural system, which are represented as green growth, green benefit, and green wealth. Among them, green growth is the method, green wealth is the foundation, and green benefit is the goal. The three embody the core elements of green development. (3) The core layer is green development, which is formed under the combined effect of the outermost layer and the middle layer.

3.1.2. Mechanism of Green Development. Based on the understanding of the green development concept, this paper constructs a mechanism model with green development as the core and composed of green growth, green wealth, and green benefit (Figure 3). It can be seen from the above analysis that the economic, social, and natural system take green growth, green benefit, and green wealth as the development direction respectively. Under the concept of green development, the economic system is represented as green growth, the social system is represented as green benefit, and the natural system is represented as green wealth. On the interaction of outer circle, green growth relies on green wealth to provide the material foundation, continuously create social and economic benefits, and promote the accumulation of green wealth and improvement of the green benefit level. Green benefit is the goal of green growth, while the improvement of green benefit is restricted by green wealth. Once green benefit surpasses the boundary of green wealth carrying capacity, it will cause damage to the natural system. Green wealth is the long-term accumulation result of green growth. On the function of the inner circle, green development is at the core position. The positive interactions of green development to green growth, green benefit, and green wealth are shown in "support-response-gain," and negative interactions are shown in "restrict-stress-consume." In addition, in order to realize the coordinated and orderly operation of the three systems, it is necessary to build a green governance system led by the government, social collaboration, and public participation; it is a governance behavior aimed at ecological destruction and environmental pollution caused by negative interactions. Also, it is a guarantee for green development and further affects the performance of green growth, green benefit, and green wealth. Therefore, green development is a sustainable development that is based on the coordination and symbiosis of economic, social, and ecological systems, with green growth, green benefit, and green wealth as its connotation and green governance as its guarantee. This paper conducts research based on the above connotation and mechanism analysis.

3.2. Methods and Index System

3.2.1. Research Methods

(1) Entropy Method. Entropy method is an objective comprehensive evaluation method, which determines the index weight coefficient according to the amount of information provided by each index observation value. The higher the order of a system, the greater the information entropy and vice versa. The principle is to use information entropy to calculate the entropy weight of each index according to the variation degree of each index, to correct the weight of each index and obtain a more objective index weight, which can

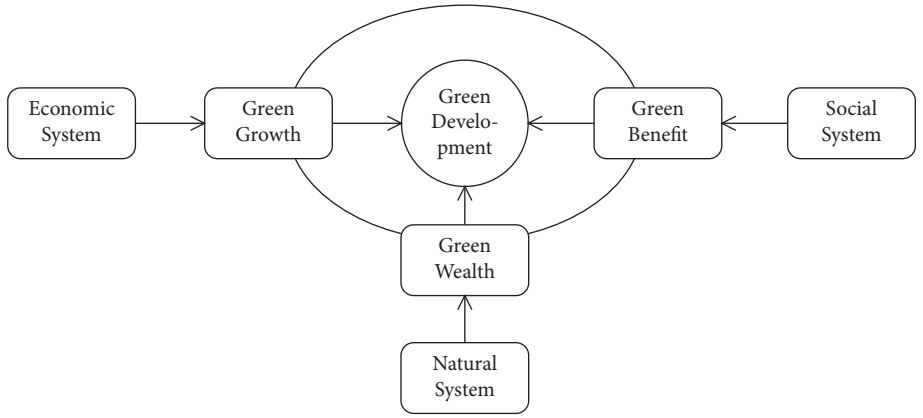

Figure 2: Concept framework of green development.

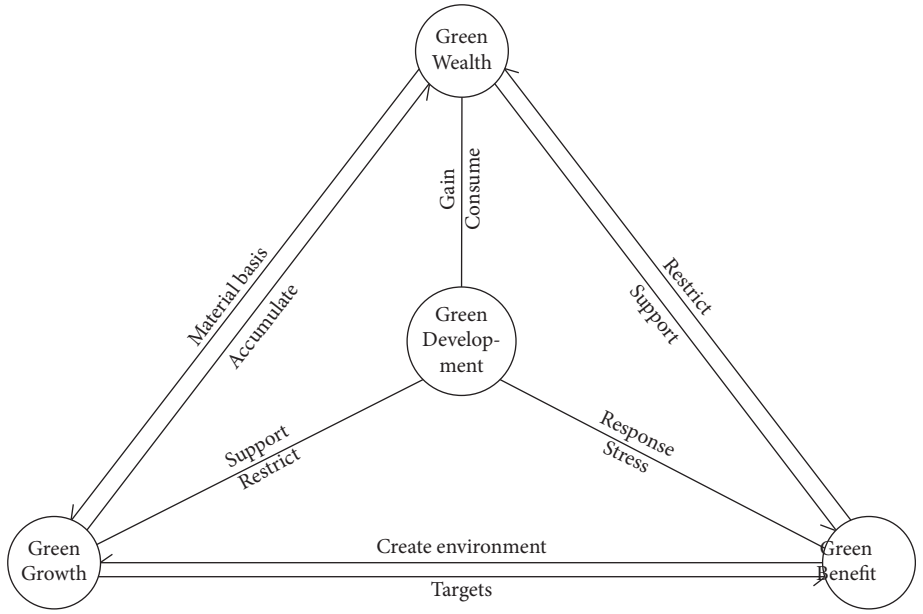

Figure 3: The green development mechanism of cities along the YRB.

also avoid human interference and has high credibility and accuracy [28, 29]. To avoid negative values of standardized values and better reflect the role of reverse indicators, the extreme value method is used to standardize the data.

(1) Standardize the indicators:

Positive indicator:

$$x_{ij}' = \frac{x_{ij} - \min\left(x_{ij}\right)}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)}. \quad (1)$$

Negative indicator:

$$x_{ij}' = \frac{\max\left(x_{ij}\right) - x_{ij}}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)}, \quad (2)$$

where x_{ij} is the original value of the i-th evaluation object corresponding to the j-th index; x_{ij}' is the standardized value; $\max(x_{ij})$ and $\min(x_{ij})$ are the maximum and minimum values of each index respectively.

(2) Calculate the entropy value of the j-th index:

$$e_j = -\mathrm{k}\sum_{i=1}^{m} P_{ij} ln\, P_{ij}, \quad (3)$$

where $k = 1/\ln(35)$, $P_{ij} = x_{ij}'/\sum_{i=1}^{m} x_{ij}'$.

(3) Determine the index weight:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad (4)$$

where $d_j = 1 - e_j$.

(4) Calculate the comprehensive index of green development:

$$Y_i = \sum_{j=1}^{n} w_j \times x_{ij}', \quad (5)$$

where $i = 1, 2, \ldots, 35$; $j = 1, 2, \ldots, 23$. Y_i is the UGDI, w_j is the index weight, x'_{ij} is the standardized value, i is the city, and j is the index. According to the research of other scholars [23], this paper divides the UGDI into the following: $Y_i > 0.5000$ indicates that the UGDI is at a high level, $0.3000 < Y_i < 0.4999$ indicates that UGDI is at a medium level; $Y_i < 0.2999$ indicates that UGDI is at a low level.

(2) Spatial Autocorrelation. Spatial autocorrelation analysis includes global spatial autocorrelation and local spatial autocorrelation analysis, which is used to explain the correlation and difference degree of a certain spatial attribute of the whole or adjacent units within the area. The Moran's I and Local Moran's I indexes are used for analysis respectively. The global Moran's I index formula [30] is as follows:

$$\mathrm{I} = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}, \tag{6}$$

where n represents the number of spatial units in the study area, i and j are two different spatial units in the area, and x_i and x_j are values of spatial attributes x in units i and j respectively. W_{ij} represents the spatial weight matrix. If i and j are adjacent, $W_{ij} = 1$; if not, $W_{ij} = 0$. $\overline{x}$ is the mean value. The value range of I is $[-1, 1]$. When $I > 0$, it means spatial correlation is positive. The larger the value, the more obvious the spatial correlation is, and vice versa. When $I = 0$, there is no spatial autocorrelation. A Z test is required for Moran's I. The formula [31] is

$$\mathrm{Z(I)} = \frac{\mathrm{I} - \mathrm{E(I)}}{\sqrt{\mathrm{Var(I)}}}, \tag{7}$$

where $E(I)$ and $\mathrm{Var}(I)$ are mathematical expectation and variance of Moran's I, respectively. When $Z(I) > 0$ and significant, there is a positive spatial autocorrelation and vice versa. When $Z(I) = 0$, there is no spatial autocorrelation.

To clarify the specific location of spatial agglomeration of high-level and low-level UGDI within the YRB, we use the local Moran's I index to identify the local spatial autocorrelation characteristics of green development. The formula [32] is as follows:

$$I_i = \frac{\sum_{i=1,j=1}^{n} W_{ij}\left(x_i - x\right)\left(x_j - x\right)}{S^2}, \tag{8}$$

where I_i is the local Moran's I index of the i-th city and $S^2 = (1/n)\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2$; the results also need to be Z-tested, as in the formula above. At a certain level of significance, according to the significance level of the Moran's I index and the results of the Z test, the research cities can be divided into four agglomeration relationships: (1) When Moran's I is significant, positive, and $Z(I) > 0$, it is a "high-high" (H-H) agglomeration relationship, and the UGDI of the research city and neighbouring cities is high; (2) when the Moran's I index is significant, positive, and $Z(I) < 0$, it is a "low-low" (L-L) agglomeration relationship, and the UGDI of the research city and neighbouring cities is low; (3) when the Moran's I index is significant, negative, and $Z(I) > 0$, it is a "high-low" (H-L) agglomeration relationship, the UGDI of the research city is high, and the UGDI of the neighbouring unit is low; (4) when the Moran's I index is significant, negative, and $Z(I) < 0$, it is a "low-high" (L-H) agglomeration relationship, and the UGDI of the research city is low, and the UGDI of the neighbouring cities is high. When $Z(I) = 0$, it is randomly distributed.

(3) Geographically Weighted Regression. The essence of geographically weighted regression is local regression [33], which is solved by local weighted least squares method, where the weight is the distance function between the geographic location of the point to be estimated and the other observed geographic locations. These parameter values estimated at various geographic spatial locations describe the changes of the parameters with geographic spatial locations and are used to explore the nonstationarity of the regression coefficient space. The model structure is

$$y_i = \beta_0\left(u_i, v_i\right) + \sum_{j=1}^{n}\beta_j\left(u_i, v_i\right)x_{ij} + \varepsilon_i, \tag{9}$$

where $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$, y_i is the value of the dependent variable at the geographic location (u_i, v_i), (u_i, v_i) is the geographic center coordinate of the sample spatial unit, $\beta_0(u_i, v_i)$ is the constant value at the geographic location (u_i, v_i), $\beta_j(u_i, v_i)$ is the spatial value of the function $\beta_j(u_i, v_i)$ at the position of i sample, and ε_i is the residual. This paper uses the AICc method to determine the optimal bandwidth and then builds a GWR model for the green development level of cities along the YRB to conduct simulation, analysis, and discussion based on the simulation and model test results.

3.2.2. Construction of Index System. Green growth is mainly manifested in the development methods and concepts of low carbon, environmental protection, and green recycling, that is, to achieve green growth by reducing environmental pollution and reducing energy and resource consumption [7]. Based on the above analysis, the GDP per capita is used to measure the city's green development potential; the proportion of tertiary industry in GDP is used to reflect the degree of optimization of the city's economic structure; sulfur dioxide emissions per unit of GDP, smoke (powder) dust emission per unit GDP, and wastewater discharge per unit GDP are used to measure the degree of urban economic green growth.

Green welfare is mainly manifested in improving social welfare and enhancing people's well-being. It is the goal of green growth, which is embodied in residents' lives and science, education, culture, and health. Based on the above analysis, the disposable income of urban residents per capita is used to reflect the living standards of the people in general; the retail sales of consumer goods per capita are used to reflect the quality of life of urban residents, the proportion of science and education expenditures in GDP, the number of college students per 10,000 people, and the books in public

libraries per 100 people; the number of medical beds per 10,000 people in a city measures the development of science, education, culture, and health in the city.

Green wealth is mainly reflected in sufficient green resources and good environmental quality, to improve people's living environment and achieve the development goals of resource conservation and environmental friendliness [34]. Based on the above analysis, the park green area per capita and the green coverage rate in built-up areas are used to measure the green space owned by urban residents; the number of days with good air quality in built-up areas, industrial wastewater discharge per capita, and industrial sulfur dioxide emissions per capita are used to measure the urban environmental quality.

Green governance is mainly manifested in pollutant governance, waste recycling, and infrastructure construction, building a green governance system guided by the government and people participating [35, 36]. Based on the above analysis, use the centralized treatment rate of urban domestic sewage, the harmless treatment rate of urban domestic waste, and the comprehensive utilization rate of general industrial solid waste to measure the degree of recycling of urban resources. The urban road area per capita, the buses per 10,000 urban residents, urban water penetration rate, and the urban gas penetration rate reflect urban infrastructure construction. The index system is shown in Table 1: "+" represents positive index and "−" represents negative index.

3.3. Study Area and Data Sources. The Yellow River is the second longest river in China. It originates from the Bayan Har Mountains in Qinghai Province and flows from west to east through China's three major steps. The upstream and midstream are divided by Hekou Town, and the midstream and downstream are divided by Taohuayu. The main stream full length is 5464 kilometers, and the drainage area is about 752,000 square kilometers. The YRB has a large span, a wide area, and a large population. The natural environment and economic and social differences in the basin are significant. In 2019, the GDP of the eight provinces in the YRB (except Sichuan) accounted for 20.26% of the country's total GDP, and the population accounted for 23.31% of the total population in China. However, the level of economic development across regions is uneven, and the population density is increasing from upstream to downstream. In addition, although there are two national-level cities in the YRB, Zhengzhou and Xi'an, resource-based cities account for 28.63% of the national total, and old industrial bases account for 27.5% of the national total. At the same time, there are also "high energy consumption, high pollution, and low-level industries" and the imbalance of the urbanization rate has seriously affected the improvement of the green development level of cities in the YRB. The research scope is shown in Figure 4.

This paper takes 2008, 2013, and 2018 as the research time points; considering the availability of data, we exclude cities with missing data such as Yushu Tibetan Autonomous Prefecture and Haidong and selects 35 prefecture-level cities along the YRB as research samples. Basic data are obtained from "China City Statistical Yearbook," "China City Construction Statistical Yearbook," and statistical yearbooks of various cities. Some environmental indicators, such as days with good air quality in built-up areas, are derived from regional environmental bulletins and economic and social development bulletins. Some missing data use interpolation for makeup.

4. Results

4.1. Analysis of the Spatiotemporal Pattern of the UGDI

4.1.1. Comprehensive Evaluation of the UGDI. Table 2 shows that the UGDI of cities along the YRB is significantly different, the comprehensive UGDI is relatively low (0.2699–0.3799), the UGDI of cities with high administrative level and economic development level is relatively high, and the UGDI of provincial capitals such as Jinan, Zhengzhou, Hohhot, and Ordos have been in the forefront of the research period. Based on the measurement data of the UGDI in three years, from the perspective of the average value: horizontally, Jinan has the highest UGDI (0.6503), and Yuncheng has the lowest UGDI (0.2699), with a range value of 0.3875. Vertically, the UGDI of 35 cities shows a slow upward trend. In 2013, it increased by 5.09% compared with 2008. In 2018, it has increased by 0.5% compared with 2013. The 35 cities are further divided into three echelons: the first echelon is Jinan, Ordos, Zhengzhou, Hohhot, Lanzhou, Dongying, and Baotou; the UGDI is greater than 0.5000, accounting for 20%; there are 17 cities in the third echelon, including Taian, Yinchuan, Zibo, Wuhai, Jining, Shizuishan, Binzhou, Luoyang, Dezhou, Wuzhong, Jiaozuo, Jiyuan, Zhongwei, Liaocheng, Xinxiang, Bayannaoer, and Linfen, with UGDI ranging from 0.3000 to 0.4999, accounting for 48.57%; the remaining 11 cities are in the third echelon, including Puyang, Kaifeng, Baiyin, Yan'an, Heze, Xinzhou, Sanmenxia, Weinan, Luliang, Yulin, and Yuncheng; and the UGDI is between 0.2000–0.2999, accounting for 31.43%.

4.1.2. Spatial Characteristics of UGDI. Figure 5 shows the UGDI of cities along the YRB varies greatly across regions, and the UGDI between cities has a strong imbalance. First, the number of cities with high green development level is generally increasing. There were 4 cities in 2008 and 6 cities in 2013 and 2018, and they were mainly concentrated in provincial capitals such as Lanzhou and Jinan, as well as cities with more developed economies. Compared with other cities in the region, these cities are driven by the advantages of natural location and policy and can obtain better development opportunities. It is easy to form a "siphon effect" in each region; advantageous resources and high-tech talents gather in provincial capitals to promote the optimization and upgrading of economic development methods, such as the transformation of economic development from labor-intensive to capital and technology-intensive, and the transformation of production input factors from labor and resources to capital and technology, which will reduce the pressure on the resource environment and labor costs, so that the UGDI can be maintained

Table 1: Evaluation index system of green development.

Target layer	Criterion layer	Index layer	Nature	Weight
Green development	Green growth	GDP per capita	+	0.0389
		Proportion of tertiary industry in GDP	+	0.0071
		Sulfur dioxide emissions per unit GDP	−	0.1747
		Smoke (powder) dust emission per unit GDP	−	0.1210
		Wastewater discharge per unit GDP	−	0.0477
	Green benefit	Disposable income of urban residents per capita	+	0.0040
		Retail sales of consumer goods per capita	+	0.0422
		Proportion of science and education expenditures in GDP	+	0.0196
		Number of college students per 10,000 people	+	0.1068
		Books in public libraries per 100 people	+	0.0597
		Number of medical beds per 10,000 people in the city	+	0.0102
		Park green area per capita	+	0.0162
	Green wealth	Green coverage rate in built-up area	+	0.0045
		Number of days with good air quality in built-up areas	+	0.0057
		Industrial wastewater discharges per capita	−	0.0429
		Industrial sulfur dioxide emissions per capita	−	0.2206
		Centralized treatment rate of urban domestic sewage	+	0.0083
		Harmless treatment rate of urban domestic waste	+	0.0038
		Comprehensive utilization rate of general industrial solid waste	+	0.0109
	Green governance	Urban road area per capita	+	0.0182
		Buses per 10,000 urban residents	+	0.0339
		Urban water penetration rate	+	0.0005
		Urban gas penetration rate	+	0.0027

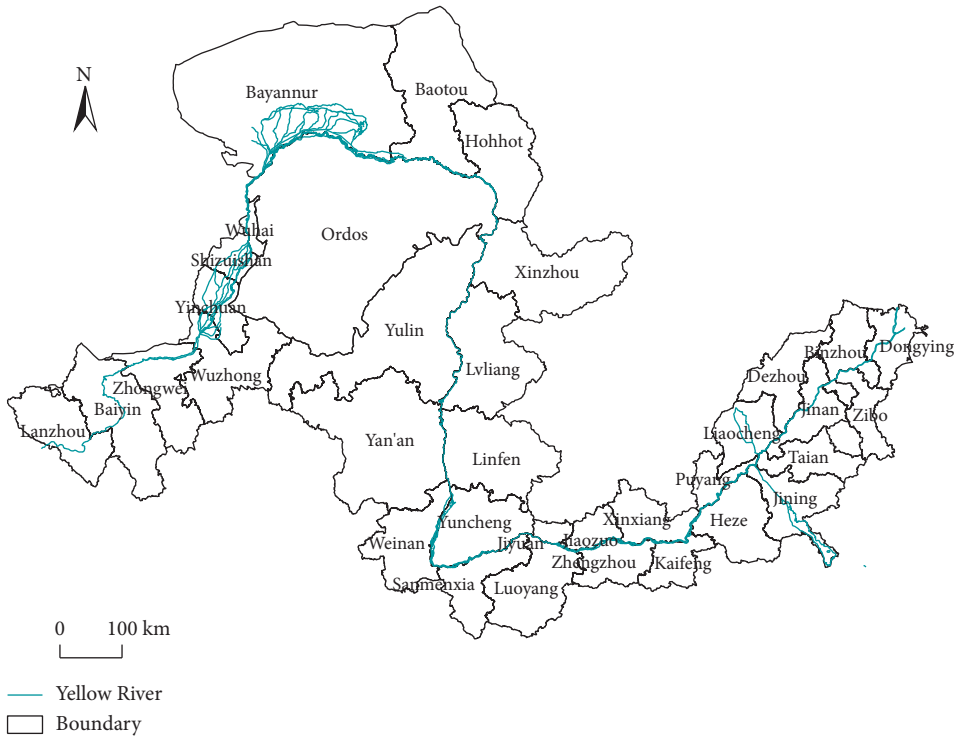

Figure 4: Sample area: the yellow river basin.

at a high level. Second, mid-high and mid-low level cities are mainly distributed around high-level cities, such as Shandong Peninsula with Jinan as the center and Central Plains with Zhengzhou as the center. These cities are obviously driven by regional central cities, which is conducive to promoting urban green development. Finally, low-level cities are widely distributed in the upper, middle, and lower reaches, such as Yulin, Lvliang, Weinan, Yan'an, and Puyang. Most of these cities are in the middle stage of industrialization, and there are problems such as single industrial structure, deterioration of ecological environment, and backward infrastructure construction.

Table 2: The UGDI of cities along the YRB.

City	Year						Average
	2008		2013		2018		
	Value	Ranking	Value	Ranking	Value	Ranking	
Jinan	0.6209	1	0.6695	1	0.6604	1	0.6503
Ordos	0.4273	9	0.6565	2	0.6244	2	0.5694
Zhengzhou	0.4683	7	0.4681	8	0.5920	3	0.5095
Hohhot	0.5908	2	0.6041	3	0.5716	4	0.5888
Lanzhou	0.4918	5	0.4724	7	0.5568	5	0.5070
Dongying	0.5392	4	0.5059	6	0.5346	6	0.5265
Baotou	0.5537	3	0.5250	4	0.4885	7	0.5224
Taian	0.4217	10	0.3992	10	0.4742	8	0.4317
Yinchuan	0.4588	8	0.5164	5	0.4595	9	0.4782
Zibo	0.4891	6	0.4500	9	0.4592	10	0.4661
Wuhai	0.3157	19	0.3800	12	0.4421	11	0.3793
Jining	0.3500	16	0.3436	15	0.3957	12	0.3631
Shizuishan	0.3216	18	0.3322	17	0.3945	13	0.3494
Binzhou	0.3745	12	0.3630	14	0.3698	14	0.3691
Luoyang	0.2508	27	0.3076	22	0.3613	15	0.3066
Dezhou	0.3510	15	0.3668	13	0.3346	16	0.3508
Wuzhong	0.2736	26	0.3149	20	0.3335	17	0.3073
Jiaozuo	0.3227	17	0.2960	24	0.3321	18	0.3169
Jiyuan	0.3055	21	0.3809	11	0.3316	19	0.3393
Zhongwei	0.3098	20	0.2904	27	0.3188	20	0.3063
Puyang	0.2411	28	0.2667	31	0.3088	21	0.2722
Kaifeng	0.3008	23	0.2691	30	0.3031	22	0.2910
Liaocheng	0.3642	13	0.3436	16	0.3031	23	0.3370
Baiyin	0.2352	29	0.2278	35	0.3027	24	0.2552
Xinxiang	0.2986	24	0.3171	19	0.3003	25	0.3053
Yan'an	0.2269	32	0.3254	18	0.2876	26	0.2800
Heze	0.2326	30	0.2615	33	0.2815	27	0.2585
Xinzhou	0.3011	22	0.2618	32	0.2700	28	0.2776
Sanmenxia	0.2300	31	0.2945	25	0.2619	29	0.2621
Bayannaoer	0.3577	14	0.2920	26	0.2567	30	0.3021
Weinan	0.1772	35	0.2568	34	0.2482	31	0.2274
Lvliang	0.2038	33	0.2742	28	0.2460	32	0.2413
Yulin	0.2023	34	0.3106	21	0.2444	33	0.2524
Linfen	0.3888	11	0.2730	29	0.2388	34	0.3002
Yuncheng	0.2905	25	0.2991	23	0.2200	35	0.2699
Average	0.3511	—	0.3690	—	0.3745	—	—

4.1.3. Characteristics Analysis of Spatial Autocorrelation. According to the adjacency relationship between various cities, the global Moran's *I* index of the UGDI in three years were calculated based on the Queen's adjacency matrix (Table 3). The results show that the Moran's *I* index of UGDI along the YRB is greater than 0. In 2008, it was 0.0351, which passed the test at a significance level of 0.01, in 2013 and 2018, it was 0.234 and 0.252 respectively, and both passed the test at a significance level of 0.05, indicating that there is a significant positive spatial autocorrelation of urban green development along the YRB. In 2013, the Moran's *I* index decreased compared with 2008, and the correlation degree of urban green development weakened. The cities with higher (or lower) green development level changed from strong agglomeration to weak agglomeration. There was an increase in 2018 compared with 2013, with an increase in concentration. Overall, the Moran's *I* Index has declined, and the degree of green development agglomeration has undergone a transformation process of "strong agglomeration-weak agglomeration-stronger agglomeration." The correlation degree of green development among cities has weakened, while the overall difference increased.

In order to further reflect the spatial correlation of green development in cities, according to the spatial relationship between each city and surrounding cities in the study year, the local spatial autocorrelation LISA index in the GeoDa software is used to study the agglomeration and distribution status of the UGDI. The results of the LISA analysis (Table 4) further show that the green development along the YRB is unbalanced. First, the "H-H" area of UGDI has gradually transformed from a massive distribution to a point-shaped distribution. From 2008 to 2018, Zibo was the only city in the "H-H" area. The reason is that Zibo is located in the economic circle of the provincial capital Jinan and is greatly influenced by the radiation of the provincial capital city cluster. The strategies of Jinan-Taian courbanization and Jinan-Zibo courbanization have accelerated the formation of a regional linkage development pattern, which is used in

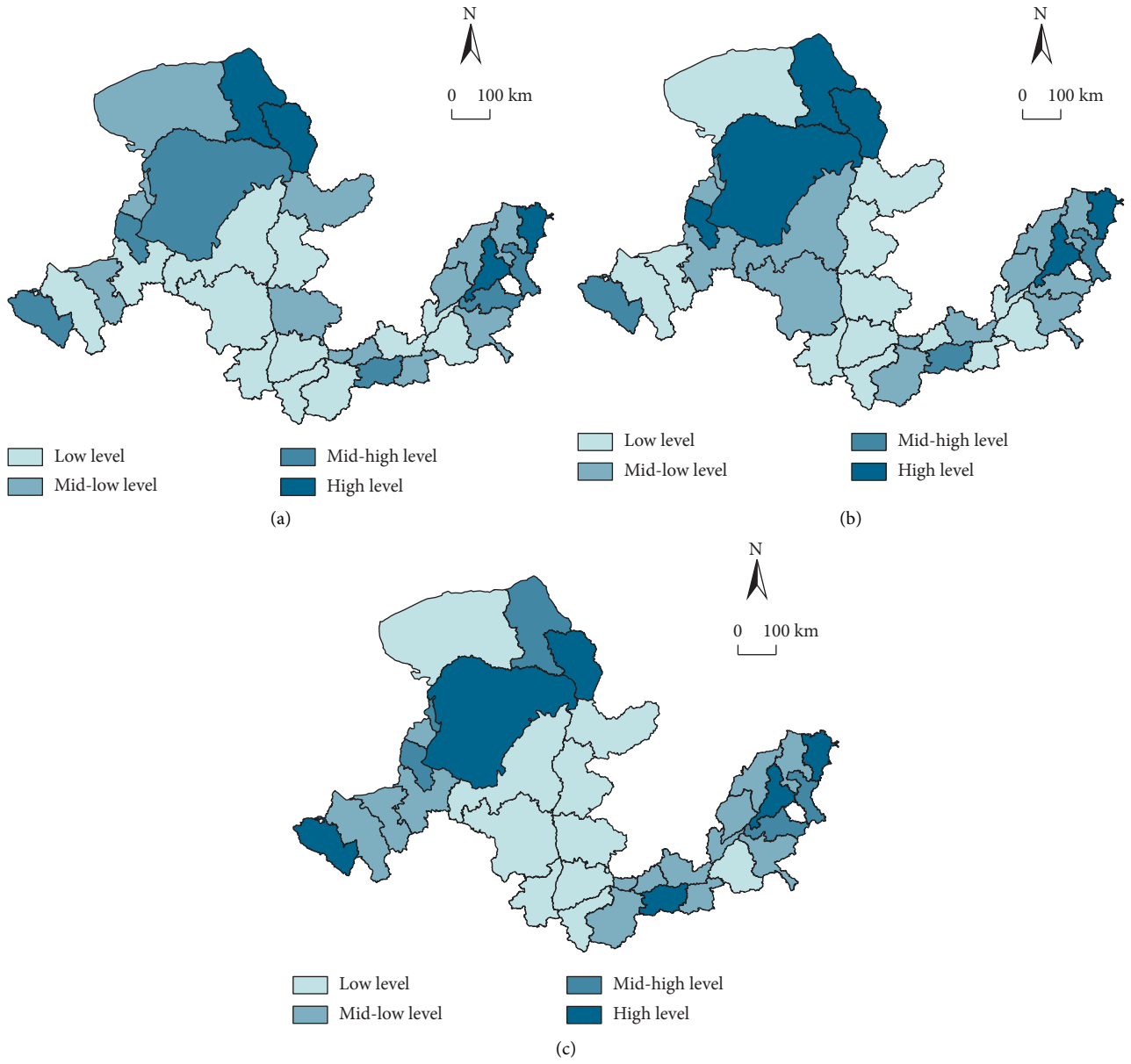

Figure 5: The spatial pattern of the UGDI in 2008, 2013, and 2018. (a) 2008. (b) 2013. (c) 2018.

Table 3: Global Moran's I index of the UGDI in 2008, 2013, and 2018.

Year	Moran's I	p value	z-value
2008	0.351	0.001	3.290
2013	0.234	0.020	2.313
2018	0.252	0.014	2.435

urban construction, ecological protection, and industrial development realizing comprehensive docking, coordinated protection, integrated development, and other aspects, thus forming a high-value area of the UGDI. Second, both "H-L" and "L-H" cities are distributed in a dot pattern, such as "H-L" cities Linfen and Lanzhou and "L-H" cities Bayannaoer and Binzhou, which are scattered in the YRB. Finally, the areas with "L-L" UGDI show obvious block-like agglomeration patterns. Shaanxi, Shanxi, and some cities in western Henan are the most concentrated, such as Yan'an, Weinan, Yuncheng, Linfen, and Sanmenxia. These cities are restricted by the "high energy consumption, high pollution, and low-level industrial and location conditions", and their economic development has encountered bottlenecks, making the UGDI always at a low level, thus forming a contiguous low-level region of green development.

Table 4: Local LISA distribution of the UGDI in 2008, 2013, and 2018.

Year	H-H	H-L	L-H	L-L
2008	Bayannur, Baotou, Binzhou, Zibo	Linfen	—	Yan'an, Yuncheng, Sanmenxia
2013	Baotou, Zibo	Lanzhou	Bayannur, Shizuishan, Binzhou	Zhongwei, Yan'an, Yuncheng, Linfen, Sanmenxia
2018	Shizuishan, Zibo	—	Bayannur, Binzhou	Luliang, Yan'an, Linfen, Weinan, Yuncheng, Sanmenxia

4.1.4. Global Trend Analysis. In order to show the spatial evolution trend of urban green development more intuitively, the trend analysis tool in ArcGIS 10.2 is used to describe the spatial distribution trend of urban green development along the YRB in 2008, 2013, and 2018, as shown in Figure 6. Among them, the Z axis represents the UGDI, the line on the X axis corresponds to the trend of the UGDI in the east-west direction, and the line on the Y axis corresponds to the trend of the UGDI in the north-south direction. Overall, the curve change of the UGDI from 2008 to 2018 is small and remains stable. In the east-west direction, the curve shows an obvious "U" distribution trend, indicating that the UGDI of the eastern and western cities along the YRB is high, while the central region forms a low value area of urban green development. Specifically, the UGDI show a trend of "high in the east and low in the west." In 2008 and 2018, there was a big difference in green development between the east and the west, while the difference in UGDI between the east and the west was small in 2013. In the north-south direction, the curve shows an obvious trend of "high in the north and low in the south," indicating that the UGDI in the north along the YRB is higher than that in the south, showing significant regional differences.

4.2. Research on Spatial Differentiation of Influencing Factors

4.2.1. Analysis Framework of Influencing Factors. Combing through the existing literature, it is found that the academic community has not yet established a recognized theory on the influence mechanism of urban green level, and the discussion on the influence factors of green development is mostly focused on three aspects: economic factors, geographical and environmental factors, and policy factors, while some scholars have added dummy variables such as financial crisis to the discussion of influence factors [37], to judge the impact of influencing factors on green development according to the regression model or obstacle degree model. The specific indicators are mainly selected from two aspects. First, they are directly selected from the evaluation indicators, such as GDP per capita, proportion of scientific and technological expenditure in GDP, and investment in environmental pollution control. Second, there are also scholars who break away from the evaluation indicators and reselect new driving factors, such as economic density, the proportion of the added value of the tertiary industry, and the amount of local water resources per capita. Referring to the existing research results of many scholars and combine the actual situation of the YRB, this paper selects variables from six aspects: economic development level (EDL) [38], industry advanced level (IAL) [39], urbanization level (UL) [40], environmental governance (EG) [38], technology level (TL) [40], and green infrastructure level (GIL) [41] and explores their impact degree on the green development of cities along the YRB (Table 5).

4.2.2. Regression Comparison of OLS and GWR Models. OLS and GWR model are mostly used to explore the spatial relationship of geographical phenomena. Using the UGDI as dependent variable and the above six influencing factors as independent variables, the OLS regression analysis was carried out by SPSS 25 software. The results (Table 6) of collinearity test showed that the variance inflation factor (VIF) of each influencing factor was less than 7.5, and the estimation equation did not appear variable redundancy. There was no multicollinearity among the factors, $R2 = 0.827$, and the adjusted $R2 = 0.790$. The model could explain most of the information. Before the GWR regression, it is necessary to test the spatial correlation of the UGDI. From the above analysis, it can be seen that the global Moran's I index is greater than 0 and at least passes the significance test at the 0.05 level. There is spatial autocorrelation in urban green development, indicating that the traditional OLS regression has estimation bias. In addition, it can be seen from the regression results of the GWR model that $R2$ and the adjusted $R2$ are 0.864 and 0.794, respectively, which are higher than those of the OLS model regression, indicating that the explanatory variables in the GWR model have stronger explanatory power on the explained variables and better goodness of fit. In summary, the GWR model is used to study the influencing factors of the UGDI in cities along the YRB, and ArcGIS 10.2 software is used to visualize the regression results.

4.2.3. Spatial Heterogeneity of Influencing Factors

(1) EDL. Figure 7 shows that there is a significant positive correlation between EDL and the UGDI; that is, the improvement of economic development is conducive to improving the urban green development level. From the perspective of supply, optimizing the economic growth mode and reforming the mechanism that hinders economic development in order to change the original crude production mode and inefficient resource allocation, improve supply efficiency and quality, so as to increase total factor productivity and the green development level. From the perspective of demand, with the progress of economy and society, people's demand has gradually increased from

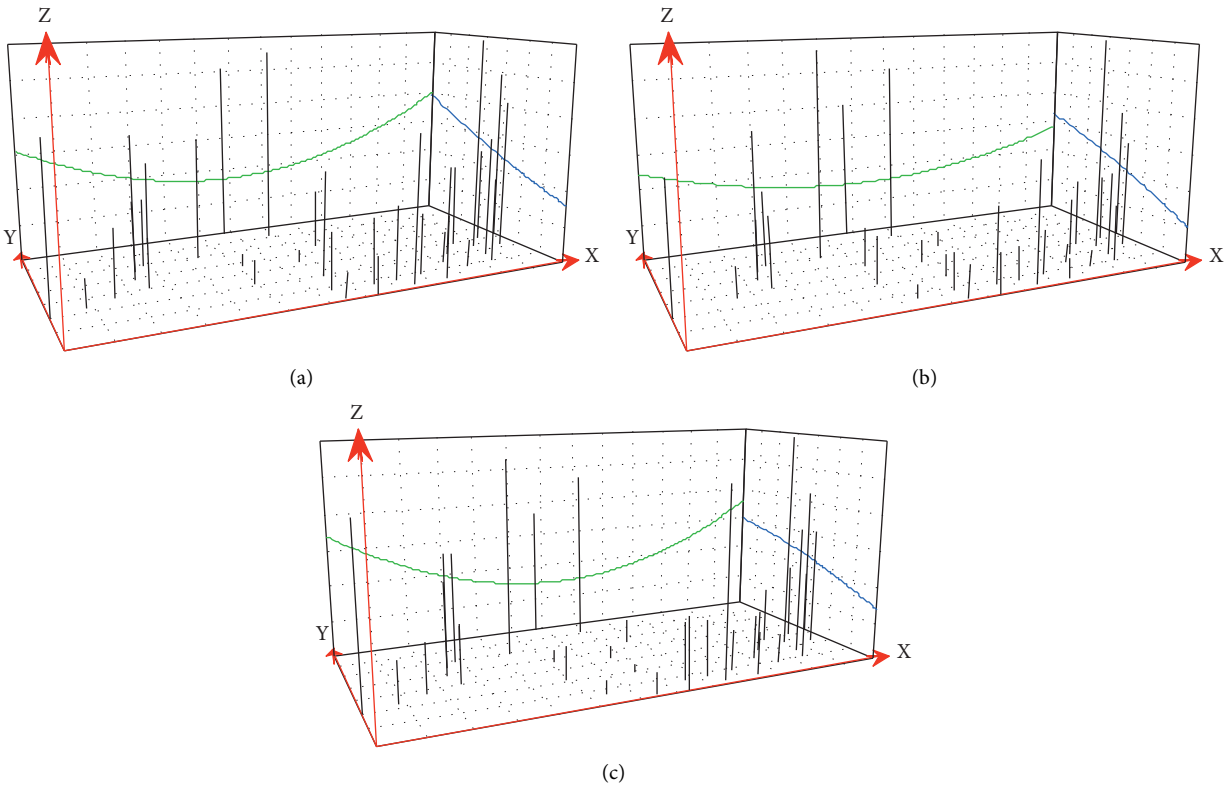

Figure 6: The spatial trend of the UGDI. (a) 2008. (b) 2013. (c) 2018.

Table 5: Selection of influencing factors for green development.

Influencing factors	Variable	Calculation
EDL	Economic density	Regional GDP/total area
IAL	Industrial structure advanced index	Tertiary industry output value/second industry output value
UL	Proportion of urban population to total population	Urban population/total population of the region
EG	Energy saving and environmental protection expenditure	—
TL	Technology expenditure as a percentage of GDP	Technology expenditure/regional GDP
GIL	Per capita public green space	—

Table 6: Regression comparison between OLS and GWR models.

			VIF				$R2 = 0.827$
OLS	EDL	IAL	UL	EG	TL	GIL	Adj
	2.0548	1.0655	2.6790	1.9722	1.0726	2.5147	$R2 = 0.790$
	Neighbours	Residual squares	Effective number	Sigma	AICc	R2	Adj $R2$
GWR	35	0.357	12.727	0.127	−23.991	0.864	0.794

material to high-quality environment and green products, which has become the internal driving force for the improvement of green development. At the same time, the impact of economic development level on the green development along the YRB has gradually weakened from east to west, indicating that economic development has improved the green development of eastern cities better than that of western cities. Areas with high coefficients are concentrated in the cities of Henan and Shandong in the eastern part of the YRB. Shandong and Henan have always been China's economically strong provinces. In 2018, the total GDP of Shandong and Henan ranked third and fifth respectively in the national rankings. For example, Henan is committed to adjusting the industrial structure. In 2008, the proportion of the secondary industry was 56.9%, while in 2018 it dropped to 45.9%, and the proportion of the tertiary industry rose from 28.6% in 2008 to 45.2% in 2018. In addition, it used the policy dividends of Central Plains Economic Zone and Henan Free Trade Zone, relying on Internet technology, striving to build an agricultural-food-fiber industry chain and build an industrial development pattern led by energy conservation, environmental

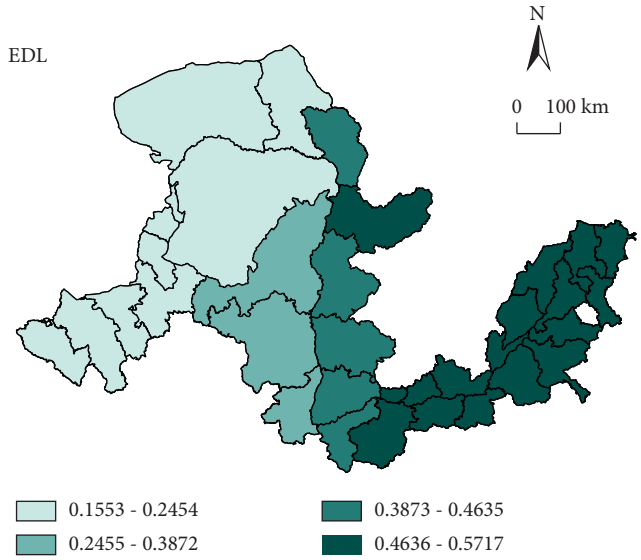

Figure 7: Spatial distribution of regression coefficient of the EDL on UGDI.

protection, biomedicine, and smart manufacturing. The industrial structure ratio has been improved, and the green economy has developed. Areas with low coefficients are concentrated in provinces and cities in the western part of the YRB, such as Gansu, Ningxia, some cities in Inner Mongolia Autonomous Region, and Weinan, Yan'an, and Yulin in Shaanxi Province. These areas are deep inland, and economic development is affected by natural location and has limited effects on the improvement of green development. In cities such as Yan'an, Weinan, and Yulin, traditional industries are the pillars of their economy. The tertiary industry has failed to truly become the driving force of economic development, lacking the power and ability to innovate new products, and the long-term dependence on resource input to stimulate economic growth has weakened. As a result, the significance of the promotion of green development by economic development is reduced.

(2) IAL. Figure 8 shows that there is a significant positive correlation between IAL and the UGDI, and the optimization of the industrial structure is conducive to the improvement of the urban green development along the YRB. The reason is that high-end and smart emerging industries have broken the previous structural restrictions, alleviating the pressure of extensive heavy chemical industries on the ecological environment under resource and environmental constraints and promoting the transformation of industrial structure to resource conservation and environmental friendliness, and effectively realize the mutual promotion and coordinated development of industrialization and green development. At the same time, the degree of impact of IAL on the green development along the YRB is spatially high on both sides and low in the central region. High-value areas are distributed in Lanzhou, Baiyin, and Yinchuan in the west of the YRB and most cities in Henan and Shandong in the east. Since the Ministry of Industry and Information Technology issued the "Approval of the Implementation Plan of the Pilot Project of Industrial Green Transformation and Development in Lanzhou," Lanzhou has strengthened mechanism and model innovation and used market methods to promote regional industrial green development. Basically forming a strategic emerging industry system with high-end manufacturing, new energy, new materials, energy conservation, and environmental protection, to achieve new leadership in green and low-carbon industries, while Yinchuan pays more attention to technological innovation to promote industrial upgrading, vigorously implements industrial transformation and upgrading, and park transformation projects such as development and a strong city through science and technology have promoted the conversion of old and new drivers. Moreover, Shandong is guided by reform and innovation and promoted ecological construction to force economic transformation, which has gradually improved the development level of the industrial structure and promoted the continuous improvement of the green development level. The low-value areas are mainly distributed in Xinzhou, Luliang, and Sanmenxia in the midstream of the YRB. For a long time, the industrial structure of these cities has significant characteristics of heavy chemical industry. The industries dominated by coal mining and thermal power generation have obvious constraints on green development, coupled with long-term dependence on energy resources and greater resistance to the optimization and upgrading of traditional industries and the transformation of economic structure. The low-level industrial structure has little effect in driving green development. For example, in Luliang, which is rich in coal resources, the secondary industry is the pillar of economic development. In 2018, the secondary industry accounted for 61.4%, and its coal output value accounted for 80% of the total industrial output value. For a long time, the coal chemical industry produced a large amount of soot and waste, which has not only increased environmental pollution, but also made green governance more difficult.

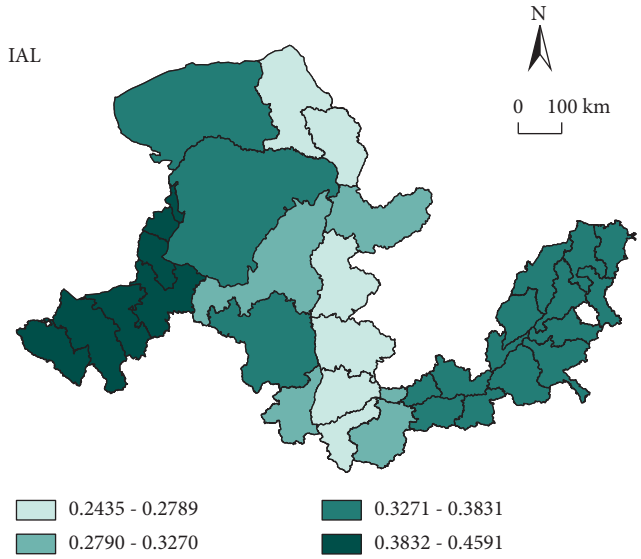

Figure 8: Spatial distribution of regression coefficient of the IAL on UGDI.

(3) UL. Figure 9 shows that there is a significant positive correlation between UL and the UGDI. The increase in the urbanization rate can actively promote the improvement of the urban green development and present the characteristics of "strong in east and weak in west"; that is, the promotion of green development in eastern cities is better than that of western cities. The reason is, first, as urbanization continues to improve, urban spatial layout and related supporting service functions have gradually improved, making urbanization more prominent as a carrier and platform for green development. Various urban development models explored in the process of urbanization, such as low carbon cities, green cities, smart cities, and livable cities will directly promote the improvement of green development. Second, the increase of urbanization means the expansion of urban population and the continuous agglomeration of industries, the release of the consumption potential of large-scale consumer groups in cities, which drives more diversification of consumption and upgrades of consumption structures, and huge urban public infrastructure, service facilities and housing demand stimulate urban economic development and indirectly promote the improvement of urban green development. However, it should be noted that a series of contradictions and problems will inevitably arise during the rapid development of urbanization, such as Baotou, Ordos, and Wuhai in the western part of the YRB. The higher urbanization rate is weaker than the eastern cities in driving the green development. The possible reason is that the urbanization development does not match the urban governance capabilities. The huge population size of the city puts greater pressure on the environment and weakens the driving effect of the improvement of the city's green development level. Therefore, it is necessary to correctly deal with the relationship between urbanization and green development, avoid related problems in time, and realize mutual promotion and integration of urbanization and green development.

(4) EG. Figure 10 shows that EG has different influences in different cities. Among them, the EG in the central and eastern regions is not conducive to the improvement of urban green development, while in the west, such as Lanzhou, Yinchuan, and Baotou, EG has a significant positive correlation with the green development, indicating that the impact of EG on the urban green development along the YRB is better than that of the central and eastern cities. In general, the government-led use of fiscal expenditure to solve ecological and environmental problems is an important method to improve the green development level. Through comprehensive treatment of air pollution, improvement of water quality, protection of the soil environment, cleaning of solid waste, and monitoring of the ecological environment, etc. cities can improve the ability of environmental pollution control and achieve the goal of resource-saving and environment-friendly ecological civilization construction. For example, as an old industrial base, Baiyin has implemented the most stringent environmental protection system to promote environmental improvement, adopting ultra-low emission transformation of coal-fired units, strengthening motor vehicle pollution prevention, dust control, and strengthening law enforcement. A total of 3.4 billion CNY has been invested in pollution prevention and control in 2015. It has achieved a 100% compliance rate of drinking water and a 90.9% good air quality rate in 2018. However, the EG in the midstream and downstream of the YRB is negatively correlated with the UGDI. This may be due to the fact that the ecological environment is fragile. Long-term overintensity development has caused severe environmental conditions. Soil erosion, the most obvious problem, cannot be completely solved. Overdraft of ecological carrying capacity has caused multiple environmental problems, relying solely on the limited energy-saving and environmental protection expenditures in the government's finances cannot effectively control the

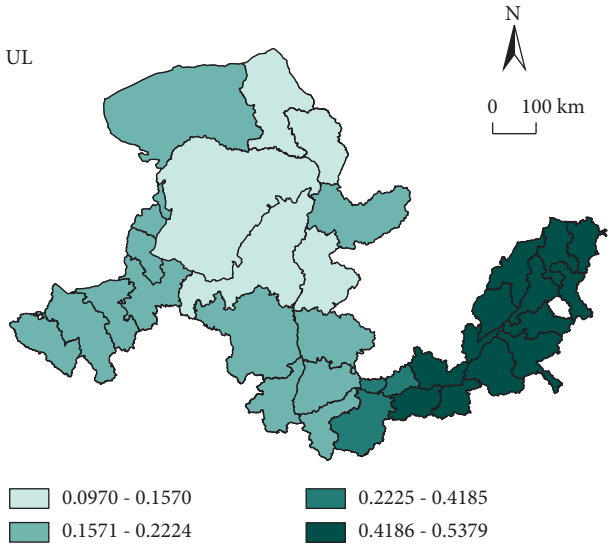

Figure 9: Spatial distribution of regression coefficient of the UL on UGDI.

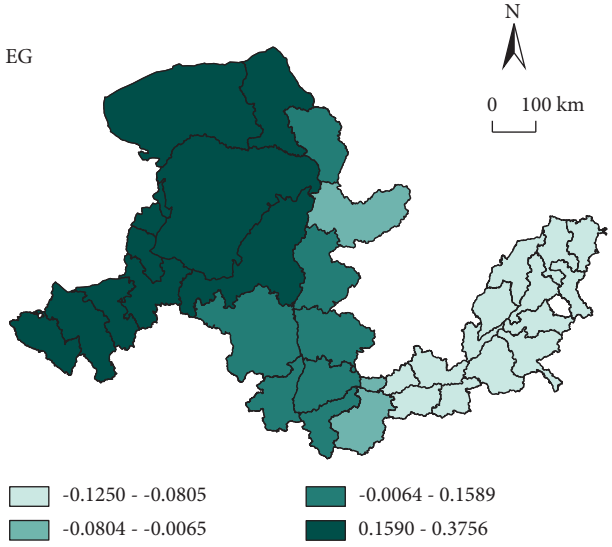

Figure 10: Spatial distribution of regression coefficient of the EG on UGDI.

chronic environmental problems in a short time. In addition, these regions are important manufacturing bases, and most of them undertake the transfer of high energy-consuming and high-polluting industries in the east. The population and industries are dense. The regions' competition makes energy conservation and environmental protection lack of regional linkage effects. The increase rate of green development brought by energy saving and environmental protection expenditure is less than the decrease rate of green development level caused by pollutant discharge.

(5) TL. Figure 11 shows that TL also has different influences in different cities, with the degree gradually weakening from west to east, indicating that the effect of TL on western cities is better than that of most eastern cities. The development of science and technology is a significant means to improve the comprehensive utilization efficiency of resources, increasing the input-output ratio and productivity. It can not only realize the optimization and upgrading of urban leading industries and promote the update and iteration of enterprise production technology, but also push forward the promotion and efficient use of new and clean energy, improve the long-existing coal-based energy resource consumption structure, and help to realize green production and green life. At the same time, scientific and technological development can enhance environmental pollution control, promote pollution control caused by production and life, and improve environmental management efficiency. For example, Lanzhou in the western part of the YRB is the political, economic, cultural, scientific, and educational center of Gansu Province, gathering a large number of high-

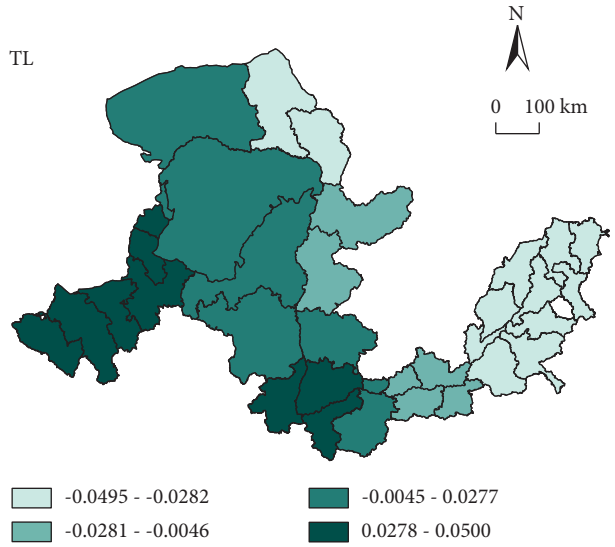

Figure 11: Spatial distribution of regression coefficient of the EDL on UGDI.

quality technological innovation elements and human resources. Since 2016, Lanzhou has achieved a total of 506 scientific and technological achievements transformation and developed 264 new products. In 2018, the city's scientific and technological progress contribution rate reached 57.1%, which greatly promoted the green development. However, technological development has not played a role in improving the green development in most of the central and eastern cities along the YRB. Combined with the current strict environmental regulations in China, this is obviously contrary to the "Porter Hypothesis," which is a "green paradox." The possible reason is that, first, it is a long and complicated process from investment in scientific and technological development to the transformation of research results into practical applications, including technology research and development, talent training and introduction, and purchase of advanced scientific research equipment. This series of processes has a certain period of time, which leads to the inability of scientific and technological investment in promoting green development. Secondly, the fact that most cities have insufficient investment in science and technology research and development cannot be ignored. The lack of high-quality talents and the insufficiency of universities and research institutes have led to low efficiency in science and technology research and development. It is difficult to rely on science and technology to promote urban green in a short time. Finally, due to favorable location factors such as convenient transportation and labor intensiveness, the central and eastern parts of the YRB have undertaken a large number of industrial transfers from coastal areas. The scientific and technological research and development are mainly concentrated on the development of traditional secondary industries, rather than investment in green and cleaner production research and development, which has limited driving effect on the improvement of green development.

(6) GIL. Figure 12 shows that there is a significant positive correlation between GIL and the UGDI, and the increase of urban per capita public green area is conducive to the improvement of green development in the YRB. At the same time, the influence of GIL on the green development level shows the spatial distribution characteristics of high in the middle and low in the east and west, indicating that the effect of GIL on green development of central cities is better than that of eastern and western cities. Urban green infrastructure construction plays a role in green development from two aspects, improving urban ecological green quantity and inhibiting environmental deterioration. By building a green operation system of urban public infrastructure, and strengthening the supply of urban green facilities and ecological services, realizing the harmonious coexistence of "production-life-ecology" functions, so as to improve the urban ecological green quantity and meet people's increasing demands for green waters and mountains in the new era, it is the direct driving force for the improvement of the UGDI. Moreover, with the continuous improvement of urban green basic social level, the city's ability to manage ecological environment problems and energy resource utilization rate have been enhanced, especially for the Sanmenxia, Lvliang, and other resource-based cities in the middle of the YRB. The effect is particularly significant, and the green development has been improved from the inhibition of environmental degradation. At the same time, it should be noted that the impact of urban green infrastructure construction represented by per capita public green space area on cities in the east and west of the YRB is low. The possible reason is that the environmental problems caused by traditional heavy chemical industries are deeply rooted, and the ability to improve environmental conditions by simply increasing urban green space is weakened. Therefore, green development must be comprehensively addressed.

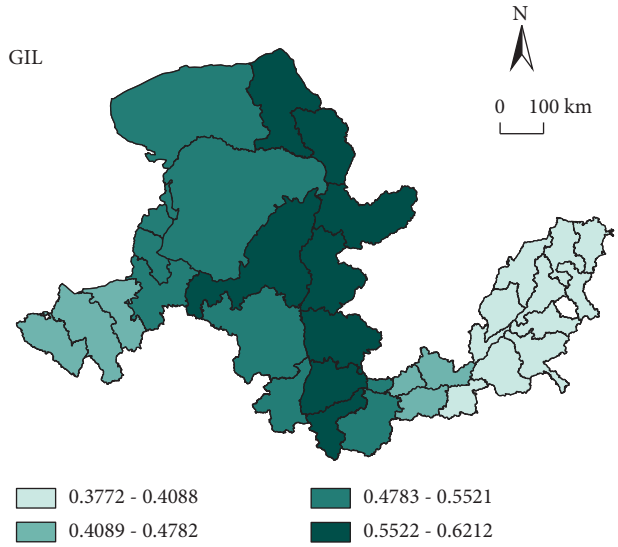

Figure 12: Spatial distribution of regression coefficient of the GIL on UGDI.

5. Conclusions and Discussions

5.1. Conclusions

(1) From 2008 to 2018, the UGDI of 35 cities in the YRB increased slowly, but it was still at a low level, and the green development level among cities was obviously unbalanced. Horizontally, the UGDI was hierarchical and can be divided into three echelons. The high-value areas of provincial capitals such as Jinan, Zhengzhou, and Lanzhou and the low-value depression areas in the central China are obvious.

(2) In 2008, 2013, and 2018, the global Moran's I index of urban green development in the YRB was greater than 0, indicating that urban green development was significantly positive spatial autocorrelation. The Moran's I index declined at the end of the period compared with the beginning, the degree of green development correlation between cities has weakened, and the overall difference has increased.

(3) The result of spatial differentiation showed that green development had great differences in the region. From the results of the global trend analysis, the UGDI showed a trend of "high in the east and west, low in the middle" and "high in the north and low in the south."

(4) There were significant regional differences in the impact of each influencing factor on the green development. Specifically, EDL, IAL, UL, and GIL had significant positive relationship with the UGDI, and the effects of EG and TL on the UGDI depend on cities, relating to the complex human and geographical factors of the YRB. Most of the space presented an irregular ladder-like distribution, with significant spatial heterogeneity.

5.2. Policy Implications

5.2.1. Innovate the Green Development Model and Enhance the Overall Economic Strength. On the one hand, strengthen cooperation in economic development between cities and give full play to the demonstration and driving role of the central city. Regional coordinated development is an inevitable trend to promote the green development of the YRB. To truly implement the national strategy of main functional zones, it is necessary to promote the free flow of green development factors, promote the rational division of labor and mutual promotion between regions, take the opportunity of central city agglomeration spillover and technology spillover as an opportunity to further promote the harmonious development of new industrialization, new urbanization, informatization, agricultural modernization and green, and combine the characteristics of cities in the YRB to build coordinated development new mechanism to serve the goal of improving green development.

On the other hand, innovate market decision mechanism to achieve efficient and rational allocation of resources. Correctly handle the relationship between the market and the government, give full play to the decisive role of the market in the allocation of resources, and establish cross-basin ecological resources and natural resources market pricing and trading mechanisms to achieve efficient and rational use of resources, through market and government incentives to guide enterprises and the public to participate in energy conservation and environmental protection, to achieve green development in the YRB.

5.2.2. Optimize the Industrial Structure and Vigorously Develop Green Industries.

First, optimize the industrial layout of cities along the YRB. Speeding up the elimination of high energy-consuming, high-polluting, and low-profit enterprises and industries, especially in the central part of the YRB, requires active new industries and abandons long time dependent on backward industries, improves independent innovation capabilities, and cultivates emerging strategic industries such as renewable energy and new energy.

Second, speed up the green transformation of traditional industries and realize green transformation. Through the construction of a circular industrial chain to create a green industrial system, transform the extensive industrial structure; accelerate the promotion of green mining, clean production, discharge standards in the basin; and strive to achieve clean production process, harmless waste treatment, and resource utilization.

Finally, under the guidance of the green development concept of low consumption and low pollution, raise the entry threshold for high-pollution and high-emission enterprises, formulate corresponding rewards and punishment systems for promoting industrial optimization and upgrading, actively guide developed regions to flow into high-tech industries, and avoid the YRB from becoming a "pollution refuge."

5.2.3. Promote the Application of Green Technologies and Improve Independent Innovation Capabilities. On the one hand, local governments should raise investment in science, technology, and education, especially in the central and eastern cities. They should strengthen support for green technological innovation and promote the establishment of a reasonable coordination and cooperation mechanism for industries, universities, and institutes, which are innovative, applicable, and cutting-edge. Provide strong support for sustainable green technologies, and provide policy incentives to companies that are conducive to the promotion of green development and application of technologies, optimize the resource allocation of technology and education related to green construction, increase the initiative and enthusiasm of enterprises, universities, and research institutes in green technology research, and attach importance to the transformation of research and technological achievements.

On the other hand, use energy-saving and emission-reduction technologies to achieve low pollution and low energy consumption in production and life, strengthen core technology research in the field of green production, and realize the technologicalization of green development. In addition, promote ecological restoration and technologicalization of environmental governance, and concentrate our efforts on the use of modern technology to control haze and other outstanding environmental problems.

5.2.4. Promote the Construction of New Urbanization Based on Ecological Carrying Capacity.

First, cities should not blindly pursue the agglomeration of population and wealth, but should strictly control the newly added urban construction land and realize the intensive use of urban land. In the process of population urbanization and land urbanization, it is necessary to adjust measures to local conditions. Innovate urban land transfer and management models based on the ecological carrying capacity of each city and region, where business is suitable for business, livable is suitable for living, and agriculture is suitable for farming, without blindly occupying ecological land, and reserve enough green space for green development. Initiating a comprehensive political, financial, and technological strategy to promote environmental protection, restore the relationship between cities and ecosystems, and create regenerative cities.

Second, promote the construction of endogenous mechanisms for urbanization. The construction of endogenous mechanisms is a complex systemic project that requires voluntary population migration as the core, new-type industrialization as the basis, market regulation as the leading factor, and government macrocontrol as the guarantee. Promote the rational and orderly coordination of various elements with green development.

5.2.5. Strengthening Infrastructure Construction and Improving Environmental Governance and Protection. Infrastructure construction plays a positive role in promoting the green development of the YRB. It is necessary to promote the balanced development of modern infrastructure and promote the continuous improvement of green level in different regions according to local conditions. In the construction of water resources infrastructure, water resources are taken as the maximum rigid constraint to strengthen the control of urban water and agricultural water. The most prominent problem in the Yellow River Basin is the contradiction of water resources. The problems such as more people and less water, less water and sediment, and water and sediment sources have long plagued the improvement of the greening level in the Yellow River Basin. Therefore, it is necessary to promote the construction of water conservancy facilities, focus on the development of water-saving agriculture along the Yellow River irrigation area, vigorously construct dryland terraces and silt dams in the middle and upper reaches, reasonably plan the water consumption of population, city and industry, adhere to the principle of determining city by water, determining land by water, determining people by water, determining production by water, and resolutely curb unreasonable water demand.

In the construction of ecological engineering facilities, strengthen the construction of regional ecological defense line, improve the coverage of urban public green space, increase urban ecological green quantity, and strengthen the

construction of ecological pollution control projects, such as accelerating the construction of nonpoint source control facilities for domestic sewage and agricultural pollution in the Weihe River Basin and accelerating the construction of industrial pollution treatment projects in the Fenhe River Basin.

In the construction of transportation and communication projects, the western regions in the basin, such as Gansu and Ningxia, should speed up the improvement of transportation network, coordinate the construction of provincial boundaries and key nodes, and provide a convenient transportation foundation for green development. In addition, it should focus on strengthening the construction of information and communication infrastructure; accelerate the deployment of 5G network and cloud computing platform; provide digital, intelligent, and new green infrastructure system; and realize the deep integration of informatization and green construction.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: Robust Two-Stage Location Allocation for Emergency Temporary Blood Supply in Postdisaster

Discrete Dynamics in Nature and Society

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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) Manipulated or compromised peer review

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.

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[1] D. Luan, A. Liu, X. Wang, Y. Xie, and Z. Wu, "Robust Two-Stage Location Allocation for Emergency Temporary Blood Supply in Postdisaster," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 6184170, 20 pages, 2022.

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Research Article

Robust Two-Stage Location Allocation for Emergency Temporary Blood Supply in Postdisaster

Dongqing Luan,[1] **Along Liu**,[2] **Xiaoli Wang**,[1] **Yanxi Xie**,[1] **and Zhong Wu**[2,3]

[1]*School of Management, Shanghai University of Engineering Science, Shanghai 201620, China*
[2]*Business School, University of Shanghai for Science and Technology, Shanghai 200093, China*
[3]*School of Management, Shanghai University of International Business and Economics, Shanghai 201620, China*

Correspondence should be addressed to Dongqing Luan; shluan@163.com

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Disaster medical rescue in China mainly adopts the "on-site rescue" model. Whether the location of emergency temporary blood supply sites is reasonable or not directly affects the rescue efficiency. The paper studies the robust location-allocation for emergency temporary blood supply after disaster. First, the factors of several candidate sites were quantified by the entropy-based TOPSIS method, and 12 candidate blood supply sites with higher priority were selected according to the evaluation indicators. At the same time, the uncertainty of blood demand at each disaster site increased the difficulty of decision-making, and then, a robust location model (MIRP) was constructed with minimum cost with time window constraints. It is also constrained by the uncertain demand for blood in three scenarios. Second, the survival probability function was introduced, and the time window limit was given at the minimum cost to maximize the survival probability of the suffered people. Finally, the numerical example experiments demonstrate that the increase in demand uncertainty and survival probability cause the MIRP model to generate more costs. Compared with the three MIRP models, the MIRP-ellipsoid set model gained better robustness. Also, given the necessary restrictions on the time window, the cost can be reduced by about 13% with the highest survival probability. Decision-makers can select different combinations of uncertainty levels and demand disturbance ratios and necessary time constraints to obtain the optimal location-allocation solution according to risk preference and actual conditions.

1. Introduction

The frequent occurrence of public health emergencies, their unpredictable, wide-ranging, and extremely devastating characteristics have attracted the attention of many scholars, and related theoretical and practical research has become increasingly complete [1]. Public health emergencies not only threaten our health but also undermine social stability and hinder economic development [2]. After disasters, the first step of rapid emergency response is to activate the emergency response network, reasonably configure emergency response resources, and improve rescue efficiency [3]. One of the most important tasks of disaster relief is to rapidly meet the emergent needs of victims, such as food, clothing, water, shelter, and medical care [4, 5]. Among them, blood transfusion is very important in disaster relief management, and blood is directly related to people's lives. The establishment of temporary blood supply stations at various disaster-stricken locations can effectively guarantee the blood needs of the affected people. The difference between the blood supply station and other basic medical facilities is as follows: the blood supply station is equipped with basic medical equipment and a variety of material accidents, can provide a stable blood transfusion environment, and is equipped with sufficient red blood cell blood to meet the needs of the seriously injured. However, when disasters occur, the geography of each area is severely affected, and the construction of blood supply stations is also affected by subjective and objective factors, such as the cost of building blood supply stations; subjective factors include supply

capacity, demand capacity, and coordination capacity; objective factors include the uncertainty of blood demand at each disaster site and time window constraints. Therefore, not all sites are suitable for the establishment of temporary blood supply stations. A systematic approach is required to solve the problem of the location of blood supply stations and blood distribution.

Recent disasters have shown the fact that insufficient blood supply led to an increase in mortality, such as the 2011 Japanese earthquake and subsequent tsunami interrupted blood supply [6]. In the 2008 Wenchuan earthquake, there were quality and wastage problems in the blood supply [7]. After the 2004 tsunami, it was difficult for Sri Lanka's national authorities to coordinate blood supply [8]. These examples have contributed to the fact that the mortality rate has increased to varying degrees, which shows that the timely supply of blood is vitally important after disasters.

Many scholars have studied the rescue of earthquake disasters and the problem of blood supply when disasters occur. For example, Şahin et al. [9] proposed a deterministic model to solve the location-allocation problem of the Turkish Red Crescent Society blood service area. Ghandforoush et al. [10] transformed the nonconvex integer programming model into a 0-1 linear problem under deterministic demand to optimize the transportation of platelets from the production center to the blood transfusion center. However, when a disaster occurs, because the extent of the disaster in each area is unknown, the number of people affected is also unknown, and each disaster is unique, so the actual blood demand and various supplies are uncertain. Under certain conditions, the research problem is not in line with reality. Therefore, some scholars have introduced stochastic optimization theory into the research. Wanget al. [11, 12] hypothesized that based on stochastic programming, accurate distributions can be obtained from historical data. However, earthquakes do not occur frequently in a certain area, and historical data of blood supply are limited, and the known distribution assumptions are somewhat incorrect. René et al. [13] proposed a stochastic planning and simulation method to optimize the inventory problem of perishable blood products. Some other research works of literature are using stochastic optimization theory [14–16]. Although the introduction of stochastic optimization makes the research more realistic, the premise of stochastic optimization is that the demand needs to obey a certain probability distribution. Usually, the probability distribution of this demand is not accurately known when a disaster occurs, and then, stochastic optimization cannot fully reflect the actual situation to a certain extent. From the literature review, it can be found that there is little research founding on such problems based on the robust optimization method of the uncertain set.

There are many advantages of robust optimization. First of all, it does not need to know the probability distribution of the target audience's needs [17]. Even in the worst case, it can perform well [18]. The key to robust optimization is how to measure uncertainty, that is, how to construct an uncertainty set, which considers the risk preference and conservativeness of decision-makers to a certain extent, and makes up for the shortcomings of stochastic optimization theory [19, 20]. Therefore, based on previous studies, the article adopts robust optimization to construct a MIRP model that is closer to the actual situation. The demand of the disaster site does not follow a single probability distribution but changes within a certain set of uncertainties. This makes the model constructed in this article more general and more in line with the actual situation.

In [21], considering the randomness and time urgency caused by the geographic location and terrain of the disaster relief point, a multiobjective fuzzy LRP optimization model based on chance-constrained planning is constructed to realize the joint decision-making of the emergency logistics center positioning and emergency vehicle path planning after the earthquake. In [22], considering the dynamic changes in the capacity of ambulance vehicles and medical facilities, the dynamic changes in the survival probability of various wounded with time, and the changes in the psychological status of the wounded, a medical facility with a secondary evacuation model for the wounded after the earthquake that maximizes the survival of the wounded and minimizes the psychological cost has been constructed. The dual-objective dynamic planning model for location selection and casualty transfer is more effective than increasing the number of temporary hospitals or capacity and the number of ambulances than increasing the number of rear hospitals or the capacity and the number of helicopters. The above research is decision-making for earthquake disasters under the multiobjective situation, which is considered. There are many factors such as capacity changes, the number of hospitals. However, we believe that the first factor to be considered when an earthquake disaster occurs is the survival probability of the victims, but there are currently few studies on this type. A similar approach has been taken in other areas, including the investment portfolio [23].

In addition, when disasters like earthquakes occur, the topography of various regions may be severely affected. Considering that the construction of blood supply stations is affected by subjective and objective factors, not all sites are suitable for building temporary blood supply stations. Therefore, a systematic approach is proposed in the article. The entropy-based TOPSIS method is employed to quantify the subjective factors of several candidate sites to select initial blood sites, by evaluating the construction cost, supply capacity, demand factors, and coordination capabilities. Due to objective factors including construction cost, time window constraints, and survival probability, it is impossible to select all alternative locations. Therefore, a robust optimization model with minimum cost and time window constraints is constructed to perform secondary location and distribution.

Based on the actual situation, the study uses the entropy TOPSIS method to initially screen the candidate sites, selects a better initial blood supply site, and then applies the robust optimization theory to the blood supply problem in disaster management. The main contributions are as follows:

(1) The site selection process of emergency facilities is redefined, combined with multicriteria decision-

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making and robust optimization methods, which were not involved in previous studies. The reason for this is that we feel that whether it is traditional site selection using multiattribute methods or robust optimization methods, it is impossible to fully consider the comprehensive factors affecting site selection. The combination of the two methods is a very good idea.

(2) A mixed-integer programming model of the blood supply problem in disaster areas is established with time window constraints. In the site selection problem, especially the site selection problem in emergency management, the time constraint is a very important factor in emergency management issues. In previous studies, time constraints were rarely considered. We think this is wrong.

(3) Robust optimization theory to measure the uncertainty of blood demand is applied by setting the level of uncertainty parameters. Robust optimization is a good method to deal with uncertain situations. Compared with stochastic programming, robust optimization does not need to know the probability distribution function of uncertain information.

(4) According to the robust optimization method, a blood supply site selection model corresponding to the three situations of uncertain demand is established, and the three models are compared, and the robustness of the three models is analyzed. To measure demand uncertainty in the form of uncertainty sets, this method is more realistic, and the comparison of multiple methods can give decision-makers more choices.

(5) Introducing the survival time probability function, decision-makers can make corresponding decisions according to the emergency time of disaster events and meet the blood supply demand with the minimum time and cost while maximizing the survival probability of disaster victims. Survival probability is rarely mentioned in previous studies. We combine survival probability with time window constraints. This is in line with the reality. A higher survival probability must correspond to a tighter time window. Therefore, decision-makers can make better decisions with reference to time and survival probability.

The rest of the organization of this article is organized as follows: Section 2 describes the subjective influencing factors of site selection and introduces the entropy weight-TOPSIS method. Section 3 describes the problem of emergency temporary blood supply sites, constructs a deterministic model and a robust optimization model, Section 4 uses the Wenchuan earthquake to carry out case simulations and select the location of secondary emergency temporary blood supply sites, and Section 5 summarizes and prospects. The research framework of this study is shown in Figure 1.

2. Alternative Location Selection Based on the Entropy-TOPSIS Method

Wenchuan earthquake on May 12, 2008, which caused more than 400,000 casualties, was the most destructive earthquake since the establishment of China [24]. It is quite necessary to conduct the site selection and construction of emergency temporary blood supply stations owing to China's large population, complex geographical environment, and the use of the mode of "on-site treatment." Since the earthquake caused severe damage, the location of the emergency temporary blood supply station should be in a place with flat terrain, unobstructed roads, a certain area of open space, and other suitable relief factors. Based on the above requirements, the entropy-TOPSIS method was adopted to analyze several candidate locations in Wenchuan County, Sichuan Province, and screen out the qualified candidate locations.

2.1. Influencing Factors of Location

2.1.1. Construction Costs. During the process of selecting the site for blood supply stations, it is necessary to consider the cost factors and reasonably calculate the construction land and labor costs in the region and to ensure scientific and reasonable planning and construction costs and maximize the utilization of limited resources. This primarily includes land construction costs and labor costs and other factors.

2.1.2. Supply Capacity. After the temporary blood supply station is built, it can not only meet the demand of blood transportation but also may involve site expansion or new distribution lines. Therefore, both the existing supply capacity and the requirements for spatial development should be emphasized in the site selection.

2.1.3. Demand Factors. In the construction of temporary blood supply stations, the severity of surrounding natural disasters should be considered to guarantee the blood demand of more demand points under the temporary blood supply stations.

2.1.4. Coordination Ability. The layout planning of temporary blood supply stations should focus on the connection with other modes of transportation. It is better to combine the layout of urban and rural transportation hubs for site selection.

For decision-makers, these four factors are appropriate for the location of emergency temporary blood supply stations. First of all, decision-makers do not want to invest too much and have the greatest benefits. In addition, because the construction of emergency temporary blood supply stations is greatly affected by topographical factors, factors must be considered when coordinating capabilities.

2.2. Location Method. There are many methods for multiattribute decision-making, such as the WSM method, VIKOR method, and ELECTRE method. The WSM method

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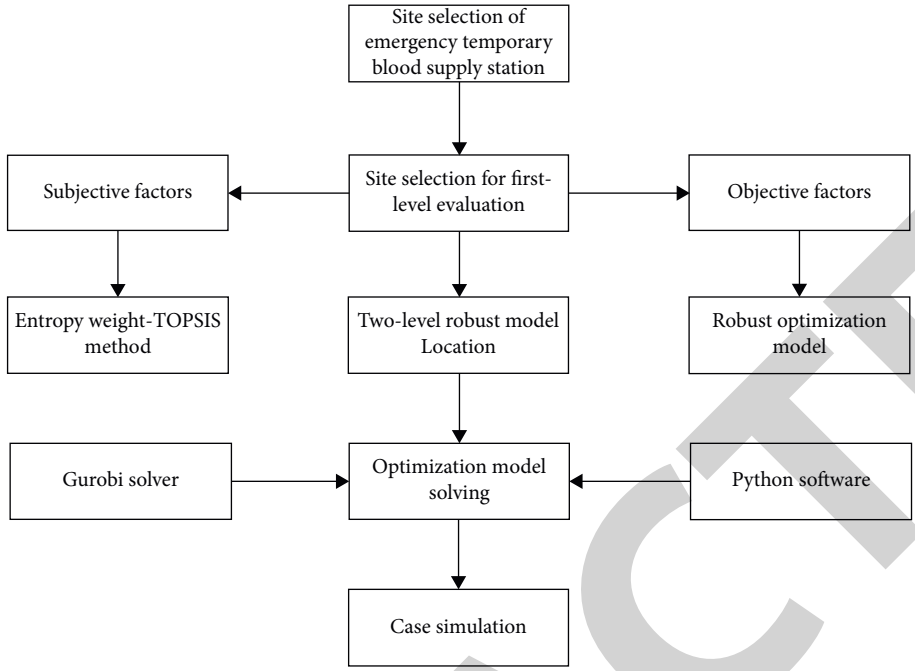

Figure 1: Research framework.

is simple and is the most widely used method. The VIKOR method is a better method to resolve conflicting factors. The calculation of the ELECTRE method is complicated. In this study, the entropy weight-TOPSI method is selected to select the first-level location of the emergency temporary blood supply station. The main reason is that it is sorted by calculating the distance between the evaluation plan and the ideal solution and the negative ideal solution. Compared with traditional methods, it has the characteristics of intuitive analysis principle, simple calculation, and low sample demand, which is more suitable for the site selection requirements of blood supply sites.

Step 1: build an index system. According to the main factors affecting the site selection of blood supply stations, four index systems were selected to construct the evaluation index system of node location.

Step 2: construct the original evaluation index matrix. There are m options to be selected and n evaluation indicators affecting each option. Then, the original decision matrix composed of the indicator data of each option is as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} = \left[a_{ij}\right]_{m\times n}, \quad (1)$$

where a_{ij} represents the data of the j^{th} indicator of scheme i.

Step 3: generate the standard matrix. By standardizing the data in the matrix, the standard matrix R after data normalization can be obtained:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}. \quad (2)$$

Step 4: calculate the weight by using the entropy weight method

(1) Standardize the decision matrix:

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}, \quad i = 1, 2, \ldots, m. \quad (3)$$

(2) Calculate the entropy value of the j^{th} index:

$$e_j = -K \sum_{i=1}^{m} p_{ij} \ln\, p_{ij}, \quad j = 1, 2, \ldots, n, \quad (4)$$

where $K > 0, K = 1/\ln\, m$.

(3) Calculate the difference coefficient of the j^{th} index:

$$g_i = 1 - e_j, \quad (5)$$

If the value difference of an index is larger, it has a greater impact on the evaluation of the scheme. Correspondingly, there will be a smaller entropy value and a larger difference coefficient. As a result, the difference coefficient can indirectly reflect the importance of the index.

(4) The weight of each index can be calculated by the difference coefficient as follows:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}. \quad (6)$$

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Step 5: generate the evaluation matrix:

$$V = \left(v_{ij}\right)_{m\times n} = \left(w_r r_{ij}\right)_{m\times n} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}. \quad (7)$$

Step 6: determine the positive ideal solution and negative ideal solution:

$$\begin{aligned} &\text{positive ideal solution: } v_j^+ = \max\left(v_{ij}\right), \\ &\text{negative ideal solution: } v_j^- = \min\left(v_{ij}\right). \end{aligned} \quad (8)$$

Step 7: calculate the distance:

$$\begin{aligned} S_i^* &= \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2}, \quad i = 1, 2, \ldots, m, \\ S_i^- &= \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, \quad i = 1, 2, \ldots, m. \end{aligned} \quad (9)$$

Step 8: calculate the fit degree for ranking:

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \quad 0 < C_i^* < 1, i = 1, 2, \ldots, m, \quad (10)$$

where C_i^* represents the relative proximity between the evaluation object i and the ideal solution. The greater the value of C_i^*, the better the evaluation object.

3. Robust Location-Allocation Optimization Modeling

In this study, the location and distribution of emergency temporary blood supply stations under uncertain conditions were explored. In this problem, two types of sites were considered, namely, emergency temporary blood supply sites and disaster area blood demand sites, as illustrated in Figure 2. Given cost minimization and demand responsiveness, the goal was to consider the number of emergency blood supply stations and to minimize the operating and management costs of emergency blood supply stations while meeting the blood demand in the disaster area and determining the proportion of blood demand points in the disaster area allocated to emergency temporary blood supply stations. Besides, the construction costs of emergency blood supply stations, transportation costs, and penalty costs for failure to arrive within the time window were considered.

3.1. Hypotheses

(1) Nodes in the network represent a demand point or emergency temporary blood supply site

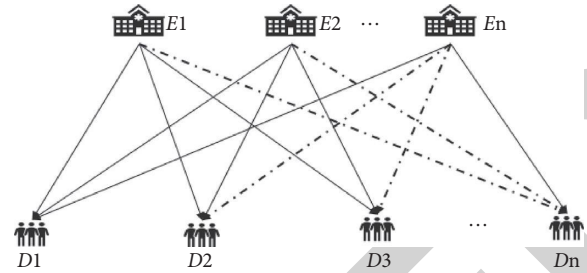

Figure 2: Distribution network of emergency temporary sites.

(2) The vehicle is set to keep uniform speed in the driving process, to make the model easy to solve

(3) Assume that the vehicle is not affected by road congestion during driving

(4) Assume that the operation of the entire system neglects device interrupt

3.2. Symbol Description

i is the blood demand point in the disaster area, $i \in \{1, 2, \ldots, m\}$

j is the emergency blood supply station to be selected, $j \in \{1, 2, \ldots, n\}$

f_j is the fixed cost of building an emergency blood supply station

g_j is the maximum blood storage capacity of each emergency blood supply station

C_{ij} is the unit transportation cost of vehicles from point j to point i

D_i is the blood demand of blood demand point i in the disaster area

d_{ij} is the distance from the emergency blood supply station j to the blood demand point i in the disaster area

$\overline{v}_j$ is the average speed of the vehicle leaving the emergency blood supply station j

O_a is the earliest time allowed to reach the demand point

O_b is the latest time allowed to reach the demand point, varying according to the survival probability

ε is the penalty cost that does not arrive within the time window

x_j is the 0-1 decision variable (if it is 1, the first emergency temporary blood supply station is selected; otherwise, it is 0)

y_{ij} is the proportion that blood demand point i in the disaster is allocated to emergency temporary blood supply station j

q_{ij} is the 0-1 decision variable (if y_{ij} is not 0, it will be 1; otherwise, it is 0)

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α_{ij} is the 0-1decision variable (if $O_a \le q_{ij} \cdot (d_{ij}/\overline{v}_j) \le O_b$, it is 1; otherwise, it is 0)

3.3. Deterministic Model (MILP). When the demand of blood demand points in disaster areas is known, the nominal model (i.e., the deterministic model) is usually expressed as follows [25–28]:

$$\min Z_1 = \sum_{j=1}^{n} f_j \cdot x_j + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot d_{ij} \cdot y_{ij} \cdot D_i + \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}\left(1 - \alpha_{ij}\right), \tag{11}$$

$$\text{s.t.} \sum_{j=1}^{n} y_{ij} = 1, \quad \forall i \in I, \tag{12}$$

$$\sum_{i=1}^{m} D_i y_{ij} \le g_j, \quad \forall j \in J, \tag{13}$$

$$y_{ij} \le x_j, \quad \forall i \in I, \forall j \in J, \tag{14}$$

$$0 \le y_{ij} \le 1, \quad \forall i \in I, \forall j \in J, \tag{15}$$

$$O_a \le q_{ij} \cdot \frac{d_{ij}}{\overline{v}_j} \le O_b, \tag{16}$$

$$x_j, q_{ij}, \alpha_{ij} \in \{0, 1\}, \tag{17}$$

where objective function (11) aims to minimize the sum of the costs of site-allocation problems of emergency blood supply stations. The costs include fixed cost, vehicle transportation cost, and time window penalty cost. Formula (12) indicates that the amount of blood sent to the blood demand point of the disaster area must meet its demand. Formula (13) suggests that the amount of blood transported by the emergency blood supply site does not exceed its maximum stock capacity. Formula (14) reflects that vehicles can only be assigned to selected emergency blood supply stations. Formula (15) reveals that the proportion on any allocated route should not exceed 1. Formula (16) represents the time window constraint. Different from the simple time constraint in the past, time and survival probability are closely combined to emphasize the survival probability and restrict time simultaneously. Formula (17) designates the 0-1 variable.

3.4. Robust Counterpart. Considering the following linear programming problems with uncertain coefficients,

$$\left\{\min_x c^T x + d:\ Ax \le b\right\}_{(c,d,A,b)\in U}, \tag{18}$$

where $c^T x + d$ indicates the objective function; $Ax \le b$ is the constraint, considering the i^{th} row of matrix A. It is assumed that only one element $\widetilde{a}_{ij}$ in the coefficient matrix is uncertain, $\widetilde{a}_{ij} = a_{ij} + \widehat{a}_{ij}\xi_j$. Among them, $\widetilde{a}_{ij}$ represents the actual value of the parameter, a_{ij} denotes the determined value of the parameter, $\widehat{a}_{ij}$ refers to the fluctuation of the parameter, ξ_j designates the uncertainty factor (is the uncertainty set), and ξ can take any value in the set. Then, the original constraint can be written as follows:

$$\sum_j a_{ij}x_j + \max_{\xi\in U} \sum_j \widehat{a}_{ij}x_j\xi_j \le b. \tag{19}$$

Its robust equivalents will be discussed in the next section.

3.4.1. Uncertain Set of Boxes. If the uncertainty set is box-like, it can be defined by an infinite norm l_∞. $U^B = U_\infty = \{\xi:\ \|\xi\|_\infty \le \psi\} = \{\xi:\ |\xi_j| \le \psi\}$, where ψ denotes the uncertainty level parameter, suggesting that the deviation coefficient from the initial value on the first-row vector does not exceed ψ. Meanwhile, it is used to measure the conservatism of constraint conditions and reflect the risk preference degree of decision-makers. The smaller the value of ψ, the higher the risk preference degree of decision-makers.

Theorem 1. *Formula (19) can be equivalently written as*

$$\sum_j a_{ij}x_j + \psi \sum_j \widehat{a}_{ij}\left|x_j\right| \le b. \tag{20}$$

3.4.2. Polyhedron Uncertain Set. If the uncertain set is a polyhedron, it can be defined by the 1-norm l_1. $U^P = U_1 = \{\xi:\ \|\xi\|_1 \le \Lambda\} = \{\xi \cdot \sum |\xi_j| \le \Lambda\}$, where Λ represents the uncertain parameter.

Theorem 2. *Formula (19) can be equivalently written as*

$$\sum_j a_{ij}x_j + \Lambda p_i \le b, \quad p_i \ge \widehat{a}_{ij}\left|x_j\right|. \tag{21}$$

3.4.3. Ellipsoidal Uncertain Set. If the uncertainty set is an ellipsoid, it can be defined by the 2-norm l_2. $U^E = U_2 = \{\xi:\ \|\xi\|_2 \le \Omega\} = \{\xi \cdot \sqrt{\sum_j \xi_j^2} \le \Omega\}$, where Ω indicates both the uncertain horizontal parameter and the radius of the uncertain set.

Theorem 3. *Formula (19) can be equivalently written as*

$$\sum_j a_{ij}x_j + \Omega\sqrt{\widehat{a}_{ij}^2 x_j^2} \le b. \tag{22}$$

3.5. Robust Optimization Model (MIRP). In this section, the MILP model is transformed into three different MIRP models, and the uncertainty set is used to replace the

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uncertainty constraint. Compared with the deterministic model, three uncertain robust optimization models are all nonconvex optimization problems. The difficulty of solving becomes greater, and the complexity of the problem increases, and as the degree of uncertainty increases, the difficulty of solving gradually increases. The blood demand in the disaster area is uncertain and defined as a random variable $\widetilde{D}$; $\widehat{D}$ is defined as the fluctuation of the demand; thus, $\widetilde{D} = D + \widehat{D}$. According to the theoretical knowledge of robust optimization [28–30], the MILP model can be transformed into three MIRP models.

3.5.1. MIRP-Box Set Model. If the initial blood demand of the disaster area is $\widetilde{D}$, the uncertain set is a box. ψ denotes the level of uncertainty. The box uncertainty set model can be expressed as equations (23)–(30).

$$\min Z_b, \tag{23}$$

$$\text{s.t.} \sum_{j=1}^{n} f_j \cdot x_j + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot d_{ij} \cdot y_{ij} D_i + \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}\left(1 - \alpha_{ij}\right) + \psi \cdot \sum_{i=1}^{m}\sum_{j=1}^{n} C \cdot d_{ij} \cdot y_{ij} \cdot \widehat{D}_i \le Z_b, \tag{24}$$

$$\sum_{j=1}^{n} y_{ij} = 1, \quad \forall i \in I, \tag{25}$$

$$\sum_{i=1}^{m} D_i y_{ij} + \psi \cdot \sum_{i=1}^{m} \widehat{D}_i y_{ij} \le g_j, \quad \forall j \in J, \tag{26}$$

$$y_{ij} \le x_j, \quad \forall i \in I, \forall j \in J, \tag{27}$$

$$0 \le y_{ij} \le 1, \quad \forall i \in I, \forall j \in J, \tag{28}$$

$$O_a \le q_{ij} \cdot \frac{d_{ij}}{\overline{v}_j} \le O_b, \tag{29}$$

$$x_j, q_{ij}, \quad \alpha_{ij} \in \{0, 1\}. \tag{30}$$

3.5.2. MIRP-Polyhedron Set Model. If the initial blood demand of the disaster area is $\widetilde{D}$, the uncertain set is a polyhedron. Λ, Λ' represent the uncertainties in the objective function and constraint, respectively; μ, μ' indicate their corresponding dual variables, respectively. Then, the polyhedral uncertainty set model can be expressed as equations (31)–(38).

$$\min Z_p, \tag{31}$$

$$\text{s.t.} \sum_{j=1}^{n} f_j \cdot x_j + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot d_{ij} \cdot y_{ij} D_i + \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}\left(1 - \alpha_{ij}\right) + \Lambda\mu \le Z_p, \tag{32}$$

$$\sum_{j=1}^{n} y_{ij} = 1, \quad \forall i \in I, \tag{33}$$

$$\sum_{i=1}^{m} D_i y_{ij} + \Lambda'\mu' \le g_j, \quad \forall j \in J, \tag{34}$$

$$y_{ij} \le x_j, \quad \forall i \in I, \forall j \in J, \tag{35}$$

$$0 \le y_{ij} \le 1, \quad \forall i \in I, \forall j \in J, \tag{36}$$

$$O_a \le q_{ij} \cdot \frac{d_{ij}}{\overline{v}_j} \le O_b, \tag{37}$$

$$x_j, q_{ij}, \alpha_{ij} \in \{0, 1\}. \tag{38}$$

3.5.3. MIRP-Ellipsoid Set Model. If the initial blood demand of the disaster area is $\widetilde{D}$, the uncertain set is an ellipsoid. Considering that the demand $\widetilde{D}$ is uncertain, $U_E^1 = \left\{\widetilde{D} \in R, \sum_{i=1}^{m} [(\widetilde{D}_i - D_i)/\widehat{D}_i]^2 \le \Omega^2\right\}$ represents the set of ellipsoids. Since the problem is a nonlinear constraint problem, $\widetilde{D}_i = \gamma_i D_i$, we set $U_E^1 = U_E^2 = \left\{\widetilde{D} \in R, (\widetilde{D}_i - D_i)^T C^{-1} (\widetilde{D}_i - D_i) \le \Omega^2\right\}$, where matrix C is an n-order diagonal matrix of element $\widetilde{D}_i^2$ (nonzero). It can be verified that $\sum_{j=1}^{n} f_j \cdot x_j + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot d_{ij} \cdot y_{ij} \cdot D_i + \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}(1 - \alpha_{ij}) + \Omega_1 \sqrt{\sum_{i=1}^{m} (\widehat{D}_i^2 y_{ij} d_{ij} C_{ij})} \le Z_e$, let $\beta_i = \sum_{j=1}^{n} y_{ij} d_{ij} C_{ij}$, $F = \sqrt{\sum_{i=1}^{m} \widehat{D}_i^2 \beta_i^2}$, as it aims to solve the minimum cost, so $\beta_i \ge \sum_{j=1}^{n} y_{ij} d_{ij} C_{ij}$, $F \ge \sqrt{\sum_{i=1}^{m} \widehat{D}_i^2 \beta_i^2}$. Similarly, $\sum_{j=1}^{n} D_i y_{ij} + \Omega_2 \sqrt{\sum_{i=1}^{m} (\widehat{D}_i^2 y_{ij})} \le g_j$, $Q = \sqrt{\sum_{i=1}^{m} y_{ij}^2 \widehat{D}_i^2}$, relaxation constraint $Q \ge \sqrt{\sum_{i=1}^{m} y_{ij}^2 \widehat{D}_i^2}$ is added.

The model can be expressed as equations (39)–(49).

$$\min Z_e, \tag{39}$$

$$\text{s.t.} \sum_{j=1}^{n} f_j \cdot x_j + \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot d_{ij} \cdot y_{ij} \cdot D_i + \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}\left(1 - \alpha_{ij}\right) + \Omega_1 F \le Z_e, \tag{40}$$

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$$\sum_{j=1}^{n} y_{ij} = 1, \quad \forall i \in I, \tag{41}$$

$$F \geq \sqrt{\sum_{i=1}^{m} \widehat{D}_i^2 r_i^2}, \tag{42}$$

$$\beta_i \geq \sum_{j=1}^{n} y_{ij} d_{ij} C_{ij}, \quad \forall i \in I, \tag{43}$$

$$\sum_{j=1}^{n} D_i y_{ij} + \Omega_2 Q \leq g_j, \tag{44}$$

$$Q \geq \sqrt{\sum_{i=1}^{m} y_{ij}^2 \widehat{D}_i^2}, \quad \forall j \in J, \tag{45}$$

$$y_{ij} \leq x_j, \quad \forall i \in I, \forall j \in J, \tag{46}$$

$$0 \leq y_{ij} \leq 1, \quad \forall i \in I, \forall j \in J, \tag{47}$$

$$O_a \leq q_{ij} \cdot \frac{d_{ij}}{\bar{v}_j} \leq O_b, \tag{48}$$

$$x_j, q_{ij}, \quad \alpha_{ij} \in \{0, 1\}. \tag{49}$$

4. Case Simulation

4.1. Site Selection Analysis. During the earthquake disaster, various terrains are destroyed, and roads are severely blocked. Therefore, it is imperative to select suitable alternative blood supply stations since the proper geographical location can provide convenient and efficient treatment conditions. The construction cost, blood supply capacity, demand factors, and coordination ability of blood supply stations constitute the screening conditions of alternative locations. Thus, 30 locations were selected as candidate locations, and the entropy-TOPSIS method was employed to compare and select the final 12 alternative locations.

4.1.1. Collecting Original Data. The original index data of 30 candidate locations are listed in Table 1.

4.1.2. Generating the Standardized Matrix. Standardized matrix is generated as follows:

$$R = \begin{pmatrix}
0.333333 & 0.177778 & 0.394737 & 0.263158 \\
0.466667 & 0.6 & 0.815789 & 0.552632 \\
0.433333 & 0 & 0.263158 & 0.078947 \\
0.533333 & 0.444444 & 0.289474 & 0.447368 \\
0.633333 & 0.933333 & 0.578947 & 0.789474 \\
0.3 & 0.422222 & 0.210526 & 0.447368 \\
0.366667 & 0.577778 & 0.026316 & 0.315789 \\
0.4 & 0.822222 & 0.947368 & 0.947368 \\
0.133333 & 1 & 0.815789 & 0.921053 \\
0.166667 & 0.444444 & 0.5 & 0.052632 \\
0.6 & 0.844444 & 0.921053 & 0.868421 \\
0.633333 & 0.444444 & 0.289474 & 0.078947 \\
0.566667 & 0.6 & 0.447368 & 0.447368 \\
0 & 0.622222 & 0.684211 & 0.052632 \\
0.466667 & 0.888889 & 0.947368 & 0.789474 \\
1 & 0.866667 & 0.815789 & 1 \\
0.866667 & 0.466667 & 0 & 0.289474 \\
0.833333 & 0.6 & 0.315789 & 0.578947 \\
0.4 & 0.711111 & 0.052632 & 0.736842 \\
0.233333 & 0.377778 & 0.394737 & 0.342105 \\
0.066667 & 0.933333 & 0.921053 & 0.736842 \\
1 & 0.911111 & 0.789474 & 1 \\
0.7 & 0.422222 & 0 & 0 \\
0.666667 & 0.555556 & 0.184211 & 0.684211 \\
0.6 & 1 & 1 & 0.736842 \\
0.733333 & 0.244444 & 0.263158 & 0.447368 \\
0.766667 & 0.288889 & 0.526316 & 0.289474 \\
0.333333 & 0.577778 & 0.263158 & 0.447368 \\
0.4 & 0.755556 & 0.710526 & 0.815789 \\
0.166667 & 0.377778 & 0 & 0.315789
\end{pmatrix}. \tag{50}$$

4.1.3. Calculating the Weight. According to formulas (4) and (6), the entropy value and weight of each indicator can be calculated. The calculation results are provided in Table 2.

4.1.4. Calculating the Distance and the Fitting Degree. According to formulas (9) and (10), the distance and the fitting degree of each evaluation vector to positive and

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Table 1: Original data of candidate location indexes.

Candidate sites	Construction costs	Supply capacity	Demanding factors	Coordination ability
J_1	5000	5.5	7.2	6.5
J_2	5200	7.4	8.8	7.6
J_3	5150	4.7	6.7	5.8
J_4	5300	6.7	6.8	7.2
J_5	5450	8.9	7.9	8.5
J_6	4950	6.6	6.5	7.2
J_7	5050	7.3	5.8	6.7
J_8	5100	8.4	9.3	9.1
J_9	4700	9.2	8.8	9.0
J_{10}	4750	6.7	7.6	5.7
J_{11}	5400	8.5	9.2	8.8
J_{12}	5450	6.7	6.8	5.8
J_{13}	5350	7.4	7.4	7.2
J_{14}	4500	7.5	8.3	5.7
J_{15}	5200	8.7	9.3	8.5
J_{16}	6000	8.6	8.8	9.3
J_{17}	5800	6.8	5.7	6.6
J_{18}	5750	7.4	6.9	7.7
J_{19}	5100	7.9	5.9	8.3
J_{20}	4850	6.4	7.2	6.8
J_{21}	4600	8.9	9.2	8.3
J_{22}	6000	8.8	8.7	9.3
J_{23}	5550	6.6	5.7	5.5
J_{24}	5500	7.2	6.4	8.1
J_{25}	5400	9.2	9.5	8.3
J_{26}	5600	5.8	6.7	7.2
J_{27}	5650	6.0	7.7	6.6
J_{28}	5000	7.3	6.7	7.2
J_{29}	5100	8.1	8.4	8.6
J_{30}	4750	6.4	5.7	6.7

Table 2: Entropy and weight of each index.

Index	Entropy	Difference coefficient	Weight
Construction costs	0.953102	0.046898023	0.211284
Supply capacity	0.967956	0.032043539	0.144362
Demand factors	0.917829	0.082171034	0.370196
Coordination ability	0.939146	0.06085385	0.274158

negative ideal solutions can be calculated. The calculation results are exhibited in Table 3.

4.2. Determining Alternate Locations. According to the ranking of the fitting degree in Table 3, the top 12 candidate locations are selected as the alternative locations of blood supply sites, namely, $J_7, J_4, J_{22}, J_{16}, J_{26}, J_9, J_3, J_{12}, J_{18}, J_{30}, J_{27}, J_5$.

4.3. Data Set. After the alternative locations of the 12 blood supply stations obtained above were determined, they were set as $j_1, j_2, \ldots, j_{12}$, respectively. Meanwhile, 25 hard-hit villages were selected as disaster area blood demand points. The relative positions of each affected point and alternative location point are illustrated in Figure 3, in which the fixed cost of each alternative location point is f_j, capacity limit is g_j, and the average speed that vehicles left point j is $\overline{v}_j$, as shown in Table 4. The nominal demands D_i of blood demand points in each area are presented in Table 5. The nominal transport costs between various nodes are provided in Table 6.

4.4. Comparison of MILP and MIRP Models. In this section, Gurobi 9.0 was adopted to solve the MIRP model under the above different uncertain sets (box, polyhedron, and ellipsoid). The results of MIRP and MILP models were compared. Besides, the minimum cost was obtained by solving the MILP model under the condition that the nominal demand was determined. Six emergency temporary blood supply stations were selected from the alternative locations, namely, E_2, E_4, E_5, E_6, E_8, and E_{10}. The specific results are illustrated in Figure 4.

4.4.1. MIRP-Box Set Model. In the MIRP-box set model, the impact of ψ on total cost is uncertain. The specific results are exhibited in Table 7. When $\psi = 0$, the result is the same as that of the MILP model, that is, 3.36×10^5, and the selected emergency temporary blood supply sites are E_2, E_4, E_5, E_6, E_8, and E_{10}. With the increasing level of uncertainty, the number of emergency temporary blood supply stations and the total cost gradually increase. The cost increases slowly, indicating that the model is conservative. Particularly, 10 emergency temporary blood supply stations are needed for blood supply

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Table 3: Distance between evaluation vectors and positive and negative ideal solutions and the fitting degree.

Candidate site	S_i^*	S_i^-	C_i^*	Ranking
J_1	0.160363	0.136661	0.460102	20
J_2	0.332282	0.225266	0.40403	29
J_3	0.12356	0.135432	0.522919	7
J_4	0.06132	0.087319	0.587458	2
J_5	0.11622	0.115369	0.498164	12
J_6	0.09653	0.064038	0.39882	30
J_7	0.077437	0.126165	0.619666	1
J_8	0.36465	0.320515	0.467793	17
J_9	0.319816	0.372576	0.5381	6
J_{10}	0.25733	0.178978	0.41021	27
J_{11}	0.323196	0.248012	0.434189	23
J_{12}	0.134699	0.147319	0.522375	8
J_{13}	0.100955	0.092925	0.479292	15
J_{14}	0.384621	0.269135	0.411675	26
J_{15}	0.362004	0.279876	0.436026	22
J_{16}	0.200734	0.246838	0.551504	4
J_{17}	0.24019	0.210635	0.467221	18
J_{18}	0.108644	0.118821	0.522371	9
J_{19}	0.238732	0.210862	0.469006	16
J_{20}	0.143195	0.106691	0.426959	24
J_{21}	0.410724	0.395887	0.490803	13
J_{22}	0.180883	0.229211	0.558922	3
J_{23}	0.226512	0.159967	0.413908	25
J_{24}	0.167234	0.140276	0.456167	21
J_{25}	0.372213	0.255395	0.406933	28
J_{26}	0.136633	0.160652	0.540399	5
J_{27}	0.19459	0.198332	0.504763	11
J_{28}	0.070024	0.060201	0.462283	19
J_{29}	0.239006	0.227668	0.487853	14
J_{30}	0.105641	0.108211	0.50601	10

when the level of uncertainty is at its maximum ($3.36 \times 10^5 = 26$).

4.4.2. MIRP-Polyhedron Set Model. In the MIRP model under the polyhedron set, the impact of Λ on the total cost is exhibited in Table 8. When Λ is 0, the MIRP model is equivalent to the MILP model, with the same cost. The total cost shows an upward trend as the value increases. Compared with the box model, the increasing speed is general, suggesting that the model has general robustness. When Λ is 23, the supply reaches saturation, and 12 blood supply stations need to be established to guarantee the demand.

4.4.3. MIRP-Ellipsoid Set Model. In the MIRP model under the ellipsoid set, the impact of Ω on the total cost is provided in Table 9. When Ω is 0, the MIRP model is equivalent to the MILP model, with the same cost. The total cost increases as the value of Ω increases. Compared with the first two models, its upward speed is relatively slow, reflecting that the model has good robustness.

4.4.4. Impact of Uncertainty Level on Total Costs. In this section, the three uncertainty set models obtained by the robust optimization theory were compared with our nominal model. Each set of uncertainty levels was implemented in the corresponding uncertainty set model. Figure 5 suggests that different MIRP models present different robustness when uncertainty levels are different. The three MIRP models are equivalent to the MILP nominal model when the uncertainty level is 0. Additionally, the cost of the three MIRP models increases as the uncertainty level increases. When the uncertainty level is less than 18, the total cost of the three MIRP models is low while the convergence is too slow. The three models tend to be stable when the level of uncertainty is 23. Among them, the MIRP-ellipsoid set model has a lower total cost and faster convergence speed compared to the other two models, demonstrating its stronger robustness.

From this part of the experiment, we can see that robust optimization can well solve the problem of the secondary location of emergency temporary blood supply sites. Different MIRP models can get different results. The uncertainty is measured by the uncertainty set. Uncertainty can also get different results, which is fully consistent with reality.

4.5. Location and Blood Supply Route Optimization. First, the MILP model was solved under certain requirements. The results after comprehensively considering all aspects of cost are exhibited in Figure 3. In the MILP model, 6 emergency blood supply sites were selected from 12 candidates. This

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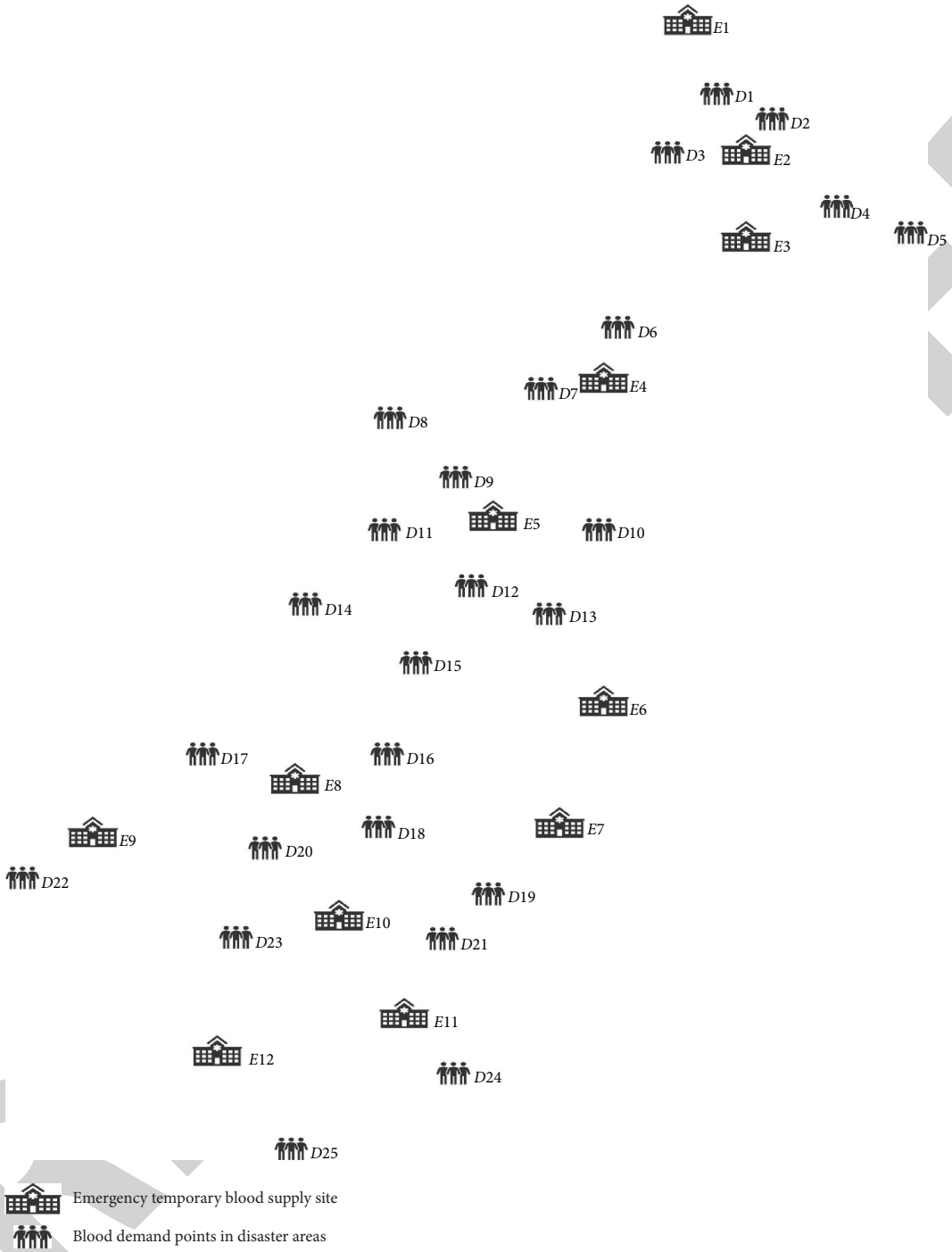

Figure 3: Relative position of the disaster site and candidate sites.

Table 4: Basic parameters of emergency temporary blood supply stations.

j	1	2	3	4	5	6	7	8	9	10	11	12
f_j	5050	5300	6000	6000	5600	4700	5150	5450	5750	4750	5650	5450
g_j	856	1100	880	788	1000	950	920	1200	980	1150	800	1000
$\overline{v}_j$	30	35	42	37	42	38	41	29	34	29	36	41

Table 5: Nominal demand of blood demand points in disaster areas.

i	1	2	3	4	5	6	7	8	9	10	11	12
D_i	200	250	181	170	235	195	210	170	250	205	220	200
13	14	15	16	17	18	19	20	21	22	23	24	25
185	180	216	186	197	235	180	190	225	215	185	176	160

Table 6: Unit transportation cost between various nodes.

C_{ij}	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
D_1	9.1	2.9	11.2	25.9	43.0	58.6	70.0	71.8	93.2	81.3	90.4	97.1
D_2	10.7	1.3	9.6	25.0	42.2	57.3	68.7	71.0	79.3	80.3	89.3	96.1
D_3	12.9	1.7	7.5	22.2	39.3	54.5	66.0	68.0	76.3	77.5	86.5	93.3
D_4	20.3	8.8	10.0	21.7	38.9	51.5	62.4	67.8	76.9	75.9	84.1	92.0
D_5	20.3	10.0	12.0	24.2	41.4	53.5	64.4	70.2	79.3	78.2	86.2	94.2
D_6	33.4	22.9	16.6	1.2	17.9	33.8	45.6	46.9	55.5	56.1	65.1	71.8
D_7	36.1	27.1	21.0	4.4	13.8	30.9	42.0	42.5	51.1	52.1	61.4	67.8
D_8	45.1	37.4	33.0	18.0	12.7	31.7	42.5	34.9	41.7	46.5	56.9	61.0
D_9	46.1	37.2	31.7	15.2	7.0	26.3	37.6	32.9	40.8	43.6	53.5	58.6
D_{10}	49.5	38.5	31.1	15.1	7.5	17.6	29.4	33.3	43.0	40.9	49.3	56.9
D_{11}	52.3	43.3	37.8	21.1	7.0	23.7	34.2	27.1	34.6	38.0	48.3	52.8
D_{12}	57.1	47.3	40.8	23.8	6.3	16.0	26.5	22.5	31.7	32.1	41.8	47.6
D_{13}	57.9	47.2	40.0	23.5	8.6	10.7	22.1	24.9	34.9	31.9	40.6	48.0
D_{14}	63.1	54.7	49.1	32.4	16.0	24.1	31.5	17.1	23.5	29.4	40.4	42.9
D_{15}	65.2	55.5	48.8	31.8	14.4	13.9	21.4	14.7	24.5	23.9	34.0	39.3
D_{16}	73.8	63.9	57.1	40.2	23.0	15.9	18.2	7.6	18.2	15.4	25.7	30.9
D_{17}	78.2	69.5	63.6	46.7	29.5	32.2	30.1	6.4	8.4	18.4	29.3	29.0
D_{18}	82.5	72.3	65.2	48.5	31.5	100.4	16.7	8.8	16.4	6.7	16.8	22.6
D_{19}	85.0	74.2	53.7	50.7	34.9	18.7	10.0	18.2	25.5	10.6	14.2	24.6
D_{20}	86.8	77.3	70.7	53.7	36.2	28.3	25.5	7.6	8.4	8.0	18.2	18.3
D_{21}	92.0	81.3	73.8	57.6	41.3	26.1	17.0	19.8	24.2	7.8	6.7	17.8
D_{22}	103.1	86.9	81.3	64.4	47.3	44.0	42.2	12.2	10.0	15.5	30.1	22.1
D_{23}	94.9	85.3	78.6	61.6	44.2	34.1	28.6	16.0	13.5	8.3	12.8	9.8
D_{24}	103.2	92.2	84.6	68.8	52.9	37.0	25.8	30.7	32.8	8.0	9.8	14.0
D_{25}	115.9	101.6	94.2	77.8	61.0	46.8	37.4	34.6	32.4	11.0	10.0	12.0

scheme was the optimal and ideal one with the lowest cost. However, the demand for blood in each disaster area is uncertain when the disaster occurs. Thus, the candidate sites and blood supply routes were selected by solving the three MIRP models when the uncertainty level was neutral ($\psi = \Lambda = \Omega = 13$) to conform to the actual situation, as presented in Figures 6–8. It can be observed that the model can also generate a good solution when the demand and the decision-maker's risk preferences are uncertain.

4.5.1. Survival Probability and Total Cost. The rescue efficiency of disaster-stricken points depends on two aspects: one is the time when the relief materials arrive, and the other is the quantity of relief materials. It is a very natural choice to use the survival probability of the trapped person over time to measure the arrival time of rescue materials to maximize the rescue effect. Therefore, when a disaster occurs, the survival probability of the wounded is closely related to time. In the event of a disaster, the survival probability of the wounded is directly related to time. Regarding the survival probability of the wounded, Fiedrich et al. [31] obtained the general form of survival probability and time function based on the actual data of multiple earthquake disasters. On this basis, Yu [32] assumed that the time T corresponding to the average survival probability of the wounded could be estimated to be 0.5 and then constructed the function of survival probability and time. In this study, this function was adopted to describe the relationship between survival probability and time. Figure 9 illustrates the graphs of survival probability function corresponding to T of 60, 120, 180, and 240 (min), respectively.

The function image at $T = 60$ was selected as the research object when the disaster of the Wenchuan earthquake is relatively severe. In practice, the latest time allowed to reach the disaster area (O_b) was changed to observe the impact of time on the total cost. Table 10 lists the actual time between $T = 60$ and survival probability of 0.5–0.95 and the change of total cost under different time constraints. As revealed from the table, the total costs of the three models all increase with the increase of survival probability when $T = 60$ since the improvement of survival probability makes the time window tighter. Therefore, it is necessary to adjust a more appropriate scheme to perform the distribution. Moreover, multiple routes or opening more emergency blood supply stations will undoubtedly increase the total cost. Compared with the three models, the MIRP-ellipsoid set model has the lowest cost,

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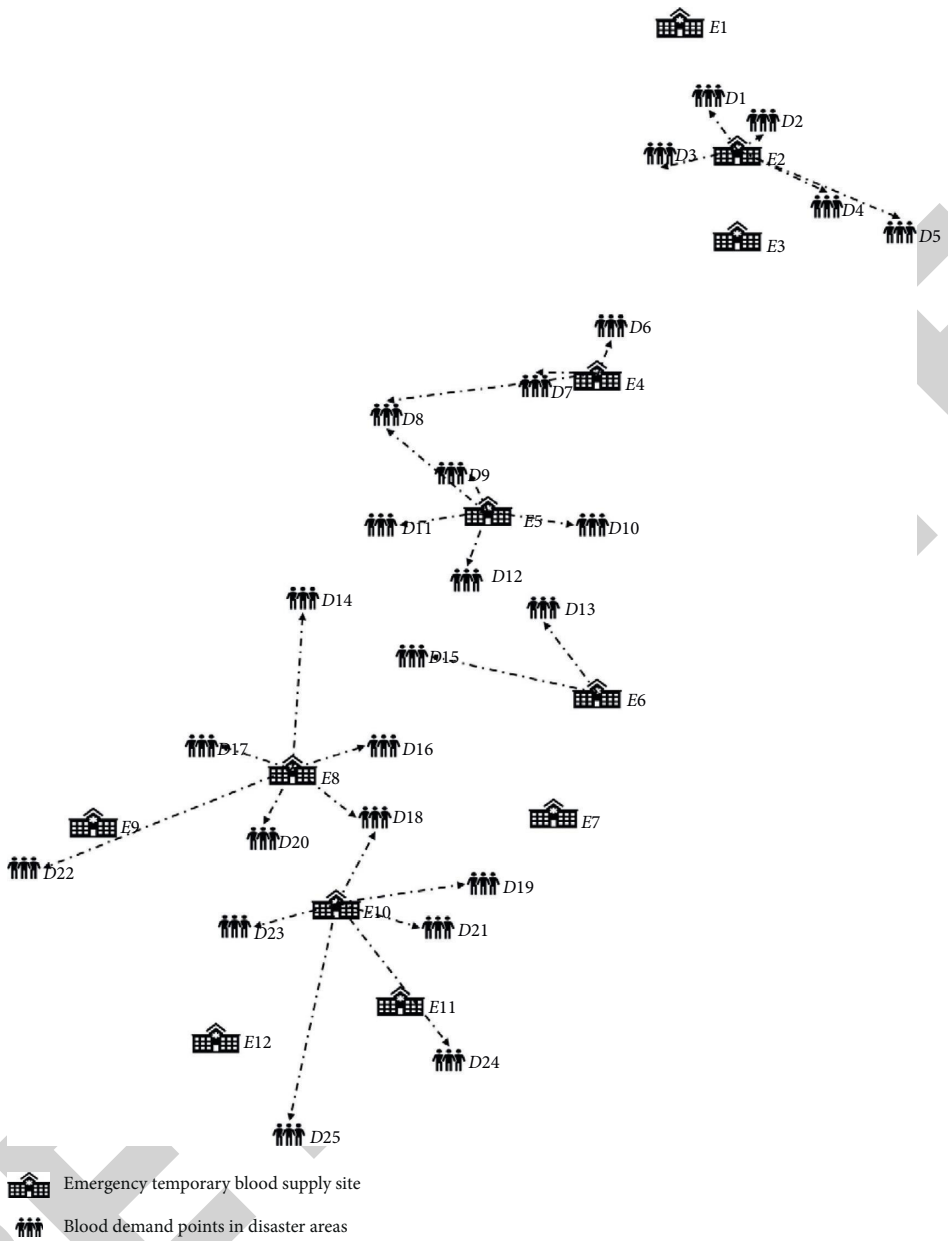

Figure 4: MILP model.

Table 7: Optimal scheme under MIRP-box set.

ψ	Costs (10^5)	Quantity	Selected sites
0	3.36	6	2, 4, 5, 6, 8, 10
3	3.79	6	2, 4, 5, 6, 8, 10
6	4.31	6	2, 4, 5, 6, 8, 10
9	4.47	8	2, 3, 4, 5, 6, 8, 10, 11
13	4.69	8	2, 3, 4, 5, 6, 8, 10, 11
15	4.86	8	2, 3, 4, 5, 6, 8, 10, 11
18	5.21	9	2, 3, 4, 5, 6, 7, 8, 10, 11
21	5.41	9	2, 3, 4, 5, 6, 7, 8, 10, 11
23	5.44	10	2, 3, 4, 5, 6, 7, 8, 9, 10, 11
26	5.53	10	2, 3, 4, 5, 6, 7, 8, 9, 10, 11

Table 8: Optimal scheme in MIRP-polyhedron set.

Λ	Costs (10^5)	Quantity	Selected sites
0	3.36	6	2, 4, 5, 6, 8, 10
3	3.78	7	2, 3, 4, 5, 6, 8, 10
6	3.85	8	2, 3, 4, 5, 6, 8, 10, 11
9	4.01	9	1, 2, 3, 4, 5, 6, 8, 10, 11
13	4.21	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
15	4.67	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
18	4.95	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
21	5.39	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
23	5.59	12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12
26	5.61	12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12

Table 9: Optimal scheme under MIRP-ellipsoid set.

Ω	Costs (10^5)	Quantity	Selected sites
0	3.36	6	2, 4, 5, 6, 8, 10
3	3.79	7	2, 3, 4, 5, 6, 8, 10
6	3.88	8	2, 3, 4, 5, 6, 8, 10, 11
9	4.12	9	1, 2, 3, 4, 5, 6, 8, 10, 11
13	4.47	9	1, 2, 3, 4, 5, 6, 8, 10, 11
15	4.61	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
18	5.12	10	1, 2, 3, 4, 5, 6, 7, 8, 10, 11
21	5.29	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
23	5.31	12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12
26	5.36	12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12

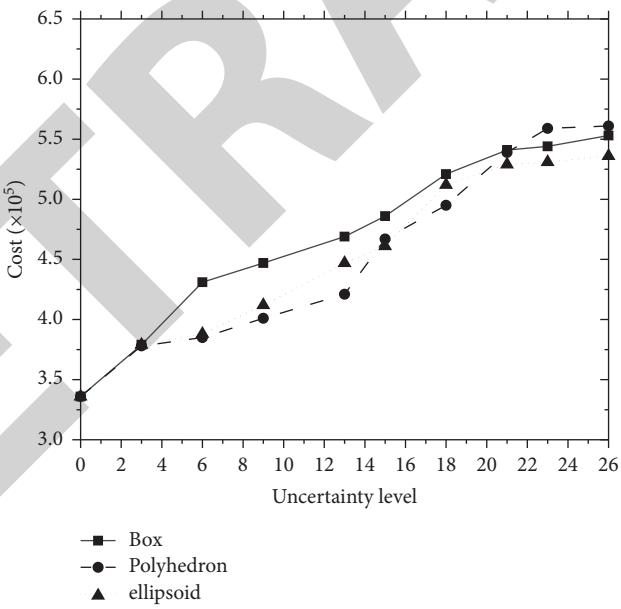

Figure 5: Impact of uncertainty level on total costs.

suggesting that the model has the smallest robustness. Since time is an imperative factor influencing the survival probability in the event of a disaster, decision-makers can set the necessary time limit according to the actual situation of the disaster at an appropriate cost, to achieve a higher survival rate.

4.5.2. Impact of Demand Disturbance on the Total Cost. The change in total cost when the demand disturbance varies is presented in Table 11. The impact of the disturbance ratio ($\xi = 0.05, 0.10, 0.15, 0.20, 0.25, 0.30$) on the target cost was mainly studied. As exhibited in the table, the total cost of the three MIRP models gradually increases when the disturbance ratio increases from 0.05 to 0.3. The greater the disturbance ratio, the greater the total cost. It can be revealed by comparing these three models that the MIRP-polyhedron set model has the highest cost, the MIRP-box model has the middle cost, and the MIRP-ellipsoid set model has the lowest cost. This demonstrates the good robustness of the ellipsoid set model. However, the MIRP-ellipsoid model generally

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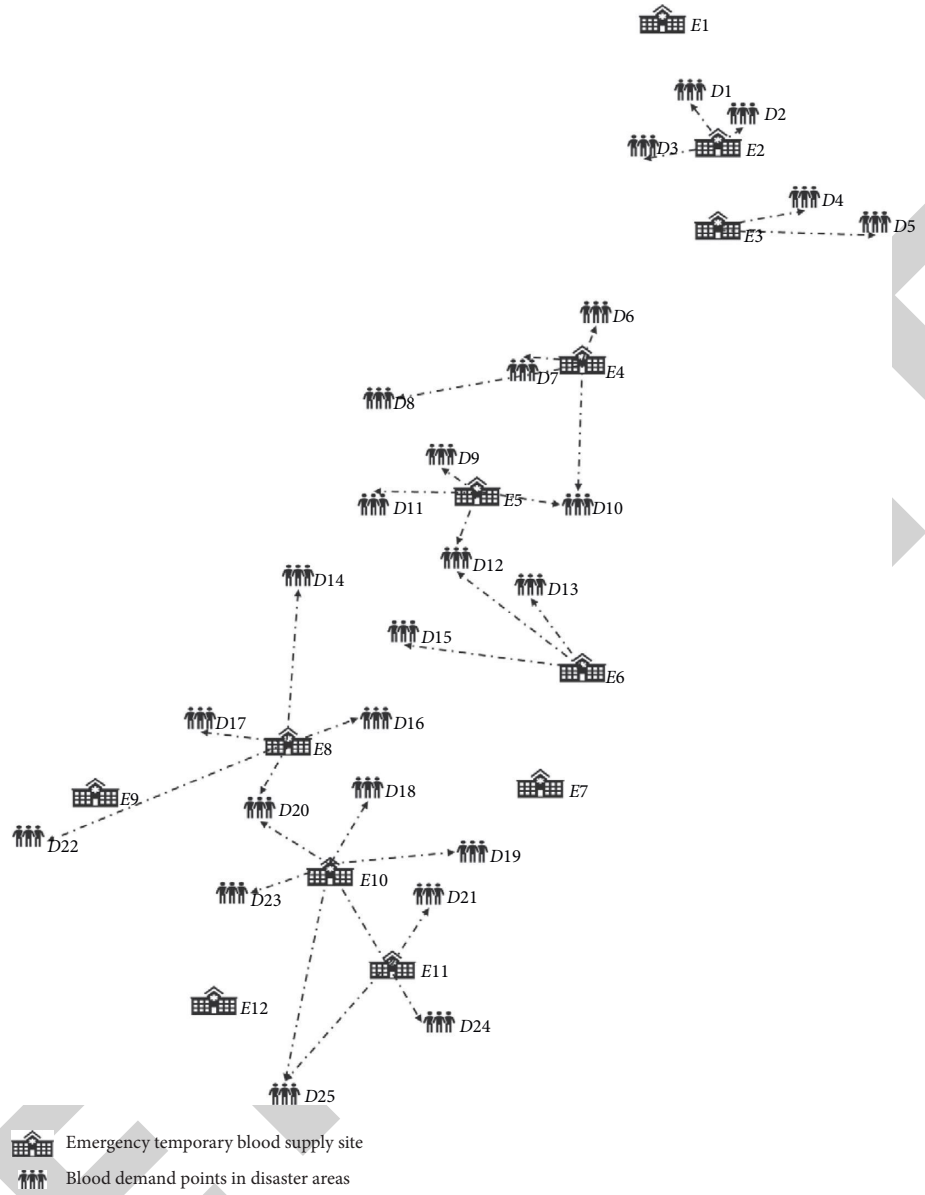

Figure 6: MIRP-box set.

chooses more emergency blood supply sites though the MIRP-ellipsoid model has good robustness, allowing decision-makers to make decisions on the basis of demand fluctuations and risk preferences. The MIRP-ellipsoid model is more suitable when there are many candidate sites and decision-makers are conservative. The impact of the demand disturbance ratio on the model cost is illustrated in Figure 10.

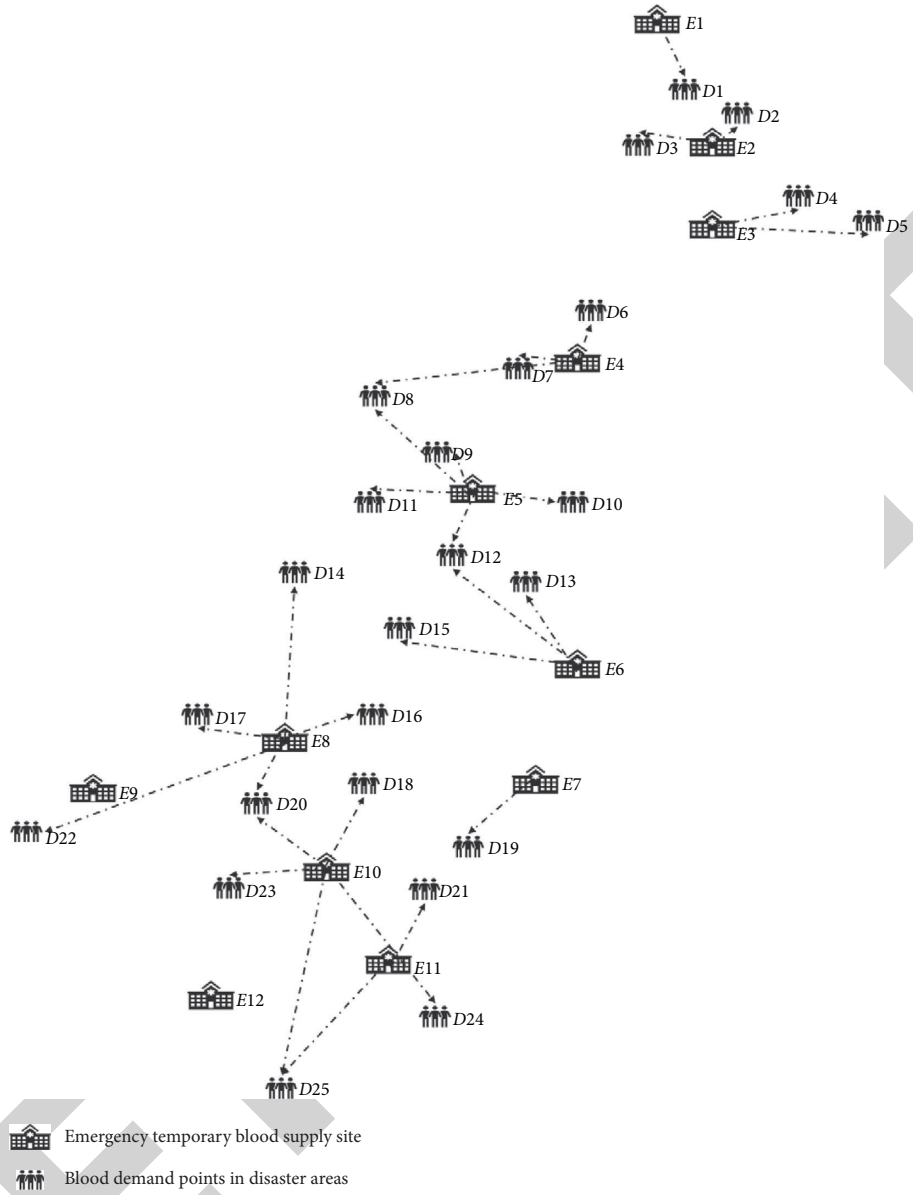

Figure 7: MIRP-polyhedron set.

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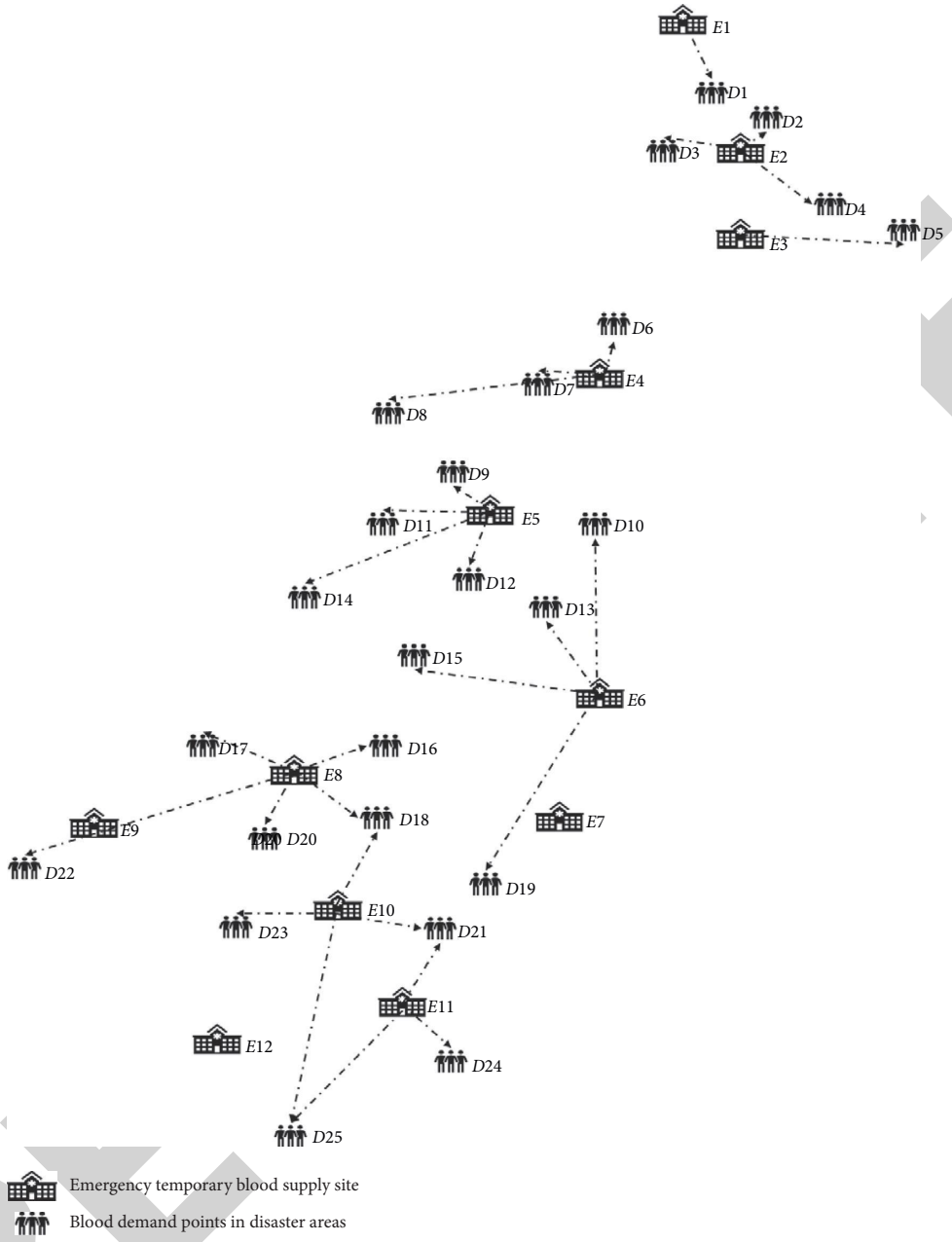

Figure 8: MIRP-ellipsoid set.

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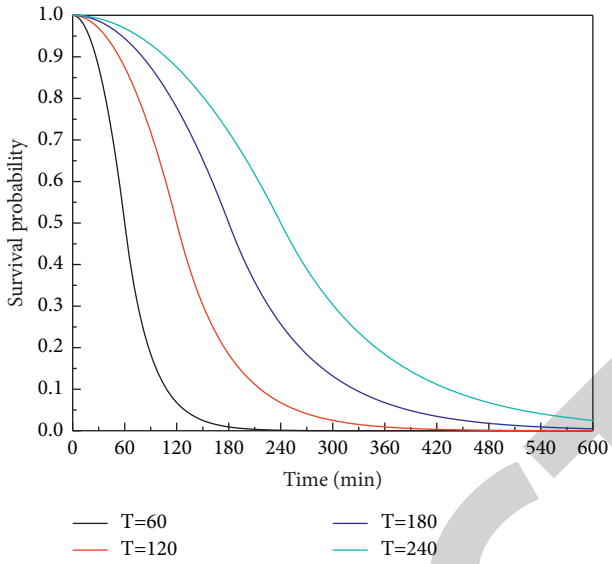

Figure 9: Function of survival probability and time.

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Table 10: Total costs at different survival probability times.

Survival probability	$T = 60$	Total costs		
		MIRP-box set	MIRP-polyhedron set	MIRP-ellipsoid set
0.5	60	3.68	3.95	3.76
0.55	57	3.74	4.17	3.95
0.6	53	3.85	4.26	4.18
0.65	50	3.96	4.37	4.27
0.7	46	4.05	4.48	4.35
0.75	42	4.18	4.54	4.41
0.8	37	4.21	4.69	4.47
0.85	32	4.38	4.85	4.56
0.9	26	4.65	5.1	4.73
0.95	19	4.97	5.45	4.82

Table 11: Impact of demand disturbance ratio on the model.

ξ	MIRP-box set		MIRP-polyhedron set		MIRP-ellipsoid set	
	Total costs	Number of selected sites	Total costs	Number of selected sites	Total costs	Number of selected sites
0.05	3.82	6	3.85	6	3.81	7
0.1	3.91	6	3.96	6	3.86	7
0.15	4.02	7	4.15	7	3.93	8
0.2	4.15	7	4.27	8	4.05	8
0.25	4.27	8	4.41	8	4.12	8
0.3	4.35	8	4.45	8	4.2	9

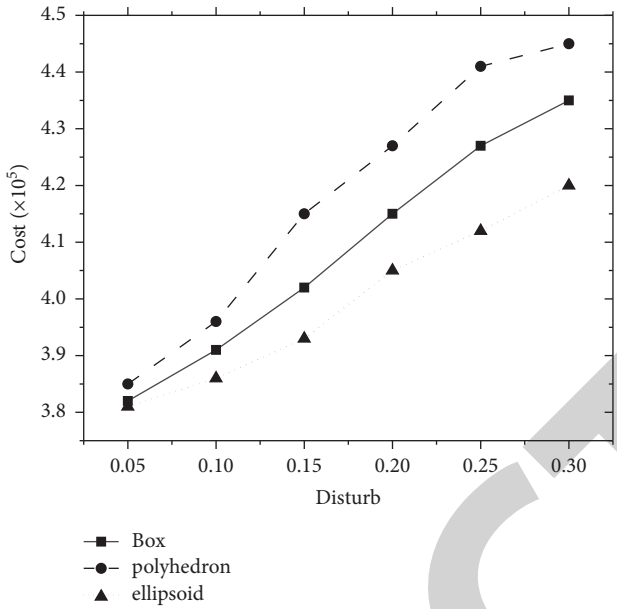

Figure 10: Impact of demand disturbance ratio on the model.

5. Conclusion

In this study, the entropy weight-TOPSIS method and robust optimization theory were applied to the site selection allocation of emergency temporary blood supply stations under uncertain time window constraints. Considering that the site selection of blood supply stations is affected by subjective factors, a systemic method was developed to solve the location-allocation problem of emergency temporary blood sites. First, the entropy weight-TOPSIS method was adopted to evaluate various subjective factors of the alternative locations. Then, the optimal one was chosen from several candidate temporary blood sites. Afterward, a minimum cost model (MILP model) determined by the nominal blood demand was proposed given the objective factors such as capital constraint, time window constraint, and survival probability constraint. An initial solution was obtained. However, decision-makers will cause waste of resources and loss of economic property when making site decisions as the demand for blood in disaster areas is uncertain after the disaster. Based on these objective factors, there is a certain deviation between the optimal solution obtained by using the deterministic method and that of practical problems. Hence, the robust optimization method was employed to transform the MILP model regarding the minimum cost for the three MIRP models based on the minimum cost of the uncertain set. Three MIRP models with uncertain demand were established. Finally, a Gurobi solver was adopted to solve the problem. In all possible cases, the maximum deviation between the solution obtained in this paper and the optimal solution was the smallest. In the uncertainty case, the risk can be avoided to the maximum extent. Although the MILP method can obtain high-quality solutions, the reliability of the results is significantly reduced due to its too ideal parameters. Among the MIRP models, the MIRP-box set model and the MIRP-polyhedron set model possess higher costs and more selected blood supply sites. Generally, the MIRP-ellipsoid set model has the smallest total cost, fewer selected candidate sites, and better robustness. Additionally, the sensitivity analysis of the demand disturbance was conducted. Besides, the time window and the survival probability are also combined in this study. With the increase in the given survival probability, the total cost increases accordingly. Furthermore, how to choose an appropriate distribution scheme within the given time to obtain the highest survival probability of victims should also be considered by decision-makers when the actual disaster occurs. The combination of the two decision-making methods in this article is a new idea, and relatively good research results have been obtained. Compared with a single decision-making method, we can consider more practical factors. This is also in line with the characteristics of emergency management decision-making because we often face the constraints of many factors in the actual decision-making process. In future research, we can also refer to this kind of thinking and take more factors into consideration. The decisions made in this way are more in line with the actual situation and more valuable.

In the location of emergency temporary blood supply sites, there are often more uncertain parameters, such as transportation cost, transportation time, and facility interruption. How to consider more uncertainties and establish related mathematical models to make the problem more in line with the actual situation is the direction that will continue to require in-depth research in the future.

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 study.

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