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Eco-Innovation in Environmental Management and Sustainability

Lead Guest Editor: Zheng Liu
Guest Editors: Wen-Long Shang and Muhammad Safdar Sial

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Retraction

Retracted: An Empirical Study on the Relationship among Mental Health, Learning Engagement, and Academic Self-Efficacy of Senior High School Students

Journal of Environmental and Public Health

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1].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.

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.

References

[1] L. Wu and C. Ma, "An Empirical Study on the Relationship among Mental Health, Learning Engagement, and Academic Self-Efficacy of Senior High School Students," *Journal of Environmental and Public Health*, vol. 2022, Article ID 4253142, 8 pages, 2022.

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Research Article

Optimization of Liner Operations and Fuel Selection considering Emission Control Areas

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The continuous expansion of shipping trade has brought about increasingly serious marine pollution problems. In the context of emission reduction in the global shipping industry, this paper focuses on the operation optimization of container ships inside and outside the emission control area (ECA). From the dual perspectives of shipowners and the general public, models in the annual operating cycle are established to study the economic and environmental benefit differences between traditional fuels, i.e., heavy fuel oil (HFO) and low-sulfur fuel oil (LSFO), and alternative fuels, i.e., liquefied natural gas (LNG) and methanol. Sensitivity analysis was carried out for the proportion of ECA and ship speed. The results show that, in the current situation of high natural gas prices, the use of HFO after the installation of scrubbers is still the most cost-effective option in the short term, followed by the use of LSFO and methanol. LNG is no longer an attractive option, while LSFO and methanol are the best options for both cost and the environment. With the tightening of ECA regulations, methanol will become the optimal choice when the ECA ratio is higher than 47%. By reducing the speed of the ship, the pollutant emission can be effectively reduced, but it will also lead to an overall decrease in profits. Considering the future "zero carbon" emission targets, slow streaming is only suitable as a short-term response measure, while switching to green power energy is a choice that is more in line with the long-term development strategy.

1. Introduction

International shipping, which serves as the main conduit for products moving across borders, transports more than 90% of goods traded globally and has made a great contribution to the growth of the world economy. However, due to the diverse, protracted, and flexible nature of ship transportation activities, the resulting large amount of air pollutants will cause serious environmental pollution in ports and coastal areas [1]. In 2018, the total emissions of the international shipping industry reached 1.056 billion tons of carbon dioxide equivalent, accounting for about 2.89% of the annual greenhouse gas emissions [2]. If no measures are taken, the total emissions are projected to increase by 50% to 250% in 2050 [3].

In this context, as the main governance bodies, various international organizations and sovereign countries have successively issued relevant policies to limit emissions from the shipping industry. The International Maritime Organization (IMO) has been dedicated to reducing carbon emissions in the global shipping sector since 2011. The most influential one is the MARPOL 73/78 Convention, which has been ratified by more than 160 countries. The convention includes six technical annexes, each of which contains detailed provisions on specific categories of pollution from ships. Among them, Annex VI imposes restrictions on the emission of pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), and greenhouse gases (GHGs) [4]. IMO has also set the Baltic Sea, the North Sea, North America, and the Caribbean Sea as emission control areas (ECAs), stipulating that from January 1, 2020, the global sulfur limit for ships' fuel oil will be reduced from 3.5% to 0.5%, while the upper limit within the ECA will be reduced from 0.5% to 0.1%, which are clearly listed in Table 1.

In addition, there is intense pressure on the shipping sector to reduce carbon emissions. With an initial strategy to

Table 1: Restrictions on sulfur content of marine fuels in MARPOL Annex VI.

Global sulfur limit	Emission control area
4.50% prior to January 1, 2012	1.50% prior to July 1, 2010
3.50% on and after January 1, 2012	1.00% on and after July 1, 2010
0.50% on and after January 1, 2020	0.10% on and after January 1, 2015

reduce greenhouse gas emissions from ships, the IMO's Marine Environment Protection Committee has ambitiously joined the global quest for a path to decarbonization, with the following vision: International shipping's carbon intensity will decrease by at least 40% by 2030 compared to 2008, with a goal of decreasing by 70% by 2050. By 2050, the greenhouse gas emissions from international shipping will be reduced by at least 50% compared with 2008 and will reach the peak of emissions [5]. At the same time, the Chinese government also formally put forward the carbon peaking and carbon neutrality goals at the United Nations General Assembly in September 2020, striving to achieve carbon peak by 2030 and carbon neutrality by 2060 [6]. Under such increasingly stringent emission requirements, it is of great significance to study the choice of fuels in the context of dividing ECA. In order to provide a reference for the decision-making of various stakeholders and to some extent encourage the sustainable development of the global shipping sector, this paper evaluates alternative fuels with both economic and environmental benefits.

The rest of the article is organized as follows: Section 2 lists the current major emission reduction measures in the shipping industry and introduces several major types of exhaust gas after-treatment technologies and common marine fuels. Section 3 establishes a mathematical model of pollutant emissions, private costs, and social costs of different fuels in the annual operating cycle from the dual perspectives of shipowners and the public. Section 4 selects a specific route to conduct an example analysis. Section 5 shows a sensitivity analysis conducted on the proportion of emission control areas and the speed of ships. Section 6 summarizes the paper and provides a set of concluding remarks.

2. Emission Reduction Measures

As the global climate continues to deteriorate, the corresponding emission reduction policies are gradually tightening, and the operations of shipping companies will be directly affected. Currently, the methods to deal with emission restrictions mainly include four types: improving technical design, optimizing operation methods, using green power energy, and introducing market mechanisms.

Technical design measures are primarily aimed at improving the hull design and optimizing the engine system, such as the bulbous bow hull design, waste heat recovery system, and exhaust gas after-treatment device so as to maximize propulsion efficiency and reduce pollutant emissions. Among them, exhaust after-treatment devices mainly include scrubbers and selective catalytic reduction (SCR) devices, which can significantly reduce NOx and SOx emissions with little impact on engine performance and fuel economy [7]. SCR technology can achieve 90%–95% NOx reduction [8, 9], making it the most efficient NOx emission reduction method, while the desulfurization efficiency of scrubbers can be as high as 97% [10], allowing ships to continue to use heavy fuel oil (HFO). Scrubbers remain an attractive emission reduction option for shipowners given the current high price trends for low-sulfur fuel oil (LSFO) and liquefied natural gas (LNG). Some studies have comparatively evaluated the economic and environmental benefits of installing after-treatment devices and fuel-switching measures on ships [11–14], as well as changes in options as factors such as fuel prices [15, 16], emission regulations [17], and government subsidies [18].

The improvement measures of the operation plan primarily include the optimization of navigation routes, speed, fuel replenishment strategy, and fleet structure. Many researchers have conducted studies from various perspectives and have extensively verified the effectiveness of the deceleration ship scheduling method [19–21].

Low-carbon fuel is an effective way to reduce the carbon footprint, and zero-carbon fuel may be the main means to achieve carbon neutrality. Alternative fuels that have been considered in the research mainly include LNG, methanol, hydrogen, ammonia, liquefied biogas, and biofuels. In addition, a series of green power systems such as fuel cells, wind energy, solar energy, and nuclear energy have been gradually developed [22]. Although the most important fuel for shipping is still HFO, more and more shipowners have chosen to install or reserve alternative fuel systems for new buildings. In the first quarter of 2022, a total of 61% of the total tonnage of newbuilding orders can use alternative fuels, of which 57% of the orders use LNG fuel and 3.4% of the orders use methanol fuel [23]. Compared with traditional marine fuels, the carbon emission reduction potential of LNG and methanol is about 20%–40% [24–26], and the overall potential of alternative fuels to reduce SOx and NOx emissions can reach 60–90% and 80–85%, respectively [9, 26]. In addition, market mechanisms such as carbon tax and carbon trading can achieve the purpose of restriction by increasing the cost of carbon emissions, which will become one of the important ways for the low-carbon governance in the future.

Based on the above research, this study comprehensively considers the newbuilding orders in recent years and the physical and chemical properties of different fuels (see Table 2), retains HFO, MGO, and VLSFO as traditional fuel options, and selects LNG and methanol as alternative fuel options. Taking the following four emission reduction measures as evaluation scenarios, a mathematical model was established innovatively from the dual perspectives of shipowners and the public, and the annual pollution emissions and costs of various fuel-powered container ships were calculated, evaluating their economic and environmental benefits.

Table 2: Physicochemical properties of different fuels.

	HFO	MGO	VLSFO	LNG	Methanol
Storage form	Liquid	Liquid	Liquid	Cryogenic liquid	Liquid
Pressure, temperature (bar, °C)	1, 25	1, 25	1, 25	1, −162	1, 25
Liquid density (kg/m^3)	986–1010	855–860	975–1010	430–470	790–792
Lower heating value (kJ/kg)	40200	42800	40500	48600	20000
Energy density (kJ/L)	39100	35800	36400	20800	18200

*Data source: summarized from the recent literature [4, 27–34].

Scenario 1: MGO (0.1%) and HFO (3.5%) are used inside and outside the ECA, respectively, and scrubbers and SCR equipment are used throughout

Scenario 2: MGO (0.1%) and VLSFO (0.5%) are used inside and outside the ECA, respectively, using SCR equipment throughout

Scenario 3: LNG is used as power throughout the process, and SCR equipment is used

Scenario 4: methanol is used as power throughout the process, and SCR equipment is used

3. Mathematical Model

The model established in this paper is based on the following assumptions:

(1) The auxiliary engine uses MGO throughout the process and does not switch with the main engine fuel.

(2) The cost of new container ships for LNG and methanol is 20% and 15% [35] higher than that of traditional fuel ships, respectively

(3) The ratio of the ship to the sailing mode and the port berthing mode is 9 : 1 [36], and the average speed in the sailing mode is 18 knots

(4) In order to meet the strict NOx emission requirements, SCR equipment is required to be used throughout the process in all scenarios

(5) The average service life of ships and SCR equipment is 25 years, and the average service life of scrubbers is 15 years [37]

3.1. Fuel Consumption. The fuel consumption of the ship is estimated by dividing it into two operating modes: sailing and port berthing. The main engine load in the sailing mode is the cubic ratio of the actual speed and the design speed, while the auxiliary engine load is generally considered to be independent of speed, and the value in this paper is 0.5 [38]. In the port berthing mode, only one auxiliary engine is reserved. The fuel consumption of the main and auxiliary engines is calculated by

$$\begin{aligned} F_M &= \mathrm{SFOC}_M \times \mathrm{EL}_M \times P_M^{\mathrm{design}} \times 10^{-6}, \\ F_A &= \mathrm{SFOC}_A \times \mathrm{EL}_A \times P_A^{\mathrm{design}} \times 10^{-6}, \end{aligned} \tag{1}$$

where F_M and F_A are the fuel consumption rate (t/h) of the main and auxiliary engines per unit time, respectively, when the ship is sailing; SFOC_M and SFOC_A are the specific fuel consumption factors (g/kWh) of the main and auxiliary engines, respectively; according to the existing research, this paper takes 196 g HFO/kWh and 216.7 g MGO/kWh, respectively [39]; EL_M and EL_A are the load factors of the main and auxiliary engines respectively; and P_M^{design} and P_A^{design} are the design rated power (kW) of the main engine and the auxiliary engine, respectively.

When using MGO and HFO inside and outside the ECA, respectively, the fuel oil consumed throughout the voyage is calculated as follows:

$$\begin{aligned} F_{\mathrm{HFO}} &= F_M \times \frac{D_O}{V}, \\ F_{\mathrm{MGO}}^M &= F_M \times \frac{D_I}{V} \times \frac{\mathrm{LHV}_{\mathrm{HFO}}}{\mathrm{LHV}_{\mathrm{MGO}}}, \\ F_{\mathrm{MGO}}^A &= n_A \times F_A \times \frac{D}{V} + \frac{1}{9} \times F_A \times \frac{D}{V}, \\ F_{\mathrm{MGO}} &= F_{\mathrm{MGO}}^M + F_{\mathrm{MGO}}^A, \end{aligned} \tag{2}$$

where F_{HFO} and F_{MGO} are the total consumption (t) of HFO and MGO, respectively; F_{MGO}^M and F_{MGO}^A are the MGO consumption (t) of the main and auxiliary engines, respectively, and the sum of the two is the total consumption of MGO; V_d is the ship's design speed and V is the actual sailing speed (kn); D_I and D_O are the sailing distance (n mile) of the ship inside and outside the ECA, respectively, while D is the total sailing distance (n mile); n_A is the number of auxiliary engines; and $\mathrm{LHV}_{\mathrm{HFO}}$ and $\mathrm{LHV}_{\mathrm{MGO}}$ are the low heating value (kJ/kg) of HFO and MGO, respectively, which can be used to convert the mass of different fuels under the same heat release.

Similarly, when VLSFO is used outside the ECA, the MGO consumption remains unchanged, and the fuel consumption of VLSFO can be expressed as

$$F_{\mathrm{VLS}} = F_{\mathrm{HFO}} \times \frac{\mathrm{LHV}_{\mathrm{HFO}}}{\mathrm{LHV}_{\mathrm{VLS}}}. \tag{3}$$

When using alternative fuels such as LNG or methanol, MGO consumed by the auxiliary engines remains unchanged, and the fuel consumption of the main engine can be expressed as

$$F_{\mathrm{ALT}} = F_{\mathrm{HFO}} \times \frac{\mathrm{LHV}_{\mathrm{HFO}}}{\mathrm{LHV}_{\mathrm{ALT}}} + F_{\mathrm{MGO}}^{M} \times \frac{\mathrm{LHV}_{\mathrm{MGO}}}{\mathrm{LHV}_{\mathrm{ALT}}}, \quad (4)$$

where F_{VLS} and F_{ALT} are the consumption of VLSFO and alternative fuel (LNG or methanol), respectively (t), and $\mathrm{LHV}_{\mathrm{VLS}}$ and $\mathrm{LHV}_{\mathrm{ALT}}$ are the low heating value (kJ/kg) of the corresponding fuel.

3.2. Pollutant Emissions. The ten pollutant emissions reported by the IMO include CO_2, CH_4, N_2O, CO, SOx, NOx, PM, NMVOC, and BC [2]. This paper selects three main greenhouse gases CO_2, CH_4, and N_2O and three atmospheric pollutants SOx, NOx, and PM as emissions for quantitative evaluation. Pollutant emissions are represented by the product of fuel consumption and the corresponding emission factor, namely,

$$E_{ij} = F_j \times \mathrm{LHV}_j \times \mathrm{EF}_i \times 10^{-6}, \quad (5)$$

where E_{ij} is the mass (t) of the emission i produced by the combustion of the fuel j, F_j is the consumption (t) of the fuel j, LHV_j is the low heating value of the fuel j (kJ/kg), and EF_{ij} is the emission factor (g/MJ) for the emission i of the fuel j. This paper assumes that the use of SCR and scrubbers can reduce NOx and SOx emissions by 90% and 95%, respectively. In addition, due to the limitations of current research on alternative fuels, some emission factors for methanol are not available. Since methanol does not contain nitrogen oxides and sulfur, we assumed that this part of the emissions is zero in the subsequent calculation. The emission factors for various fuels are shown in Table 3.

3.3. Annual Cost and Profit. The number of ships operating on a route in a year can be expressed as

$$n = \left[\frac{(365 \times 24 \times 9 \times V)}{10} \times D \right]_{\mathrm{Floor}}, \quad (6)$$

where the mathematical symbol $[]_{\mathrm{Floor}}$ means the floor function. The costs involved in the operation of ships mainly include three parts: capital cost, operating cost, and fuel cost. The capital cost mainly includes the construction and installation cost of the new building and related equipment. Generally, the depreciation method of the average service life of the ship is adopted; i.e., the total investment cost is divided by the service life. The operating costs are the costs incurred by shipping companies to maintain normal shipping services, including equipment operating costs, crew wages, maintenance costs, and insurance and management fees, and port fees, loading and unloading fees, anchoring fees, etc., are generally 15%–50% of the capital cost [45, 46], and the compromise value in this paper is 30%. The fuel cost is affected by various conditions such as ship size, speed, and fuel and can be expressed as the product of fuel consumption, price, and number of sailings. For shipowners, the choice of an emission reduction plan mainly depends on the trade-off between capital expenditure (CAPEX) and operating expenditure (OPEX) [47].

Table 3: Emission factors for different fuels.

	HFO	MGO	VLSFO	LNG	Methanol
CO_2	77	75	74	54	69
CH_4	0.0015	0.00142	0.00143	0.562	N/A
N_2O	0.004	0.003738	0.00357	0.00463	N/A
SOx	1.277	0.0467	0.2347	0.00056	N/A
NOx	1.532	0.483	0.483	0.1611	0.28
PM	0.1811	0.0227	0.1014	0.0037	0.0043

*Data source: summarized from the recent literature [10, 28, 40–44]. **N/A means data for that indicator are not available.

The private cost and its subdivision cost ($) can be calculated as

$$\begin{aligned} \mathrm{PC} &= C_{\mathrm{FUEL}} + C_{\mathrm{CAPEX}} + C_{\mathrm{OPEX}}, \\ C_{\mathrm{FUEL}} &= \left(\sum_i F \times P \right) \times n, \\ C_{\mathrm{CAPEX}} &= \left(\frac{C_{\mathrm{ship}} + C_{\mathrm{SCR}}}{25} + i \times \frac{C_{\mathrm{scrubber}}}{15} \right), \\ C_{\mathrm{OPEX}} &= 30\% \times C_{\mathrm{CAPEX}} + (8\% + s \times 2\%) \times C_{\mathrm{FUEL}}, \end{aligned} \quad (7)$$

where PC is the private cost of the shipping company, C_{FUEL} is the fuel cost, and C_{CAPEX} and C_{OPEX} are the capital cost and operating cost, respectively, which can be seen in Table 4; C_{ship} and C_{scrubber} are the investment cost of the new building and scrubber, respectively; F and P are the annual consumption (t) and price of the fuel ($/t); s is a 0-1 variable; if 0 is taken, it means that the scrubber does not need to be installed in this scenario, and if 1 is taken, it means that the scrubber needs to be installed.

The net profit of a single voyage can be expressed as the difference between the total revenue and the total private cost:

$$P = n \times r \times \mathrm{CL} \times \mathrm{FR} - C, \quad (8)$$

where n is the number of voyages in one year as required above, CL is the container ship's load capacity (TEU), and r is the utilization rate of the space. In the situation where it is difficult to get one cabin, this paper takes the value of 1. According to the statistics of USDA [50], we take the average freight for all kinds (FAK) in the first half of this year as 1270 $/TEU.

3.4. Social Cost. Under the same conditions, shipowners and the public tend to prefer different optimal emission reduction options. Driven by economic interests, shipowners usually only pay attention to the private cost when they choose schemes, and their goal is to maximize the total profits on the basis of meeting the minimum emission requirements, while for the public, they are more concerned about whether the option reaches the best balance between economy and environment. Therefore, they need to consider the social cost of emissions, which can be expressed as the

Table 4: CAPEX and OPEX for the scrubber and SCR equipment.

	CAPEX	OPEX
Scrubber (m$)	2.5–3 (open-loop) 4.5–5 (closed-loop)	1–3% of fuel cost
SCR ($/kW)	40–135	7–10% of fuel cost

*Data source: summarized from the literature [48, 49].

sum of the emissions of various pollutants multiplied by the corresponding cost factors:

$$SC = \sum_j \sum_i E_{ij} \times CF_{ij}, \quad (9)$$

where SC is the social cost ($), E_{ij} is the emission i of the fuel j calculated above (t), and CF_{ij} is the social cost factor for the emission i of the fuel j ($/t). The social cost factors of different pollutants are shown in Table 5.

4. Case Analysis

4.1. Parameter Value. This paper selects the Northeast Asia-Australia route (A3N) operated by COSCO Shipping as an example. The route departs from Yokohama Port, goes through Osaka, Busan, Qingdao, Shanghai, and Kaohsiung Port, stops at Melbourne Port, and returns via Sydney Port and Brisbane Port and finally returns to the starting port of Yokohama Port, completing a round-trip voyage with a total sailing distance of about 13740 n miles. This paper only considers the countries and regions that have clearly divided the ECA; based on the longitude and latitude of the port and the reference point along the ECA, the total sailing distance within the ECA is calculated to be about 720 n miles. According to the latest shipping schedule released by COSCO Shipping, it can be seen that the operating ships of this route are post-Panamax container ships. The relevant parameters are shown in Table 6.

In 2020, the average price of LNG will remain around 400$/t, which is about 80% of the price of MGO fuel. Compared with expensive low-sulfur fuel, LNG has great price advantage and is considered to be a better emission reduction solution than other fuels in terms of economic and environmental effect [35, 43]. However, since the second half of 2021, the market price of natural gas has risen rapidly and the supply has become tight, and the conflict between Russia and Ukraine in 2022 further exacerbated this trend. Within a year and a half, the average price of LNG has risen to four times the original price, and the peak price even reached more than 3,000 $/t. At these prices, it is worth considering whether LNG ships are still a credible option to reduce emissions.

Based on the statistics of Ship & Bunker, this paper takes the average price of HFO, VLSFO, MGO, and LNG in Rotterdam Port from January to June 2022 as the benchmark price, which are 664, 884, 1120, and 1783 $/t, respectively; based on the statistical data of Methanex, this paper takes the mean value of the nondiscounted reference price of methanol in the same time period as the benchmark price, i.e., 630 $/t, and substitutes it into the mathematical model established above.

Table 5: Social cost factors of different polluting gases [4].

Gas	Social cost factors $/T
CO_2	56.6
CH_4	1750
N_2O	15000
SO_2	24900
NOx	34700
PM	79500

4.2. Pollutant Emissions. As can be seen from Figure 1, before the application of exhaust after-treatment equipment, the emission of pollutants from alternative fuels is significantly lower than that of traditional fuels. However, it is worth noting that when LNG is used as fuel, there is serious methane leakage, and the methane emission can be nearly 300 times that of ordinary fuel oil and more than 1000 times that of alternative clean fuels. Therefore, LNG may not be an effective scheme to mitigate climate change under comprehensive consideration.

Compared with HFO, alternative fuels can reduce SOx emissions by more than 99%, but the CO_2 emissions of LNG and methanol do not have obvious advantages compared with traditional fuels. After switching to LNG and methanol, CO_2 emissions can only be reduced by about 21.7% and 7.5%, respectively. After the application of scrubbers and SCR equipment, the SOx and NOx emission levels of traditional fuels are reduced to the emission range of alternative fuels, which is an effective emission reduction measure. Therefore, for shipowners, the choice of the best emission reduction scheme will depend on the trade-off between the installation and operating costs of different emission reduction equipment and the cost of switching fuel.

4.3. Cost. For shipowners, when making the choice of the best emission reduction scheme, the ultimate reference is the private cost. It can be seen from Figure 2 that, due to the absolute advantage of traditional fuel oil in price, the use of MGO and HFO inside and outside the ECA, respectively, is still the best choice for shipowners under the condition that exhaust after-treatment equipment is installed to meet the emission requirements, followed by the use of MGO and VLSFO inside and outside the ECA and the use of methanol. The skyrocketing price of LNG makes it no longer an attractive option.

When making decisions, the public should comprehensively consider private costs and social costs and make choices that have both economic and environmental benefits. It can be seen that the best solution at present is to use MGO and VLSFO inside and outside the ECA, followed by methanol as power. LNG can gain cost advantages over VLSFO only when the price drops by more than 40% and can obtain comprehensive advantages over methanol and VLSFO when the price drops by about 14 and 30%, respectively, which may not be possible in the short term.

Table 6: Sample vessel and engine parameters.

Sample ship				
Builder	TEU	DWT	Speed (kn)	Price (m$)
New Times SB	7000	81689	20	75.13
Main engine				
Model	Type	Bore/stroke	Power (kW)	Speed (rpm)
MAN B. & W. 7G80ME-C10.5	2-stroke 7-cyl	800 mm × 3720 mm	26280	72
Auxiliary engine				
Model	Type	Bore/stroke	Power ∗ number (kW)	rpm
HHI-EMD (HiMSEN) 8H32/40	4-stroke 8-cyl	320 mm × 400 mm	4000 ∗ 3	720

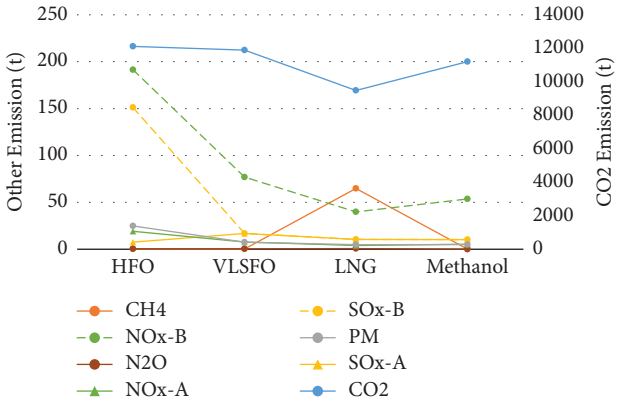

Figure 1: Pollutant emissions of different options.

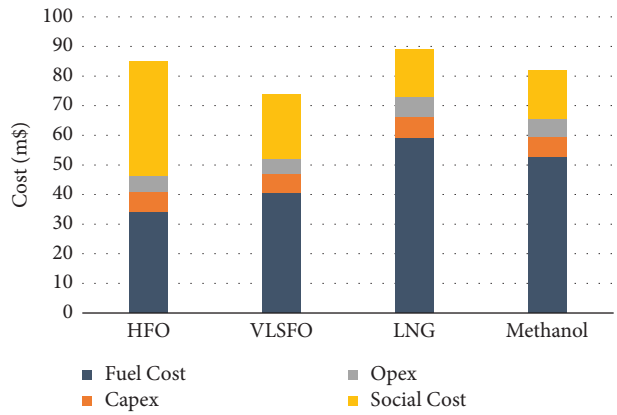

Figure 2: Cost of container ships under different options.

5. Sensitivity Analysis

5.1. Ratio of ECA. More and more countries and regions have begun to divide the ECA and expand the scope of the existing ECA. With the increasingly tightened emission regulations, it is necessary to consider the impact of the proportion of ECA on emission reduction options. This paper calculates the changes in pollutant emissions, costs, and benefits when the time proportion of ships sailing in ECA increases from 2% to 20% in increments of 2%. Since both LNG and methanol are used in the whole process, the ratio of ECA has no effect on them. Meanwhile, the change in the ECA proportion has no impact on the single voyage time of the ship, so the total operating income remains the same, and the scheme with the lowest private cost is the scheme with the highest profit.

In terms of private costs, traditional fuel has great advantages. As shown in Figure 3, the use of MGO and HFO inside and outside the ECA, respectively, is the best choice, regardless of the proportion of the ECA. But after considering the social cost, when the proportion of the ECA is less than 46%, the best choice is VLSFO, methanol, and HFO in turn. When it is higher than 47%, methanol will be the best choice, followed by VLSFO and HFO, but when it rises to 58%, HFO will become better than VLSFO. Only when the proportion of the ECA is greater than 82%, LNG can have certain advantages over VLSFO, but the cost is still far higher than that of methanol. However, if VLSFO ships are also equipped with scrubbers, the environmental benefits will far exceed the investment and operating costs of scrubbers, and it will always be the best choice for shipowners when the ECA ratio is not more than 85%.

Extending this conclusion to other ships, it can be seen that if a container ship of the same size carries out short-range ocean transportation, when the proportion of its sailing in ECA exceeds 46%, it can be considered switching to use methanol as power. When the proportion is less than 85%, using VLSFO on the basis of adding scrubbers will bring the greatest profit.

5.2. Speed. In order to see the impact of speed on operating costs and emissions more intuitively, the range of speed is set to be 12–20 knots, and the pollutant emissions and costs are calculated separately. As the speed decreases, the load of the ship's engine gradually decreases, the corresponding fuel consumption and the emission of various pollutants will be reduced, and the overall fuel cost and operating cost of the corresponding solutions will drop. Under the condition of constant investment cost, both private and social costs show a decreasing trend. However, due to the decrease in speed, the operating voyages in one year will be reduced, and the annual profit at different speeds is shown in Figure 4.

Under the balance between the reduction of voyage benefits and the reduction of private costs, although the overall profit shows a gradual downward trend, there is an optimal speed in each speed segment, which enables the shipowner to obtain the highest profit, which is about 18.9

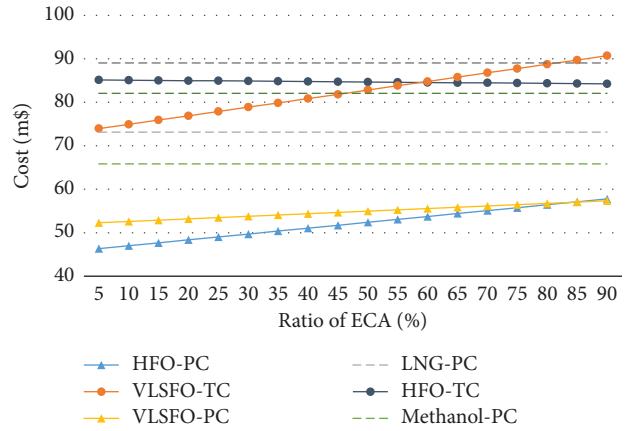

Figure 3: Private cost and total cost under different ratios of ECA.

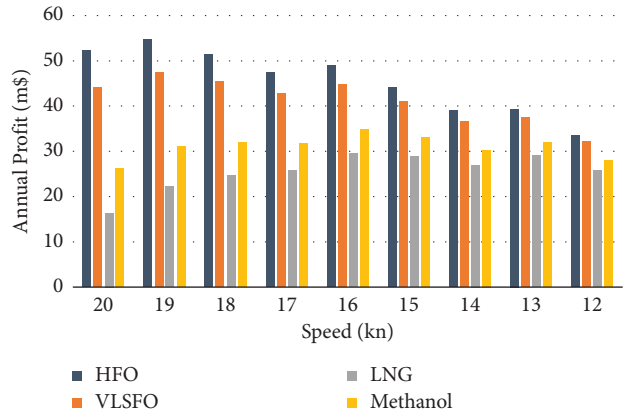

Figure 4: Annual profit at different speeds.

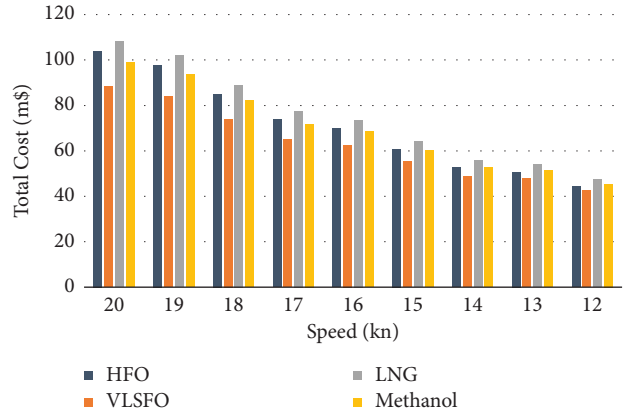

Figure 5: Total cost at different speeds.

knots, 15.7 knots, and 12.6 knots, of which 18.9 knots can be used to maximize profits.

For the public, after taking the emission cost into consideration, it can be seen from Figure 5 that VLSFO is the most economical and environmentally beneficial choice at different speeds. When the speed is greater than 14 knots, methanol is the second-best choice; but with the decrease in speed, the price advantage of HFO will be more prominent, and its total cost will be lower than that of methanol.

6. Conclusion

Shipowners must consider different emission reduction solutions when placing orders for new ships in order to comply with increasingly stringent international conventions and regulations, including continuing to use HFO after adding scrubbers and switching to low-sulfur fuel oil and cleaner alternative fuels such as LNG and methanol.

This paper assesses the pollutant emissions of various fuels in the annual operation cycle of ships, taking into account both the economic and environmental benefits. A private and social cost model was developed to assess the best mitigation options in the context of current fuel prices. The study takes into account how compliance decisions made by shipowners and the general public alter under various ECA ratios and speed situations, and the following results are drawn:

(1) VLSFO, LNG, and methanol can effectively reduce SOx emissions by more than 90% compared with HFO, but LSFO and methanol can only reduce CO_2 emissions by 2% and 8%, respectively, and have no obvious advantages in CO_2 emission reduction.

(2) The most economical option at the moment is to continue using HFO after installing scrubbers, but converting to LSFO will be preferable when taking into account the social cost of emissions.

(3) When the ECA ratio is greater than 47%, methanol will become the best choice for both the environment and the cost. At the same time, reducing the speed of sailing is indeed one of the effective measures to reduce emissions in the short term, although it will reduce the annual profit.

The service life of ships is often between 20 and 30 years, and the choice of a power system will have a long-term impact on the future environmental climate. Considering the number of new ship orders, we focused on container ships as research objects, but similar methods can be extended to other ship types, such as dry bulk carriers and oil tankers, providing useful reference for various stakeholders to make dynamic decisions through horizontal comparisons, reduce cost, and maintain market competitiveness in the context of tightening environmental policies and changing fuel prices. In addition, it should be pointed out that this paper substitutes the historical average data of fuel prices into the calculation, but considering the instantaneous changes in fuel prices, it will be possible to update fuel prices, fuel consumption, and other parameters in real time and expand the existing model into a dynamic decision-making model in the next step.

When it comes to choosing a long-term sustainable alternative fuel, there is no single answer as to which is the best choice. It is determined by a number of elements, including various operation modes, the scope of ECA laws, and the principal authority making the decision. However, it

is apparent that the transition to cleaner and more efficient fuels will be an unavoidable trend 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.

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Research Article

Timing Decision of Low-Carbon Technology Investment Adoption by High Energy Consuming Enterprises under Carbon Trading and Subsidies

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Although government subsidies provide some financial support for firms to invest in low-carbon technologies, carbon price fluctuations bring greater uncertainty risks to firms' investment. The paper constructs a real option model to analyze the timing of low-carbon technology adoption between upstream dominant high energy consuming firms and downstream retailers in case of collaborative decision-making and Stackelberg game, and a numerical simulation is conducted to analyze factors affecting the timing for low-carbon investment. We find that the proportion of cost subsidies, carbon price volatility, carbon emission reduction rate, and cost-sharing ratio will affect firms to choose the optimal investment opportunity.

1. Introduction

High energy consuming enterprises have become the main carbon emission units. Because they consume more fossil energy, they bring higher carbon emissions, but have higher emission reduction potential and efficiency. The innovation and adoption of low-carbon technology by high energy consuming enterprises is an important way to achieve China's "carbon peaking and carbon neutrality" goal, and the carbon emission trading market established in China can have an impact and can promote enterprises to adopt low-carbon technology through the role of market mechanism. In recent years, China's carbon price fluctuates frequently, which brings great uncertainty risk to enterprises' low-carbon technology investment, and enterprises will wait to find the best investment opportunity. At the same time, the government has issued a series of subsidies and preferential policies to mobilize the enthusiasm of high energy consuming enterprises to invest in low-carbon technologies and accelerate the investment process of enterprises. Therefore, it is of great significance to evaluate the risks and investment opportunities of low-carbon technology adoption by high energy consuming enterprises under carbon trading and government subsidy policies.

The concept of low-carbon development has permeated all walks of life. Many scholars have studied the management of carbon emissions and the decision-making of emission reduction in different industries and fields. Bi et al. built an incentive mechanism based on a unified queueing, neural network model to enhance the energy efficiency of the urban transportation network [1]. Liu et al. has built an integer scheduling model to optimize the transportation path for the problem of high energy consumption in the field of cold chain fresh logistics [2]. Liu et al. discussed the low-carbon decision-making of automotive parts supply chain based on the smart city construction context [3]. In order to improve the robustness of urban road network and energy efficiency, Shang et al. analyze the topological characteristics of urban road network, a new method for measuring the robustness of road interruption was proposed [4, 5]. With the introduction of complex network, Shang et al. has discussed the impact of COVID-19 pandemic on user behavior and environmental benefits of shared bicycles through big data [6]. Most of the existing literature examines the impact

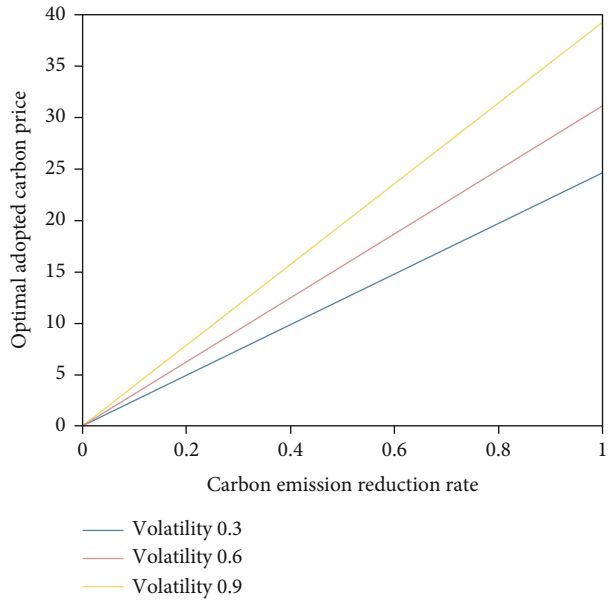

Figure 1: Impact of carbon emission rate on optimal adopted carbon price.

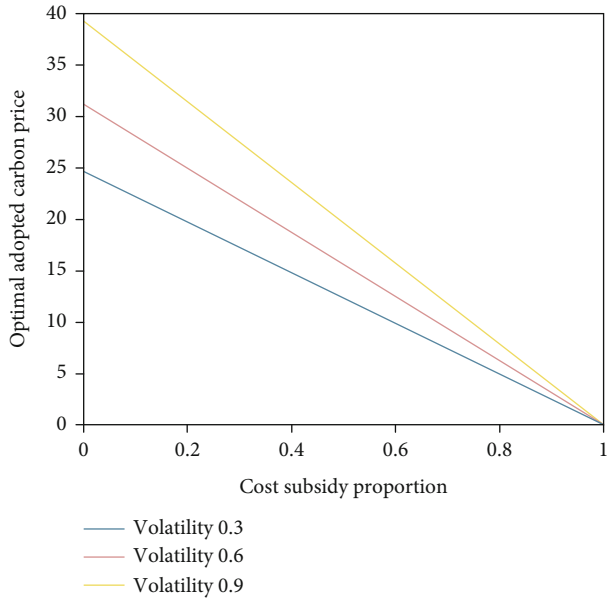

Figure 2: Impact of cost subsidy proportion on the optimal adopted carbon price.

of carbon trading and carbon taxes on carbon reduction investments from the perspective of government policy. Richstein et al. developed carbon price difference (ccfds) contracts to reduce the risk of investment in political and market uncertainty given the higher operating and investment costs faced by low-carbon investment in the steel industry and the insufficient and uncertain carbon price [7]. Hasan et al. exemplify warehouse operation and transportation logistics system as emission sources, and develop three models to optimize carbon tax, quota and transaction, inventory level, and technology investment decision under strict regulations on carbon restrictions [8]. Liu et al. investigated the impact of government regulation policies on the stabilization strategy of reducing emissions in the supply chain of green products and medical recycling by building an evolutionary game model [9, 10]. Yan et al. took power companies as an example to discuss the impact of different strategic combinations of carbon quota and trading mechanism, the standard policy of renewable energy portfolio [11]. Lu et al., taking carbon cap trading and carbon offset policy into account, constructed a Stackelberg game model, studied the optimal solution between supplier and buyer, and analyzed its influencing factors [12]. Zhang et al., taking iron and steel companies as an example, an evolutionary game model is constructed to discuss the strategic choice between large and medium enterprises under government subsidy and carbon trading mechanism [13]. Comparison of different emission reduction strategies by Liu et al. found it difficult to achieve the coordination of supply chain benefits by relying solely on carbon taxation policies [14]. Yi et al. considered consumers' low-carbon preferences and considered the effect of green subsidies and emission taxes on improving green innovation in the supply chain consisting of producers and retailers [15]. Bai et al. established two optimization models of technology investment with and without manufacturer-led guidance and studied the impact of contribution in maintainability innovation on supply chain finance and natural execution [16]. Taking OECD countries as an example, Ganda et al. researched on the role of investments in innovation and technology in improving environmental quality [17]. Liu et al. focused on agricultural carbon emissions and discussed the impact of carbon taxes and investment cooperation on decisions to reduce emissions from agricultural supply chains through game modeling [18]. Some researchers have also used the real options model to study investment decision-making in carbon emission reduction. Liu et al., to evaluate the investment value and timing based on the impact of innovation learning, developed a new model of real option investment decision-making and proposed a two-figure component-based innovation learning curve method to anticipate the end of the toll taken on each component [19]. Compernolle et al. built a dynamic real options model to analyze the impact of positively correlated price uncertainty on the decision time of investment [20].

Most existing studies have investigated supply chain coordination and investment decision-making in carbon emission reduction from the perspective of carbon trading, carbon taxes, and consumer preference for low-carbon emissions. Few studies, however, have investigated the timing of low-carbon technology investment in both scenarios of collaborative decision-making and Stackelberg game from the perspective of carbon trading and the government subsidy composite politics. Thus, this paper studies the decision-making of low-carbon technology investment of high energy consuming enterprises under the dual carbon trading and government subsidy policies, solves the enterprise investment threshold driven by government policies, and analyzes the impact of carbon price fluctuations and the proportion

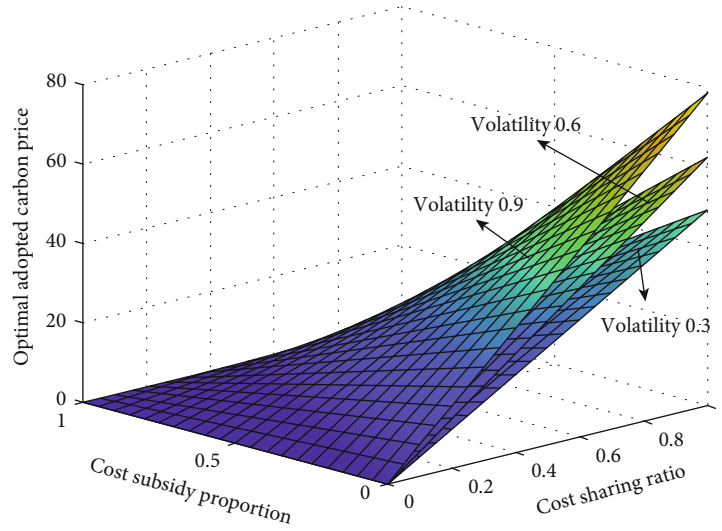

Figure 3: Impact of cost subsidy proportion and cost sharing ratio on retailers' optimal adopted carbon price.

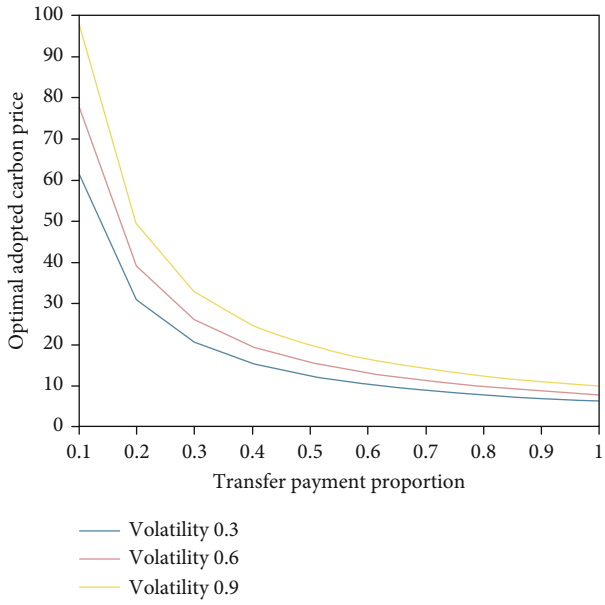

Figure 4: Impact of transfer payment ratio on retailers' optimal adoption of carbon price.

of government subsidies on the timing of low-carbon technology investment, so as to provide a basis for low-carbon investment of enterprises and to provide the government with a reference for formulating a more focused whole.

2. Problem Description and Basic Assumptions

Hypothesis 1. High energy consuming enterprises only make one product, and the product sales volume reaches the annual maximum production capacity of the enterprise is Q (constant). The adoption of low-carbon technology has no impact on production efficiency, this investment is irreversible, and the enterprise's risk appetite is neutral. After adopting low-carbon technology, high energy consuming enterprises will immediately obtain carbon emission reduction amount and hold it for a long time and can invest at the earliest at moment $t = 0$.

Hypothesis 2. Suppose that the carbon emission per unit item before the adoption of low-carbon technology is e_0, the carbon emission per unit product after the adoption of low-carbon technology is e, the emission reduction rate of low-carbon technology is $\eta = e_0 - e/e_0$, and the one-time investment cost of carbon emission reduction technology for high energy consuming enterprises is $1/2\lambda\eta^2$, of which λ is the cost coefficient of high energy consuming enterprises adopting low-carbon technology and on behalf of the cost level of low-carbon technology.

Hypothesis 3. Suppose that the price of carbon emission right at time t is $p_c(t)$, and it obeys geometric Brownian motion, which satisfies

$$d_{p_c(t)} = \alpha p_c(t)\mathrm{d}t + \beta p_c(t) d_{z(t)}. \quad (1)$$

Among them, $\alpha > 0$ and $\beta > 0$ are the drift term and variance, the drift coefficient is the expected growth rate, and meets $0 \le \alpha < r$ (r is the risk-free interest rate, which is measured by the average return rate of the capital market), and β the variance represents the carbon price fluctuation; $d_{z(t)}$ is the increment of the standard Wiener process, and there is $d_{z(t)} \sim N(0, d_t)$ [21]; dt is the time interval of infinite approaching zero.

Hypothesis 4. The government gives a certain cost subsidy to high energy consuming enterprises for low-carbon technology investment, and the subsidy proportion is μ.

3. Model Construction and Optimal Adoption Timing Analysis

3.1. Collaborative Decision Analysis

3.1.1. Model Building. Suppose that high energy consuming enterprises adopt low-carbon technology at time t, and the adoption of low-carbon technology is an investment that can benefit for a long time. Considering that the random fluctuation of carbon commerce value can manufacture uncertainty risk, real choices are often wont to evaluate the expectation of carbon emission reductions within the carbon commerce market. The expected net income of enterprises after adopting emission reduction technology is

$$W(t) = E\left[\int_t^{\infty} p(s)\eta e_0 Q e^{-r(s-t)}\mathrm{d}s - \frac{1-\mu}{2}\lambda\eta^2\right] = \frac{\eta e_0 Q p(t)}{r-\alpha} - \frac{1-\mu}{2}\lambda\eta^2. \tag{2}$$

3.1.2. Analysis of Emission Reduction Technology Adoption Threshold. The risk attitude of the enterprise is risk neutral. Therefore, the adoption of emission reduction technology will be considered only when it is profitable; that is, when the expected investment income of high energy consuming enterprises adopting emission reduction technology is positive, then Equation (2) must be satisfied that is greater than or equal to 0; that is, when $p(t) \geq (1-\mu)(r-\alpha)\lambda\eta/2e_0Q$, it is profitable for high energy consuming enterprises to invest in emission reduction technology, so that p^* is the threshold carbon price for high energy consuming enterprises to adopt emission reduction technology, then

$$p^* = \frac{(1-\mu)(r-\alpha)\lambda\eta}{2e_0Q}. \tag{3}$$

3.1.3. Analysis of Investment Opportunity of Low-Carbon Technology. Before adopting low-carbon technologies, high energy consuming enterprises hold investment options and do not generate carbon trading gains during the waiting period. High energy consuming enterprises will choose the time of adoption according to the principle of maximizing the expected return of the adoption of low-carbon technologies; that is, they will stop waiting for the implementation of investment actions until the trading price of carbon emission rights reaches the adoption threshold for the first time at a certain time. Therefore, this problem is an optimal stopping time problem.

Before adopting low-carbon technology, for supply chain enterprises, the adoption opportunity of low-carbon technology can be regarded as a real option equity owned by them, which is determined by the change profit and loss of option value of carbon emission reduction obtained by adopting low-carbon technology. In the waiting range, the change of option value satisfies Bellman equation:$\mathrm{rWdt} = E[\mathrm{dW}]$.

Combined with Ito lemma, the expected value function of call option satisfies the differential equation: $(1/2)\beta^2p^2W'' + (r-\alpha)pW' - rW = 0$.

The general solution of the above formula is $W = C_1p^{\zeta_1} + C_2p^{\zeta_2}$, where ζ_1 and ζ_2 are constants.

It can be deduced from the conclusion of Dixit and pingdyck: $C_2 = 0$,$\zeta_1 = (1/2) - (\alpha/\beta^2) + \sqrt{((\alpha/\beta^2) - (1/2))^2 + 2r/\beta^2} > 1$.

Assuming that high energy consuming enterprises stop waiting for investment actions at time T, the expected benefits of adopting low-carbon technologies can be maximized. Let W_T represents the option value function of the income from emission reduction technology adoption, then

$$W_T = \max_{T\geq 0} E\left[\left(\frac{\eta e_0 Q p(t)}{i-\mu} - \frac{1-\mu}{2}\lambda\eta^2\right)e^{-r(t-T)}\right]. \tag{4}$$

From $E[(\eta e_0 Qp(t)/r-\alpha) - (1-\mu/2)\lambda\eta^2]e^{-r(t-T)} = ((\eta e_0 Qp_T/r-\alpha) - (1-\mu/2)\lambda\eta^2)(p(t)/p_T)^{\zeta}$,order $(\partial/\partial p_T)((\eta e_0 Qp_T/r-\alpha) - (1-\mu/2)\lambda\eta^2)(p(t)/p_T)^{\zeta} = 0$, and the optimal adopted carbon price of emission reduction technology is

$$p_T^{**} = \frac{\zeta}{\zeta-1}\frac{(1-\mu)\lambda\eta}{2e_0Q}(r-\alpha). \tag{5}$$

By observing Equations (3) and (5), it can be found that the optimal adopted carbon price p_T^{**} is more than the threshold carbon price p^* by a factor of $(\zeta/\zeta-1) > 1$, indicating that the threshold carbon price is the carbon price level at the breakeven point of adopting emission reduction technology, and the carbon price level of the best investment opportunity of supply chain enterprises is higher than the threshold carbon price.

Inference 1: the threshold carbon price of emission reduction technology p_T^{**} is in direct proportion to the carbon emission reduction rate η, and increases with the increase of carbon emission reduction rate η, indicating that with the increase of carbon emission reduction rate, the threshold carbon price of high- and low-carbon technology adoption will be pushed, delaying the adoption of emission reduction technology. On the contrary, the lower the carbon emission reduction rate is, the lower the threshold carbon price will be. Supply chain enterprises choose to adopt emission reduction technologies, which can speed up the adoption process.

Inference 2: the threshold carbon price p_T^{**} is inversely proportional to the cost subsidy ratio μ, and decreases with the increase of the cost subsidy ratio μ, indicating that if the government increases the cost subsidy ratio, it will reduce the investment threshold for supply chain enterprises to adopt emission reduction technologies and accelerate the process of emission reduction technology adoption. When the proportion of government cost subsidies is high, it eases some of the financial pressure on enterprises, and is conducive to enhancing the willingness of enterprises to adopt low-carbon technologies, thereby accelerating the adoption process. When the proportion of cost subsidies is low, emission reduction technology investment is difficult to receive returns in the short term, and requires more funds. Therefore, enterprises will delay investment and wait for the opportunity for higher returns from the adoption of emission reduction technologies.

In the case of collaborative decision-making, the option value W of the supply chain adopting emission reduction

technology can be expressed as

$$W(p(t)) = \begin{cases} \left(\frac{\eta e_0 Q p_T^{**}}{r-\alpha} - \frac{1-\mu}{2}\lambda\eta^2\right)\left(\frac{p(t)}{p_T^{**}}\right)^{\lambda}, p(t) < p_T^{**} \\ \frac{\eta e_0 Q p_T^{**}}{r-\alpha} - \frac{1-\mu}{2}\lambda\eta^2, p(t) \geq p_T^{**} \end{cases}. \tag{6}$$

The corresponding optimal investment opportunity is

$$T^* = \frac{\ln\left(p_T^{**}/p_{c0}\right)}{\alpha - \left(\beta^2/2\right)} = \frac{\ln\left((\zeta/\zeta-1)[((1-\mu)\lambda\eta/2e_0Q) - k](r-\alpha)/p_{c0}\right)}{\alpha - \left(\beta^2/2\right)}, \tag{7}$$

where T^* is the moment when the carbon price reaches the optimal investment threshold for the first time.

3.2. Stackelberg Game Analysis

3.2.1. Stackelberg Game Model. Based on the basic supply chain model, this paper further analyzes the investment opportunity of emission reduction technology under the scenario of cooperation between enterprises within the supply chain. Assuming that in the supply chain, high energy consuming enterprises are the leaders in adopting emission reduction technologies, and the proportion of emission reduction technology projects requiring retailers to jointly bear the total cost of adoption investment is θ $(0 \leq \theta \leq 1)$, the investment amount of retailers is θI, and the investment amount of high energy consuming enterprises is $(1-\theta)I$. If the high energy consuming enterprise promises to pay the carbon trading market income to the retailer in proportion of γ $(0 \leq \gamma \leq 1)$, the present value of the net investment income of the high energy consuming enterprise adopting low-carbon technology is

$$\begin{aligned} W_M(t) &= E\left\{\int_t^{\infty} [p(s)\eta e_0 Q(1-\gamma)] e^{-r(s-t)} ds\right\} - \frac{1-\mu}{2}\lambda\eta^2(1-\theta) \\ &= \frac{\eta e_0 Q p(t)}{r-\alpha}(1-\gamma) - \frac{1-\mu}{2}\lambda\eta^2(1-\theta). \end{aligned} \tag{8}$$

The present value of the expected net income of retailers' investment in adopting low-carbon technology is

$$W_R(t) = E\left\{\int_t^{\infty} [p(s)\eta e_0 Q\gamma] e^{-r(s-t)} ds\right\} - \frac{1}{2}\theta\lambda\eta^2 = \frac{\eta\gamma e_0 Q p(t)}{r-\alpha} - \frac{1}{2}\theta\lambda\eta^2. \tag{9}$$

When solving the problem, we can first find out the time when retailers adopt low-carbon technology according to the expected net income function, then deduce the transfer payment proportion of high energy consuming enterprises, and finally obtain the time of supply chain technology investment.

Use Ito lemma and Bellman equation to solve the optimal investment opportunity of retailers.

The value function of retailers waiting for the adoption of low-carbon technologies is

$$W_R(T) = \max_{T \geq 0} E\left[\left(\frac{\eta\gamma e_0 Q p(t)}{r-\alpha} - \frac{1-\mu}{2}\theta\lambda\eta^2\right) e^{-r(t-T)}\right]. \tag{10}$$

From $E[((\eta\gamma e_0 Q p(t)/r-\alpha) - (1-\mu/2)\theta\lambda\eta^2)e^{-r(t-T)}] = ((\eta\gamma e_0 Q p_T/r-\alpha) - (1-\mu/2)\theta\lambda\eta^2)(p(t)/p_T)^{\zeta}$, order $(\partial/\partial p_T)((\eta\gamma e_0 Q p_T/r-\alpha) - (1-\mu/2)\theta\lambda\eta^2)(p(t)/p_T)^{\zeta} = 0$, the best adopted carbon price of low-carbon technology available to retailers is

$$p_{\mathrm{TR}} = \frac{\zeta}{\zeta-1}\frac{\theta\lambda\eta}{2\gamma e_0 Q}(r-\alpha)(1-\mu). \tag{11}$$

At this time, the optimal investment opportunity for retailers is

$$T_R^{**} = \frac{\ln\left(p_{\mathrm{TR}}/p_{c0}\right)}{\alpha - \left(\beta^2/2\right)} = \frac{\ln\left((\zeta/\zeta-1)(\theta\lambda\eta/2\gamma e_0 Q)(r-\alpha)(1-\mu)\right)}{\alpha - \left(\beta^2/2\right)}. \tag{12}$$

The option value of retailers' investment in low-carbon technology is

$$W_R(p(t)) = \begin{cases} \left(\frac{\eta\gamma e_0 Q p_{\mathrm{TR}}}{r-\alpha} - \frac{1-\mu}{2}\theta\lambda\eta^2\right)\left(\frac{p(t)}{p_{\mathrm{TR}}}\right)^{\zeta}, p(t) < p_{\mathrm{TR}} \\ \frac{\eta\gamma e_0 Q p_{\mathrm{TR}}}{r-\alpha} - \frac{1-\mu}{2}\theta\lambda\eta^2, p(t) \geq p_{\mathrm{TR}} \end{cases}. \tag{13}$$

Inference 3: In the Stackelberg game, the retailer's optimal adopted carbon price p_{TR} and the optimal investment opportunity T_R^{**} are inversely proportional to the cost subsidy ratio θ; that is, the higher the subsidy ratio given by the government, the lower the retailer's optimal adopted carbon price for adopting low-carbon technology, and the adoption will be implemented in advance. On the contrary, the lower the subsidy proportion given by the government, the higher the optimal adoption carbon price of retailers will be, and the adoption of low-carbon technologies will be postponed.

Inference 4: In the Stackelberg game, the retailer's optimal adoption of carbon price p_{TR} and the optimal investment opportunity T_R^{**} are proportional to the proportion of cost sharing θ; that is, the higher the proportion of investment cost shared by the retailer, the higher the retailer's optimal adoption of carbon price, which will delay the adoption of emission reduction technology. On the contrary, the lower the proportion of investment cost shared by retailers, the lower the optimal adopted carbon price of retailers will be, and the optimal investment opportunity will be advanced.

3.2.2. Analysis on the Transfer Payment Proportion of Carbon Trading Income of High Energy Consuming Enterprises. After

deriving the optimal investment threshold and expected return of retailers, high energy consuming enterprises should determine the transfer payment proportion γ according to the timing of retailers' adoption of emission reduction technology to ensure the maximization of their expected return.

The option value function of the manufacturer during the waiting period for the adoption of emission reduction technology is

$$W_M(p(t)) = \left[\frac{\eta e_0 Q p_{\mathrm{TR}}}{r-\alpha}(1-\gamma) - \frac{1-\mu}{2}\lambda\eta^2(1-\theta)\right]\left(\frac{p(t)}{p_{\mathrm{TR}}}\right)^{\zeta}. \tag{14}$$

Find the first derivative of the above formula for γ and make it 0 to obtain

$$\gamma_1 = \frac{\theta\zeta - \theta}{\theta + \zeta - 1}. \tag{15}$$

And considering the boundary condition $(\eta\gamma e_0 Q p_0/i - \mu) - (1/2)\theta\beta\eta^2 \geq 0$ that the retailer's income needs to meet, we get

$$\gamma_2 = \frac{\theta\beta\eta(i-\mu)}{2e_0 Q p_0}. \tag{16}$$

Then, the optimal transfer payment proportion of carbon trading income that high energy consuming enterprises can choose is

$$\gamma = \min\left\{\frac{\theta\zeta - \theta}{\theta + \zeta - 1}, \frac{\theta\beta\eta(i-\mu)}{2e_0 Q p_0}\right\}. \tag{17}$$

3.2.3. Timing of Supply Chain Adoption. In the Stackelberg game, the overall expected return of the supply chain is $W_S = W_M + W_R$. Referring to the collaborative decision-making derivation process, it can be concluded that the optimal carbon price for the adoption of emission reduction technology in the supply chain is

$$p_T^{***} = \frac{\zeta\lambda\eta(1-\mu)}{2e_0 Q(\zeta\text{-}1)}\left(1 + \frac{\theta}{\zeta - 1}\right). \tag{18}$$

The optimal investment opportunity in the Stackelberg game is obtained as follows:

$$T^{***} = \frac{\ln\left(p_T^{***}/p_{c0}\right)}{\alpha - \left(\beta^2/2\right)} = \frac{\ln\left(\left(\zeta\lambda\eta(1-\mu)/2e_0 Q(\zeta\text{-}1)\right)(1 + (\theta/\zeta - 1))\right)}{\alpha - \left(\beta^2/2\right)}. \tag{19}$$

4. Simulation Analysis

4.1. Collaborative Decision Analysis. Assign parameters to the low-carbon technology adoption decision-making model: $\alpha = 0.05$, $r = 0.8$, $e_0 = 5$, $\lambda = 500000$, $Q = 1000$, and β value separately 0.3, 0.6, and 0.9.

From Figure 1, the optimal adopted carbon price increases with the increase of carbon emission reduction rate; that is, the greater the carbon emission reduction rate, the higher the optimal adopted carbon price. With the reduction of enterprise carbon emissions, enterprises can sell more excess carbon emissions and obtain more benefits from the carbon trading market. Therefore, enterprises will delay the adoption of low-carbon technologies and wait for higher opportunities for carbon trading benefits, which verifies inference 1. In addition, the optimal adoption of carbon price increases with the increase of carbon price volatility. The greater the fluctuation of carbon price, the higher the risk of carbon trading. Enterprises will delay the adoption of low-carbon technologies and wait for better investment opportunities.

From Figure 2, the optimal adopted carbon price decreases with the rise of the proportion of value subsidies; that is, the higher the proportion of cost subsidies, the lower the optimal adopted carbon price of enterprises under collaborative decision-making, which indicates that when the government increases the proportion of cost subsidies, enterprises will accelerate the adoption of emission reduction technologies to reduce carbon emissions, which verifies inference 2.

4.2. Stackelberg Game Decision Analysis. Assign parameters to the low-carbon technology adoption decision-making model: $\alpha = 0.05$, $r = 0.8$, $e_0 = 5$, $\lambda = 500000$, $Q = 1000$, $\eta = 0.5$, $\gamma = 0.5$, and β value separately 0.3, 0.6, and 0.9.

(1) It can be seen from Figure 3 that the value of optimal use of carbon decreases with the increase of the value subsidy proportion; that is, the upper the proportion of subsidies given by the govt. to high energy intense enterprises, the lower the optimum adoption carbon value of low-carbon technology by retailers, which is able to promote them to participate within the cooperation of adopting emission reduction technology within the provide chain prior to, that verifies inference 3

(2) As shown in Figure 3, the optimal adopted carbon price increases with the increase of the cost sharing ratio; that is, the more the retailer shares the cost, the higher the optimal adopted carbon price level. At this time, the retailer will delay the opportunity to participate in the supply chain to adopt emission reduction technology and wait for a better investment opportunity, which verifies inference 4

From Figure 4, it can be seen that the proportion of transfer payment is inversely proportional to the optimal carbon price adopted by retailers, and the larger the proportion of carbon trading income given by high energy consuming enterprises to retailers, the lower the optimal carbon price adopted, and retailers will choose to invest in emission reduction technologies in advance.

5. Conclusion

High energy consuming enterprises need to purchase carbon emission rights in the carbon trading market in order to meet the government's environmental protection standards due to their large carbon emissions, so they are more vulnerable to the impact of carbon trading price fluctuations. Under the compound policy of carbon trading and government subsidies, carbon trading prices fluctuate frequently, making high energy consuming enterprises face greater uncertainty risks when investing in low carbon technologies, and government subsidies provide some support for high energy consuming enterprises to adopt low-carbon technologies. This paper analyzes the impact of carbon price fluctuations and government subsidies on the optimal timing of low-carbon technology investment of high energy consuming enterprises by constructing a real option model.

The main conclusions are as follows: (1) In the case of cooperative decision-making, the greater the fluctuation in carbon trading value, the higher the uncertainty risk presented by firms, and consequently, intense high-energy firms delay low-carbon investment; once the government increases the proportion of subsidies, it will relieve the monetary pressure on the offer chain firms and accelerate investment in low-carbon technologies.

(2) In the Stackelberg game, increasing the proportion of government subsidies will speed up the process of retailers adopting low-carbon technologies, but the higher the proportion that retailers share costs, the more likely they are to delay investing in low-carbon technology

This paper investigates the impact of carbon trading and government subsidy policies on the timing of low-carbon investment by companies. In the actual investment process, however, firms will also be affected by factors such as consumers' low-carbon preference and firms' investment risk attitude. This is also the direction of future research.

Data Availability

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

Conflicts of Interest

All authors declare no conflicts of interest in this paper.

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Research Article

The Study on the Influence of Green Inclusive Leadership on Employee Green Behaviour

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As a result of the implementation of the "double carbon" strategy, the issue of how to encourage green behaviour has become a prominent one in society. According to the cognitive-affective processing system theory, this study constructs two paths through which green inclusive leadership influences employee green behaviours: the cognitive pathway mediated by pro-environmental goals clarity and the affective way mediated by green organization identification. Data analysis of 372 employees in chemical enterprises reveals that first, employees' perception of green inclusive leadership positively affects employee green behaviour; second, green inclusive leadership enhances employee awareness of environmental goals and green organization identification so that employees are more likely to behave environmentally; furthermore, green HRM practices positively moderate the relationship between green inclusive leadership and pro-environmental goals clarity, as well as positively moderate the relationship between green inclusive leadership and green organization identification. This study aims to provide theoretical and practical insight into how to promote the green development of organizations from the perspective of leadership style to facilitate green development.

1. Introduction

The world is pumping about 51 billion tons of greenhouse gases into the atmosphere every year, which is making the phenomenon of global warming increasingly serious, along with the attendant environmental problems such as rising sea levels, rising Arctic temperatures, and natural disasters. To avoid climate catastrophe, humans need to stop pumping greenhouse gases into the atmosphere and achieve zero emissions. The country has implemented the "double carbon" strategy of carbon peak and carbon neutrality, which calls for enterprises to reduce carbon emissions and lead enterprises in sustainable management practices. To respond to the national double-carbon policy, academia and entrepreneurs are focusing on what kind of leadership mode enterprises should adopt to encourage employees to take the initiative in green behaviour. A new leadership style has been proposed called green inclusive leadership [1]. In contrast with other leadership styles, this style is characterized by an openness to employee suggestions for green ideas, a willingness to discuss with employees the organization's environmental goals, and an acceptance of employees' input regarding ecological challenges. A recent study shows that green inclusive leadership can create a green psychological atmosphere and increase engagement with green work [1]. It remains unclear, however, whether green inclusive leadership will influence employees' green behaviour and through what mechanism. We discuss the above problems to provide reference significance to enterprises promoting green behaviours among their employees.

Previous studies have explored the relationship between green leadership and employees' green behaviour, but the mechanism of how green inclusive leadership affects employees' green behaviour has not been examined. Cognitive-affective system processing theory suggests that a person's cognitive response and affective response are intertwined and affect each other simultaneously. By influencing the employee's cognition and affection, the leader can influence the employee's behaviour. Currently, studies primarily focus on affective factors, such as employees' environmental

responsibility [2] and positive emotion [3], ignoring the influence of cognition on employee behaviour. The basic concept of cognitive-affective processing system theory holds that behaviour is determined by how cognition and affection interact. Therefore, we believe that, on the one hand, green inclusive leadership cognitively conveys the environmental goals of the organization and expectations for environmental performance to employees. Employees will be more explicit about the objectives. They will pay better attention to the organization's environmental objectives, aligning their behaviour towards its goals, and encouraging employees to behave greenly. On the other hand, environmental protection and green values are conveyed emotionally to employees through green inclusive leadership. Employees will demonstrate green behaviours if the organization's values are aligned with their own. We explored how green inclusive leadership influences employees' green behaviour by introducing two cognitive and affective units of proenvironmental goal clarity and green organization identification as critical cognitive and affective units between green inclusive leadership and green behaviour [4]. Therefore, proenvironmental goal clarity and green organization identification may mediate between green inclusive leadership and employee green behaviour.

Moreover, it is not just the leader who has the power to influence employees. Human resource management systems are all responsible for recruiting, selecting, evaluating, and promoting employees, so policies and measures implemented by the human resource management department can also influence and alter employees' working attitudes and behaviours. It is more likely that employees will accept the green concept conveyed by the organization when the human resource department makes corresponding green policies and requires them to pay attention to sustainable and green development. HRM measures in green management are called green HRM practices, specifically incorporating environmental protection and green sustainability concepts into various HRM modules [5]. Employees will be more likely to engage in green behaviours if they know that a high-level green human resource management practices are being implemented in the organization. Alternatively, if the organization does not implement green human resource management practices, employees will not pay attention to green behaviour, resulting in lower performance. We incorporated green human resource management practice as a moderating variable in our theoretical model based on social information processing theory [6]. We tested whether green human resource management practice moderates the relationship between cognitive and affective units and green inclusive leadership. Examine what boundary conditions green inclusive leadership requires.

Three aspects contribute mainly to the research contribution of this paper. Firstly, from the perspective of "cognition-affection," the influence mechanism of green inclusive leadership on employees' green behaviour is discussed, expanding the research content of green inclusive leadership and breaking from previous limitations based on the single emotional perspective. We proposed and tested the dual mediating effect of proenvironmental goal clarity and green organization identification, revealing how cognitive and affective factors influence green inclusive leadership and green employee behaviour. Secondly, few studies have simultaneously examined the impact of organizational human resource management practices and leadership behaviour. It indicates that green human resource management practices have a moderating effect on individual behaviour, enriching the research on the relationship between human resource management and individual behaviour, as well as expanding the research on the context of green inclusive leadership and its boundary conditions. Thirdly, employee green behaviour is crucial in improving their environmental performance for organizations to achieve environmental goals. This paper enhances research on influencing factors of green behaviour among employees. A cognitive-affective model has rarely been used to study employee green behaviour. In this study, cognitive and affective approaches were used to explore the antecedent effects of green inclusive leadership on employee environmental goal clarity and green organization identification, enhancing research on leadership and individual behaviour.

2. Research Hypothesis

2.1. Green Inclusive Leadership and Employee Green Behaviour. A green inclusive leadership style involves interacting with employees to achieve environmental protection and cleanliness organizational goals [1]. Openness, effectiveness, and accessibility are the characteristics of this leadership style. The organization's leaders are open to new green ideas and willing to discuss environmental goals and consult on environmental issues. Employee green behaviour refers to the behaviours of employees in the workplace that support environmental sustainability [7], such as turning off lights, providing environmental protection advice, or participating in environmental protection projects. In the process of work, the leader is the core of moral guidance for the members of the organization. The employees will be more actively committed to the green behaviour of the organization when the leader supports the internal environmental protection work of the organization, takes the initiative to guide them, and tolerates opinions and suggestions that differ from their own [8].

According to social information processing theory, people's attitudes and behaviours are influenced by the environment around them. How employees process and analyze information and cues influences work attitudes and behaviours. The concept of green, environmental protection, and sustainability is carried out in the interaction between green inclusive leaders and their subordinates. Employees will store such information in their memory when they receive it. When relevant events require judgment and further action, employees will retrieve information about environmental protection and sustainability in their memory and make judgments and inferences based on it. Leaders who support employees' environmental behaviours will give them fundamental guarantees that they will participate in proenvironmental behaviours and develop environmental initiatives. These behaviours will influence employees

psychologically, resulting in an internal motivation to engage in green behaviour [9].

Researchers have found that green inclusive leadership affects employees' green psychological atmosphere [1] and then promotes green behaviours. Leadership that is inclusive sets an example for employees, sees everyone as equal, and recognizes their efforts, all while maintaining an open view of individuals' differences with their different opinions and suggestions [10]. As a result of this psychological state, employees are more likely to express their ideas and more inclined to work towards the organization's goals. Supporting and encouraging employees' green behaviours in their daily work will likely increase their green behaviours. Accordingly, the following hypothesis is proposed:

(H1) : green inclusive leadership positively influences employees' green behaviour.

2.2. The Mediating Effect of Pro-environmental Goal Clarity and Green Organization Identification. Cognitive-affective processing system theory proposes that employees are rational and sensual organisms. Cognitive-affective units interact with events that people encounter and ultimately determine their behaviours. Therefore, employees' green behaviours are influenced by their cognition and affection. On the one hand, as employees become familiar with the organization's expectations for environmental performance and goals, they will become more cognizant of environmental protection and green behaviours. On the other hand, employees will be infected and influenced when the organization has a green atmosphere and conveys the sentiment of being green and sustainable, which will lead them to develop a green psychological atmosphere and act greenly. Cognition-affective system theory provides a good perspective on how leadership contributes to employee green behaviour. In particular, green inclusive leadership affects employees' green behaviours cognitively and affectively.

In one sense, proenvironmental goal clarity is reasonable as a measure of cognitive response. The characteristics of cognitive responses suggest that when individuals process information from the perspective of analysis, they will carefully observe things and evaluate them logically and causally [11]. The clarity of environmental goals reflects the understanding and clarity of individual employees' green and environmental goals [12], which should be determined objectively. As a measure of affective reaction, green organization identification is reasonable. An organization's leadership style reflects its culture, while green inclusive leadership reflects its environmental and green values. When employees reflect on the organization's green culture, they will identify with the green organization [13] and then show green behaviour.

Using cognitive-affective system processing theory, social information processing theory, and organizational identity theory, we also reveal how green inclusive leadership affects employees' green behaviour cognitively and affectively.

2.2.1. The Mediating Effect of Pro-environmental Goal Clarity. Employees can become more aware of the external environment by being exposed to organizational goals. A difference in understanding and acceptance of organizational goals will lead to varying clarity of goals and cognitive differences [14]. According to the social information processing theory, green inclusive leaders are one of the main sources of information for employees to know and understand the organization's environmental goals, providing them with information about the organization's environmental behaviour, and strengthening employees' awareness of the organization's environmental goals. On the one hand, within the organization leadership style for the green inclusive leadership, staff and leaders will be in benign interactions and communication, and leaders will be tolerant of employee questions and made mistakes. They will accept suggestions and comments that differ from their own. In this case, employees are more likely to accept the organization's objectives, further clarifying organizational goals. On the other hand, green inclusive leadership communicates environmental goals to employees, who will accept their green and sustainable ideas and understand that environmental protection is also the work goal of the organization's members, making employees' environmental goals clear.

Goal clarity refers to a person's understanding of job objectives and responsibilities [15]. The goal-setting theory suggests that clear work goals can help individuals make good decisions, make them more focused, and help them achieve their goals [16]. A clear and specific perception of the organization's goals will lead to employees understanding of their own goals. The clarity of environmental objectives reflects that employees can clearly and accurately understand the environmental objectives of the organization, as well as the clarity of individual employees' environmental protection objectives and responsibilities. Employees with a high definition of environmental goals clearly understand that going green is one of the goals of the organization members, for their responsibilities and organization has a more precise and accurate cognition of their expectations, thereby reducing behaviour blindness, improving employees' self-control ability, motivating them to pursue their goals and perseverance, pursuing an environment consistent with the organization's environmental goals, and exhibiting more green behaviour.

As a result of green inclusive leadership, employees can be better informed about the organization's environmental goals, improve their clarity of environmental goals, have a clearer understanding of their environmental responsibilities, reduce blindness to actions, and act more environmentally friendly. Based on this, we put forward the following hypothesis:

(H2) : proenvironmental goal clarity mediates the relationship between green inclusive leadership and employee green behaviour.

2.2.2. The Mediating Effect of Green Organization Identification. Green organization identification is a model established by the organizational members to identify environmental management and green innovation to give meaning to environmental protection behaviour [17]. Employees with organization identification are emotionally connected

to the organization. The words and actions of leaders profoundly impact organizational members, so they contribute to employees' identification with the organization [18]. Identifying with green organizations results from employees' feelings about environmental protection and sustainable development conveyed by green inclusive leadership. Employees will commit to green behaviours more actively if they are emotionally consistent. Employees' organizational identity is significantly affected by their organization's image [19]. An excellent organizational image is essential for employees to form an organizational identity, and the management style affects how the organization shapes its image. The leadership style of its leaders may shape an organization's image. Employees can enhance their green organizational identity by working in an environment that promotes environmental protection and sustainability. Organizational climate, however, significantly impacts organization identification [20]. An excellent organizational climate helps employees form more positive perceptions of the organization. They are incorporating green environmental protection into the organizational climate resulting from green inclusive leadership. Meanwhile, inclusive leadership fosters a harmonious atmosphere within the organization and contributes to employees' identification with the organization as green. Organizational identity is also significantly influenced by organizational culture [21]. The role of leaders in influencing organizational culture is to give meaning to employees and to build meaning for them. An organization's green and environmental protection culture can be shaped by green inclusive leadership. Employees should then have a green identification in their organization.

According to some studies, identifying an organization as green may improve its environmentally friendly behaviour [22]. According to the organizational identity theory, persistence in pursuing goals can be affected by organizational identity. In general, the more employees identify with an organization, and the more enthusiastic they are about taking action. Alternatively, employees with a solid organizational identity will identify more with their organization and evaluate it more highly, improving its image and quality through positive behaviours. Employees' emotional connection to how an organization handles environmental issues encourages them to consider environmental protection as one of their responsibilities and exhibit green behaviour as a result.

Having green inclusive leadership will lead to a green and environmentally friendly organization image, create a green organizational atmosphere, shape a green and sustainable organizational culture, and enhance employees' sense of belonging to a green organization. Employees with high green organization identification will take more positive actions to protect the organization, leading to more green behaviours. Based on this, the following hypothesis is proposed:

(H3) : green organization identification plays a mediating role between green inclusive leadership and employee green behaviour.

2.3. The Moderating Effect of Green Human Resource Management Practice. As leaders and HRM practices in the organization affect employee attitudes and behaviours, we introduce green HRM practices into the research model. For organizations to carry out green management, green human resource management practice is a method, which is to say, the human resource management of organizations carries out green management, standardizing the management of employees' green behaviours on a system and policy level [23]. Among the practical dimensions of green human resource management are recruitment and training, compensation design, performance appraisal, and employee participation [24].

In organizations with green and inclusive leadership styles, employees perceive clearer and more accurate environmental goals and behave more sustainably. The role of human resource management is to connect the organization with its employees. The organization uses it to conduct training, compensation design, and performance appraisals for its employees. The organization provides the employees with corresponding environmental protection clues, conveys the organization's concept and goal, and can improve their understanding of the environmental protection goal. During the recruitment process, green human resource management focuses on selecting employees who align with the environmental values of the organization. Since these employees are more convinced of the green inclusive leadership style, they can help clarify environmental objectives. The training session promotes environmental knowledge and skills among employees. In this case, it makes sense to deepen employees' understanding of green inclusive leadership so they realize the organization values green goals and thus improve environmental goals' clarity. In the process of employee performance appraisal and salary design, tying green environmental responsibility to employee performance and salary will promote the application and practice of green environmental protection and sustainable concepts advocated by green inclusive leadership and motivate employees who perform green environmental responsibility with salary. As a result, employees will be more aware of the organization's environmental goals. Green and inclusive leadership styles can encourage employees to set clear environmental goals within an organization. At this time, if the organization implements green human resources management practices, from staff recruitment, training, compensation design, performance appraisal, and employee involvement, employees will provide clues to their organization's commitment to preserving the environment. Both leadership and management systems provide employees with environmental cues that emphasize the importance of environmental protection. According to the cued coherence theory [25], this further enhances employees' perception of the organization's environmental goals and clarifies employees' environmental goals.

As mentioned above, when the internal leadership style of an organization is green and inclusive, it will create a green corporate image, organizational atmosphere, and organizational culture, and employees will generate more green organization identification, which will lead to green behaviour. As a result of green human resource management practices, leaders conduct green management among

employees, and employees will have more trust and understanding of green inclusive leadership and form the same pursuits of green values as the organization, resulting in higher recognition of green organizations. During recruitment, green human resource management practices emphasize selecting employees with good environmental awareness [26]. They are more likely to identify with green organizations because they are more likely to identify with green inclusive leadership styles. The training process will include attention to the green culture and concept of the enterprise, strengthening the understanding of green inclusive leadership of employees, which will lead to green organization identification. As part of employee performance appraisals and salary designs, green environmental responsibility should be incorporated into employee salaries so that employees know the organization's sustainability expectations. Employees are more likely to identify their organization as green when exposed to green inclusive leadership practices and concepts. When employees recognize the significance of the organization's green human resource management practices, the impact of green inclusive leadership on employees will be enhanced, and employees will identify more with green organizations.

Following the social information processing theory, employees will have more trust in green inclusive leadership when they experience the implementation of green human resource management practices, which leads to a clearer understanding of employees' environmental goals and a better ability to identify green organizations. Based on this, the following hypotheses are proposed:

(H4) : green human resource management practices positively modify the relationship between the green inclusive leadership and the proenvironmental goal clarity.

(H5) : green human resource management practices positively modify the relationship between the green inclusive leadership and the green organization identification.

To sum up, the dual-mediation theoretical model established in this study is shown in Figure 1.

3. Research Methods

3.1. Data Collection and Research Samples. The study was conducted online and field research for six months, from November 2021 to April 2022. This paper aims to examine green behaviour in five large chemical enterprises in Qingdao, Beijing, and other places since green behaviour is prevalent in chemical enterprises. An adapted two-stage survey method was used in this study to reduce the influence of common method bias. A survey was conducted twice, with a three-month interval between each questionnaire. Employee perceptions of green inclusive leadership, green HRM practices, and control variables were included in the first stage survey. In contrast, the second stage survey included employees' proenvironmental goals clarity, green organization identification, and employee green behaviour.

The survey purpose was explained to the enterprise in advance, and the survey results were kept confidential. As a condition of receiving the research results, we promised not to use them for any other purpose. A field survey was conducted for the first survey. A numbered questionnaire was distributed to the employees through the human resource management department, and the human resource management department and researchers recorded the employee numbers. The total number of questionnaires distributed this time was 500. Employees who answered the questionnaires effectively in the first survey were selected for the second survey three months later. We distributed 430 questionnaires to employees online. In order to match the information of the two surveys, we also numbered them.

Ultimately, this survey collected effective data on 372 employees, resulting in a recovery rate of 74.4%. In the sample analysis, males accounted for 52.2%, and females accounted for 47.8%; (2) 18.3% of the employees are under 25 years old, 44.3% are between 26 and 35 years old, 27.7% are between 36 and 45 years old, and 9.7% are over 46; (3)18.3% of employees have a high school degree or below, 28.2% have a college degree, 44.4% have a bachelor's degree, and 9.1% have a master's degree or above. (4) 21.2% of the employees have worked for less than one year, 30.6% for one to three years, 32.3% for four to six years, and 15.9% for more than seven years.

3.2. Research Tools. All variables in this study were measured using the developed mature scale. All questions were translated and back-translated to avoid misunderstandings due to cultural differences. All the questionnaires were evaluated by a Likert 7-point scale, where 1 means "strongly disagree" and 7 means "strongly agree." Specific variable items are shown in Table 1.

Green Inclusive Leadership (GIL): a 3-question scale developed by Bhutto et al. [1]. In this study, the reliability coefficient of the scale was 0.887.

Proenvironmental Goal Clarity (PGC): a 5-question scale developed by Liang et al. [18]. In this study, the reliability coefficient of the scale was 0.822.

Green Organization Identification (GOI): a 6-item scale developed by Chen [27]. In this study, the reliability coefficient of the scale was 0.883.

Employee Green Behaviour (EGB): a 7-item scale developed by Robertson and Barling [28]. In this study, the reliability coefficient of the scale was 0.858.

Green Human Resource Management Practices (GHRM): the scale developed by Ogberbu et al. [29] is divided into three dimensions: green recruitment and selection, green performance and compensation, and green training participation and development. According to the Chinese context, this study selected 14 items on the scale. Employees select the perceived green HRM practices according to the actual situation. In this study, the reliability coefficient of the scale was 0.910.

The employees' age, gender, and education level are used as control variables. Furthermore, since the employee's working years will affect their working behaviour and performance, the employee's working years are also included as a control variable.

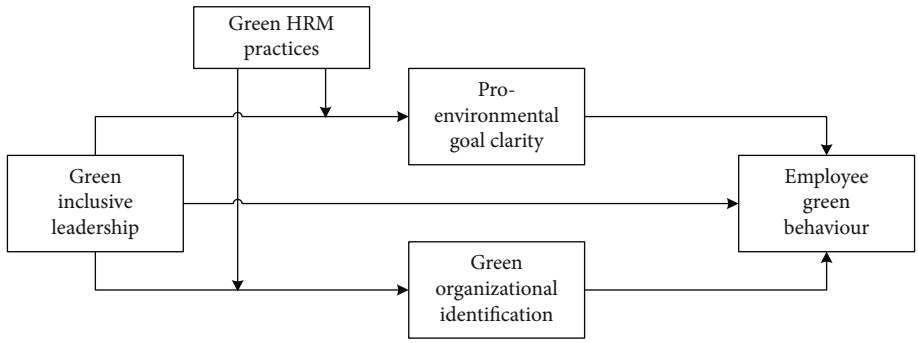

Figure 1: Mechanism of the role of green inclusive leadership on employee green behaviour.

Table 1: Variable items.

	Items
GIL	(1) The leadership in the organization is willing to discuss with employees environmental goals at work and new green ways to achieve these goals (2) Employees can consult with leaders in the organization about environmental issues at work (3) The organization's leaders are willing to listen to and deal with employees' requests related to environmental issues at work
PGC	(1) I am clear about my environmental responsibilities (2) I have a clear understanding of my environmental objectives (3) I am clear about the expected outcomes of my environmental activities (4) I am clear about which environmental activities will be positively evaluated (5) I am aware of the link between my environmental activities and the overall objectives of my department
GOI	(1) Employees are very aware of the company's environmental management and conservation history (2) Employees are proud of the company's environmental goals and mission (3) Employees believe that the company has achieved an important position in environmental management and protection (4) Employees believe that the company has established a clear set of environmental objectives and mission (5) Employees are aware of the company's environmental traditions and culture (6) Employees strongly agree with the company's actions in environmental management and protection
EGB	(1) I will print on both sides when possible (2) I will put compostable items in the compost bin (3) I will put recyclable materials in the recyclable bin (4) I will bring reusable tableware to work (5) I turn off lights that are not in use (6) I will participate in environmental projects (7) I would make suggestions about environmental practices to improve the environmental performance of the organization
GHRM	(1) The company focuses on recruiting and selecting employees who are environmentally conscious and have environmental knowledge and skills (2) The company attaches importance to the candidate's attitude and concern for environmental protection in the recruitment process (3) The company carefully design interview questions to examine candidates' attitudes, knowledge, skills, and concern for the environment (4) The environmental objectives set by the company's management can be implemented (5) The company incorporates environmental performance indicators into the evaluation system of managers' work (6) The company includes environmental performance indicators in the evaluation system of employees (7) The company gives nonmonetary rewards to employees who achieve environmental performance targets (8) The company will adjust employee compensation based on environmental performance (9) Employees are well-recognized and rewarded for their environmental initiatives (10) The company provides training for employees in environmental protection-related knowledge and skills (11) The company provides training for managers in environmental protection-related knowledge and skills (12) The company has a job description that describes its environmental responsibilities (13) Company members participate in discussions on environmental issues (14) After receiving training in environmental protection skills, company members can apply green knowledge in their daily work

4. Data Analysis and Results

4.1. Confirmatory Factor Analysis. To determine the validity of the variables, we conducted a confirmatory factor analysis on five key variables, such as "green inclusive leadership," "proenvironmental goals clarity," "green organization identification," "green human resource management practice," and "employee green behaviour." Table 2 compares the fitting results of the five-factor, four-factor, three-factor, two-factor, and one-factor models. There is a significant improvement in the relevant effect of the five-factor model ($\chi^2/df = 2.01$, RMSEA = 0.05, TLI = 0.90, CFI = 0.91, SRMR = 0.045), and each index is significantly better than the other four models. These data indicate that the five variables in this study have good discriminant validity.

4.2. Common Method Bias Analysis. An anonymous questionnaire was filled out during the data collection stage, and a two-stage collection method was used. To reduce the homologous variance problem, we promised employees before completing the data collected by this questionnaire that the research results would not be used for any other purpose than scientific research before completing the questionnaire. To assess the severity of the common method bias in the study data, the Harman single factor test [30] was used. The principal component factor analysis was conducted on all items of the five main variables. In the test results, 23.596% of the variation was explained by the first principal component and 68.235% by the cumulative component, which did not account for 40% of the total variance. The KMO was 0.869, and the Bartlett was 13061.083, which were significant at the 0.001 level. Also, all the fit indices for the five-factor model are within the reference range. In contrast, all of the fit indices for the one-factor model are outside the reference range, indicating that the fitting degree of the research data is good to some extent. As a result, this study does not exhibit any homologous severe variance bias.

4.3. Descriptive Statistical Analysis. Each variable's mean, standard deviation, and correlation coefficient are shown in Table 3. Green inclusive leadership is positively correlated with the proenvironmental goals clarity, green organization identification, and employee green behaviour ($r = 0.437$, $P < 0.01$; $r = 0.291$, $P < 0.01$; $r = 0.263$, $P < 0.01$); the green behaviour of employees was positively correlated with the proenvironmental goals clarity and green organization identification ($r = 0.378$, $P < 0.01$; $r = 0.346$, $P < 0.01$), which provided a preliminary basis for further exploring the relationship between variables.

4.4. Hypothesis Testing

4.4.1. Main Effect Test. This study uses five nested models to examine the simultaneous mediating effects of proenvironmental goals clarity and green organization identification. The results are shown in Table 4. Using M1, a partial mediation model, we explore the direct impact of green inclusive leadership on employee green behaviour and the simultaneous mediating effect of proenvironmental goals clarity and green organization identification. The M2 model deleted the direct path and only included the full mediation model that dictates that proenvironmental goals clarity and green organization identification indirectly influence employee green behaviour. The M3 model measures the influence of green inclusive leadership on the proenvironmental goals clarity of employees after controlling for green organization identification. Employee green behaviour is directly affected by green inclusive leadership and indirectly by green organization identification. M4 is a partial mediation model in which proenvironmental goals clarity is the mediating variable after controlling for green inclusive leadership's influence on employees' green organization identification. Employee green behaviour is directly influenced by green inclusive leadership and indirectly influenced by proenvironmental goals. The M5 model is a direct action model. After controlling green inclusive leadership for its influence on green organization identification and proenvironmental goals clarity, it is examined for its direct impact on employee green behaviours. Gender, age, education, and tenure are used as control variables in the five models.

Based on the test results of M5, it is demonstrated that, after controlling the influence of green inclusive leadership on the proenvironmental goals clarity and the green organization identification, green inclusive leadership significantly affects employee green behaviour ($\beta = 0.212$, $P < 0.001$), proving hypothesis 1. Green inclusive leadership also had a significant impact on proenvironmental goals clarity ($\beta = 0.368$, $P < 0.001$) and green organization identification ($\beta = 0.216$, $P < 0.001$). After adding two mediating variables, M1 was obtained. At this time, compared with the test results of M5, the impact of green inclusive leadership on employee green behaviour was no longer significant ($\beta = 0.010$, $P > 0.05$). However, the proenvironmental goals clarity had a significant positive impact on employee green behaviour ($\beta = 0.386$, $P < 0.001$). There was a significant positive relationship between green organization identification and employee green behaviour ($\beta = 0.281$, $P < 0.001$). A significant relationship between employee green behaviour and green inclusive leadership was found when comparing M3 with M5 when M3 offered only green organization identification. A comparison between M4 and M5 showed that only when the proenvironmental goals clarity was introduced into M4, the effect on the green behaviour of employees was not significant ($\beta = 0.072$, $P > 0.05$). Furthermore, the two mediating variables had significant effects on the dependent variable. There was a standardized path coefficient of 0.281 ($P < 0.001$) between green organization identification and employee green behaviour in M3 and 0.382 ($P < 0.001$) between proenvironmental goals clarity and employee green behaviour in M4. In the above model, the two mediating variables play a synchronous mediating role in the relationship between green inclusive leadership and employee green behaviour.

The analysis results in Table 4 show that the cognitive and affective mediating variables fully mediate the relationship between green inclusive leadership and employee green behaviour, which shows a better fit than when only the cognitive path or emotional path is considered. According to

Table 2: Confirmatory factor analysis.

Model	χ^2	Df	χ^2/df	RMSEA	TLI	CFI	SRMR
Five-factor model	1102.76	550	2.01	0.052	0.90	0.91	0.045
Four-factor model	1728.86	554	3.12	0.076	0.79	0.80	0.084
Three-factor model	2914.76	557	5.23	0.107	0.58	0.60	0.166
Two-factor model	3571.73	559	6.39	0.121	0.46	0.50	0.168
One-factor model	4472.25	560	7.99	0.137	0.31	0.35	0.174

Note: five-factor model (green inclusive leadership; proenvironmental goals clarity; green organization identification; green human resource management practice; and employee green behaviour); four-factor model (green inclusive leadership; integration of proenvironmental goals clarity and green organization identification; green human resource management practice; and employee green behaviour); three-factor model (green inclusive leadership; integration of proenvironmental goals clarity, green organization identification and green human resource management practices; and employee green behaviour); two-factor model (integration of green inclusive leadership, proenvironmental goals clarity, green organization identification and green human resource management practices; and employee green behaviour); single-factor model: all variables are combined.

Table 3: Mean, SD, and correlations coefficient of the studied variables.

Variables	M	SD	1	2	3	4	5	6	7	8
1 Gender	1.48	0.52	—							
2 Age	2.29	0.88	-0.077	—						
3 Education	2.44	0.88	0.052	-0.015	—					
4 Tenture	2.43	1.00	0.008	0.131**	-0.011	—				
5 GIL	4.25	1.50	-0.037	0.020	-0.012	-0.002	—			
6 PGC	4.71	1.13	0.096	0.016	-0.006	-0.010	0.437**	—		
7 GOI	5.08	1.05	0.069	0.025	-0.055	-0.045	0.291**	0.207**	—	
8 EGB	4.54	1.05	-0.006	0.041	0.004	-0.045	0.263**	0.378**	0.346**	—
9 GHRM	5.52	0.92	0.070	-0.033	0.102	0.045	0.197**	0.003	0.024	0.043

Note: $n = 372$, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Table 4: Comparison between structural equation models.

	M1 GIL ⟶ PGC ⟶ EGB GIL ⟶ EGB GIL ⟶ GOI ⟶ EGB	M2 GIL ⟶ PGC ⟶ EGB GIL ⟶ GOI ⟶ EGB	M3 GIL ⟶ PGC GIL ⟶ EGB GIL ⟶ GOI ⟶ EGB	M4 GIL ⟶ PGC ⟶ EGB GIL ⟶ EGB GIL ⟶ GOI	M5 GIL ⟶ PGC GIL ⟶ EGB GIL ⟶ GOI
GIL ⟶ PGC	0.524***	0.371***	0.370***	0.370***	0.368***
PGC ⟶ EGB	0.386***	0.390***		0.382***	
GIL ⟶ EGB	0.010		0.151***	0.072	0.212***
GIL ⟶ GOI	0.220***	0.220***	0.220***	0.220***	0.216***
GOI ⟶ EGB	0.281***	0.284***	0.281***		
χ^2/df	1.682	1.673	1.679	1.679	1.667
RMSEA	0.043	0.043	0.043	0.043	0.042
CFI	0.964	0.965	0.965	0.964	0.965
TLI	0.959	0.960	0.960	0.959	0.960
SRMR	0.041	0.041	0.041	0.041	0.036

this paper, M2 was the most complete and had the highest reasonable degree of the five structural equation models, so M2 was selected as the final model.

4.4.2. Mediating Effect Test. This study used the Hayes' Process program and Bootstrap method to estimate and test the mediating effect. A Bootstrap sample is run 5000 times, and the results are presented in Table 5. There is an indirect effect of proenvironmental goals clarity between the green inclusive leadership and the employee green behaviour of 0.141, 95% CI is 0.071, 0.238; and the confidence interval does not include 0. Hypothesis 2 is therefore confirmed. An indirect effect of

Table 5: Comparison of mediating effect and double mediating effect.

	Estimate	Standard deviation	Lower limits	Upper limits
GIL ⟶ PGC ⟶ EGB (a)	0.141	0.043	0.071	0.238
GIL ⟶ GOI ⟶ EGB (b)	0.062	0.023	0.026	0.114
(a, b)	0.079	0.049	-0.002	0.188

Table 6: Results of the moderating effect analysis.

Variable	PGC			GOI		
	T1	T2	T3	T4	T5	T6
Gender	0.098	0.120**	0.132***	0.075	0.088	0.092
Age	0.025	0.013	0.014	0.037	0.030	0.031
Education	-0.011	0.003	0.001	-0.058	-0.052	-0.056
Tenure	-0.014	-0.007	-0.012	-0.051	-0.048	-0.055
GIL		0.460***	0.453***		0.300***	0.291***
GHRM		-0.087	-0.044		-0.033	0.021
GIL × GHRM			0.126***			0.162***
R^2	0.010	0.213	0.226	0.012	0.098	0.121
F	0.924	15.219***	16.789 ***	1.071	6.634***	7.181***
$\triangle R^2$	0.010	0.203	0.013	0.012	0.086	0.023

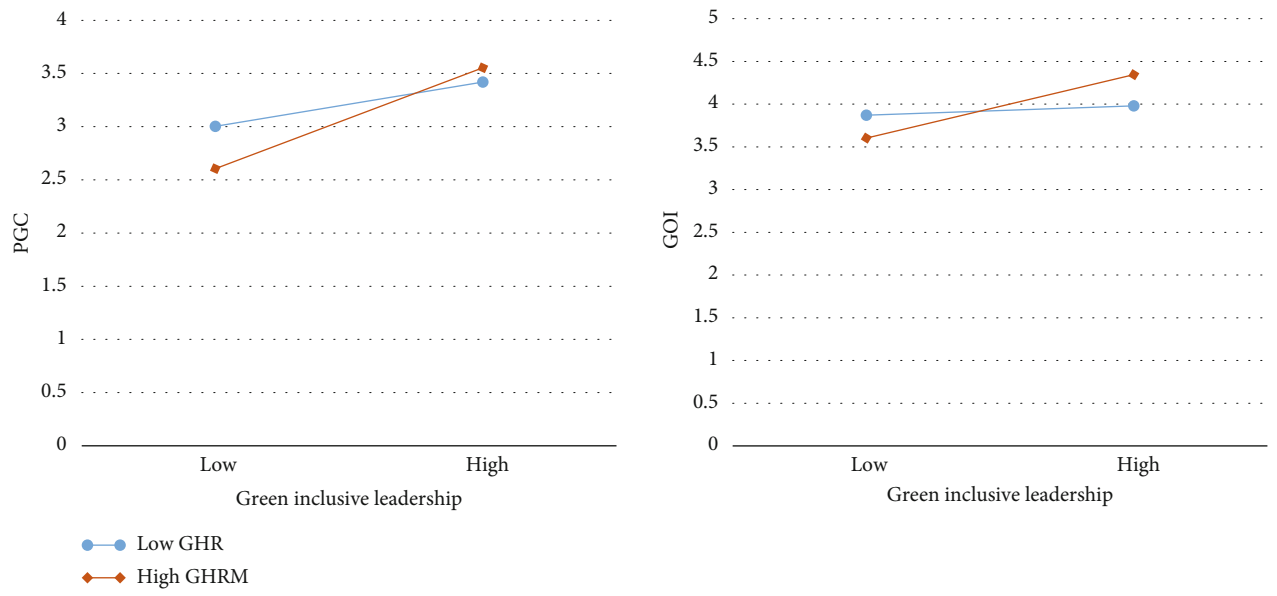

Figure 2: Reconciliation path diagram.

green organization identification on employee green behaviour is 0.062, 95% CI is 0.026, 0.114; and the confidence interval does not include zero. It confirms hypothesis 3. The mediating effects of the two mediators were compared and tested using a double-mediation comparison model. The estimated value was 0.079, 95% CI was -0.002, 0.188; and the confidence interval included zero, which indicates that the two mediators have the same indirect effect status between green inclusive leadership and employee green behaviour. That is, they play an equally significant role.

4.4.3. Moderating Effect Test. To test the moderating effect in this study, we used hierarchical regression analysis, and the results are shown in Table 6. We standardized green inclusive leadership and green human resource management practices to avoid multicollinearity.

Table 6 shows that the green inclusive leadership practices and the green human resource management practices significantly influence employee proenvironmental goals clarity ($\beta = 0.126$, $P < 0.01$). As found by T1, T2, and T3, after including green inclusive leadership, green human

resource management practices, and their interaction terms, the overall explanatory quantity R2 of the model significantly increased, suggesting that green human resource management practices positively moderated the relationship between the green inclusive leadership and the proenvironmental goals clarity. Therefore, hypothesis 4 is true. Interaction between green inclusive leadership and green human resource management practices significantly enhanced employees' green organization identification($\beta = 0.162$, $P < 0.001$). After incorporating green inclusive leadership, green human resource management practices, and their interaction terms, the overall explanatory quantity R^2 of the model significantly improved. Accordingly, green human resource management practices positively regulate the relationship between green inclusive leadership and green organization identification, which confirms hypothesis 5.

To clarify the impact of green human resource management practices, Figure 2 shows the difference in the impact of green inclusive leadership on employee green behaviours under different degrees of green human resource management practices, with one standard deviation higher than and one standard deviation lower than the mean value of green human resource management practices. According to Figure 2, the more green human resource management practices, the stronger the impact of green inclusive leadership on proenvironmental goals clarity and green organization identification; conversely, the weaker. As can be seen, green human resource management practices have a moderated effect.

5. Conclusion and Discussion

5.1. Research Conclusions. The study examined 372 valid data samples based on the cognitive-affection processing system framework. It came to relevant conclusions about green inclusive leadership, proenvironmental goals clarity, green organizations identification, implementation of green human resources management practices, and employee green behaviour. Based on the results, we can conclude that firstly, a green inclusive leadership strategy can significantly increase the green behaviour of employees; secondly, environmental goals clarity and green organization identification play an integral role in mediating between green inclusive leadership and employee green behaviour; furthermore, green human resource management practices moderate the impact of green inclusive leadership on the identification of green organizations and the clarity of environmental goals.

5.2. Implications for Practices. Using the cognitive-affective processing system framework, we examine the relationship between green inclusive leadership and employees' green behaviour and draw the following implications for management practice:

(i) Enterprises must give the promotion effect of green inclusive leadership on employees' green behaviours a high priority. To be specific, the enterprise should be planned and targeted to develop green inclusive leadership, improve leadership's environmental protection knowledge and skills, establish green leadership, environmental protection, sustainable ideas, and concepts, to allow leaders to accept differences and open to green concepts, and actively promote green inclusive leadership. Furthermore, enterprise leaders should improve their interaction with employees on a two-way basis. As part of the communication process with employees, they should respect and acknowledge the efforts and contributions of each employee in environmental protection and encourage employees to express their opinions and suggestions

(ii) Besides attaching importance to inclusive green leadership, enterprises need to adopt and implement green human resource management practices so that employees' green behaviour can be more effectively promoted and the organization's sustainable development can be promoted. Specifically, relying only on the leader's leadership style for management has limits, as ensuring that the leader's values convince every employee is challenging. As a result, enterprises should establish a set of standardized rules and regulations related to green management, integrate environmental protection into each human resource management module, and provide institutional guarantees for leaders' green management behaviours. Implement a sound green human resource management system

(iii) Enterprises should emphasize employees' clear cognition and understanding of corporate environmental goals, as well as employees' green identification within the organization, in applying green inclusive leadership and green human resource management. Employees should be informed of the company's expectations for environmental goals and the environmental responsibilities they should take to incorporate them into their job duties. The organization should also establish a green consciousness and correct environmental concept among its employees, make them consistent with its environmental protection concept, let employees participate in the work to protect the environment, and encourage them to behave in a greener way

(iv) In addition to the management of enterprises, employees should also be inspired. Employees should pay attention to the importance of environmental goals in the workplace or in unusual places, actively cooperate with the initiative of green inclusive leadership, take the initiative to comply with the relevant regulations put forward by green human resource management, and take the initiative to make green behaviours. Employees should clearly realize that this is not only the behaviour that the enterprise values, but also the green behaviour that is beneficial to the country and even the world

5.3. Research Limitations and Further Research Directions. Due to the conditions, this paper still has the following

shortcomings: as a first step, we only explore the influence mechanism of green inclusive leadership on employee individual behaviour and explore the influence of leadership on employee behaviour from the perspective of individual perception. Insufficient research has been conducted on other levels and across levels. Examining the influence mechanism at the team and organizational levels can further expand the research in this area.

Additionally, based on the research data, the questionnaire was issued with certain limitations. In the future, research should expand the scope, provide prosperous research industries and regions, increase the number of representative studies, and make research conclusions more universal and extensible.

Furthermore, although this paper uses two-node questionnaire surveys, the data are still cross-sectional. Therefore, in the future, it can use longitudinal research methods to test the impact of green inclusive leadership on employee behaviour and examine the dynamic effect of green inclusive leadership on employees' green behaviours, improving the study's accuracy.

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 declared that they have no conflicts of interest regarding this work.

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Research Article

Spatiotemporal Relationship between Ecosystem Service Value and Ecological Risk in Disaster-Prone Mountainous Areas: Taking the Upper Reaches of the Minjiang River as an Example

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Mountainous areas are susceptible to disasters; the frequent occurrence of disasters drives the changes in ecosystem service value (ESV) and also brings certain ecological risk, which further increases the incidence of disasters. However, few scholars have investigated the spatiotemporal correlation between the ESV of disaster-prone mountainous areas and ecological risk index (ERI) with basin as the unit. This paper aims to clarify the spatial relationship between ESV and ERI under the changes of land use. Taking the upper reaches of the Minjiang River as the study area, the authors collected the land use data of 2000–2020, estimated ESV by the value equivalent factor per unit area method, and constructed the ERI. On this basis, the relationship between ESV and ERI was investigated in details. The results show the following: (1) From 2000 to 2020, the total ESV exhibited a fluctuating upward trend. The spatial distribution of ESV was greatly affected by slope and altitude; an important reason for the rising ESV in the study area is the increase of forest area and water area. (2) The upper reaches of the Minjiang River had a generally low ERI and relatively good overall ecoenvironment. After 2010, however, the ecological risk continued to rise. Most of the strongly high risk areas are areas with frequent human activities, such as low-altitude areas and river banks. (3) There is a spatial correlation and coupling between ESV and ERI in the study area; i.e., the strongly high ESV areas generally had a low ecological risk. The correlation intensified with the elapse of time. The changes in the service value of regional ecosystems driven by unreasonable land use will have a great impact on the ecoenvironment. By clarifying the spatiotemporal relationship between ESV and ERI, this research provides theoretical basis and data support to the formulation of ecoenvironmental restoration and protection plans for the upper reaches of the Minjiang River and to the coordinated development between society, economy, and ecoenvironment in the region.

1. Introduction

Ecosystem service assessment and ecological risk assessment are closely correlated with each other. Both are important aspects of ecosystem quality assessment [1]. Ecosystem services are the supply of various material products and intangible services obtained by humans from the ecosystem. The ecological risk mirrors the ecoenvironmental situation and reflects the security of regional ecology [2, 3]. The integration of ecosystem services and ecological risks can effectively introduce ecosystem services into ecological risk assessment, making ecosystem assessment more complete [4]. At present, the research on ecosystem services and that on ecological risks have gradually

moved closer to each other, forming new research hotspots and directions [5].

Land use, the closest bond between human and nature, refers to the way and state of human utilization of the natural features and functions of land [2, 6–10]. Land use changes are an integral part and a major driver of the variation in regional ecoenvironment. It comprehensively reflects the interaction between multiple factors within the terrestrial ecosystem. The continuous change of land use patterns brings changes to the service functions of regional ecosystem [11]. In recent years, many scholars started to study ecoenvironment from the angle of land use. There is a close relationship between land use and ecosystem services. Different types of land use vary significantly in the value of individual ecosystem services. The changes in land use are often resulted from the combined effects of human activities and natural changes, which in turn affect regional ecosystems [12]. The land use pattern affects the living environment and the distribution of resources, as well as the ecosystem service functions. The difference in ecosystem services stems from the disparity in land [13, 14]. Costanza et al. [15] were the first to determine the calculation theory and method of ecosystem service value (ESV). Xie et al. [14, 16] proposed the ESV equivalence system in the light of the actual situation of China and constructed a dynamic evaluation system for China's territorial ecosystem values based on the value equivalent factor per unit area method. Since then, the ESV theory has been continuously applied to assess the ecosystem service capabilities of watersheds, farmlands, cities, wetlands, etc. [17–20]

With the deepening of research, the ecosystem risk caused by land use changes has piqued more and more interests. The land cover variation induced by land use change alters the structure and function of the ecosystem, which in turn influence a series of ecological processes, such as the air, soil, water cycle, and biology [21]. Land use changes, especially land degradation, will bring a string of ecological risks and worsen ecosystem services. Therefore, how to quantify the ecological risk brought by land use has become the focus of research. Relevant research methods include the relative risk model (RRM) [22], the $R = P \times D$ model, and the ecological risk index (ERI) [23]. Many algorithms are emerging in the meantime, such as genetic algorithm, ant colony algorithm, and particle swarm optimization [24]. On this basis, multiple evaluation frameworks have been established for the ecological risk under land use changes, namely, the pressure-state-response (PSR) framework, the risk probability-sensitivity-intensity (PSI) framework, the driver-pressure-state-response (DPSR) framework, and the driver-pressure-state-impact-response (DPSIR) framework. These frameworks were utilized to quantify the land use ecological risk in different regions [25–27].

The above analysis shows that land use variation affects the ESV. Irrational use of land will bring ecological risks of different degrees. The relationship between ecosystem and ecological risk under land use changes has always been a key research problem. However, few scholars have investigated the mountain-plain transition zones, which are fragile ecologically and prone to mountain disasters. The upper reaches of the Minjiang River, a typical mountain-plain transition zone in China, serve as a key ecological barrier of the Chengdu Plain, and directly bear on regional ecological security. According to the existing research results, there is a spatiotemporal correlation between the ESV and ecological risks [1, 4, 5]. Based on this understanding, this paper assumes that the spatiotemporal correlation exists in the upper reaches of the Minjiang River and relies on the value equivalent factor per unit area method to quantify the spatiotemporal evolution of ESV and ERI in the study area, using the data on land use. On this basis, the spatial relationship between ESV and ERI was investigated in details. The research results clarify the ecosystem quality of the upper reaches of the Minjiang River from both ESV and ERI, help to grasp the spatiotemporal relationship between ESV and ERI, provide basic data support to the coordinated promotion of the ecosystem service improvement and comprehensive management of the ecoenvironment in the upper reaches of the Minjiang River, and promote the synergistic development between society, economy, and ecoenvironment in the region.

2. Materials and Methods

2.1. Study Area. The upper reaches of the Minjiang River belong to the eastern margin of the Qinghai-Tibet Plateau (30.7°N–33.2°N, 102.5°E–104.3°E) (Figure 1). With a drainage area of about 24,783.08 km^2, this region has a great significance ecologically, for it is the primary ecological barrier and water source of the Chengdu Plain. The terrain of the region is high in the northwest and low in the southeast. The mean elevation surpasses 3,000 m. The region is crisscrossed by river valleys with a height difference of more than 5,000 m. There is a huge elevation difference (2,000–3,000 m) between the ridges and river valleys. The study area has various types of landforms, ranging from plateaus to high mountains. Strong tectonic movements have brought frequent geological disasters to the region. Extremely serious mountain geological disasters have hit the region, namely, the Wenchuan earthquake, and the Maoxian County high landslide. In addition, the ecoenvironment is fragile, and soil erosion is serious. As a plateau alpine monsoon climate zone, the study area features vertically distributed climate belts, as well as cold winters and cool summers. The soil types are mainly alpine meadow soil, brown soil, yellow-brown soil, and cinnamon soil; the vegetation types are mainly coniferous forest, shrub, alpine meadow, subalpine coniferous forest, and dry valley shrub.

2.2. Research Data. The land use data come from the Resource and Environment Science and Data Center (http://www.resdc.cn), and its spatial resolution is 30 m × 30 m. Using ArcGIS, the land use types were classified into six categories: farmland, forestland, grassland, water area, construction land, and unused land. The main information source is the remote sensing images shot by Landsat satellites. The data of 2000, 2005, and 2010 were taken from the remote sensing images of Landsat-TM/ETM. The data of 2015 and 2020 were taken from those of Landsat 8. The

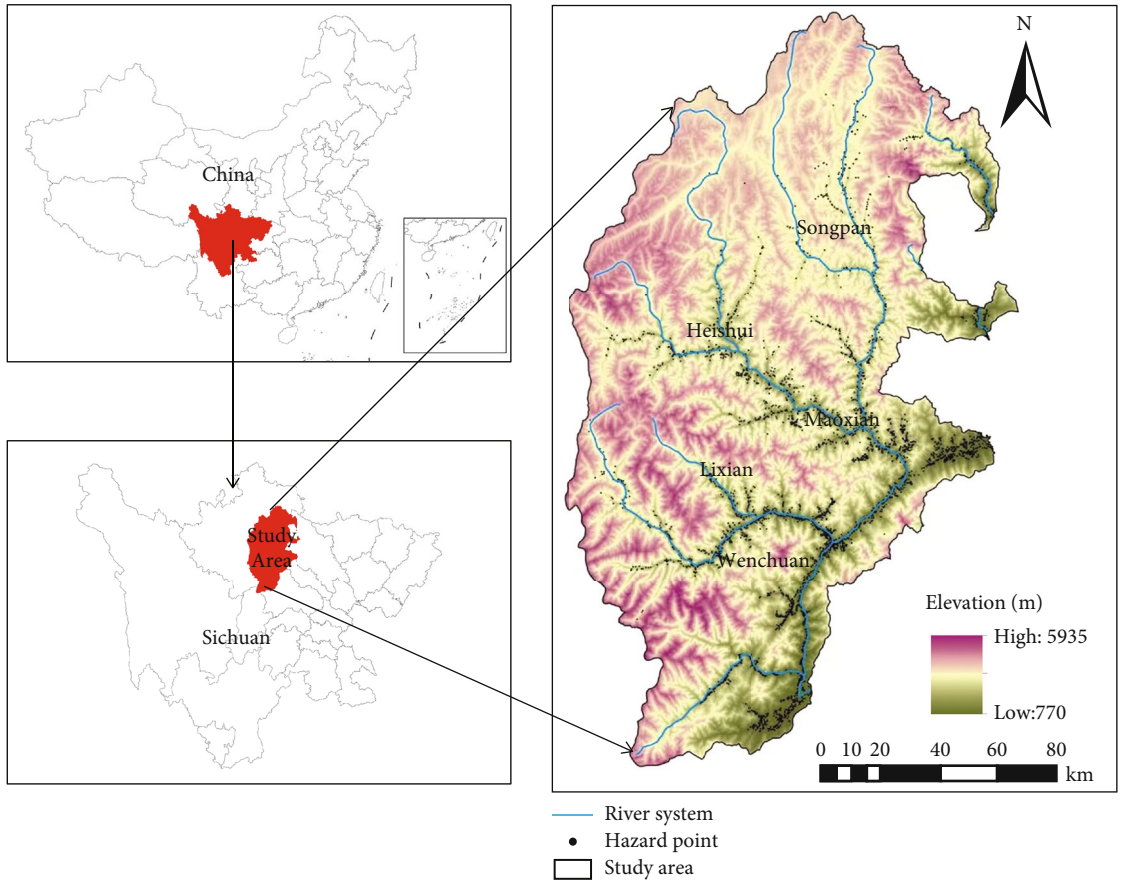


Figure 1: Location of study area.

highly precise data guarantee the reliability of the calculated ESV values in the subsequent analysis. The DEM data were obtained from SRTM (Shuttle Radar Topography Mission) of Resources and Environmental Science and Data Center, with a spatial resolution of 30 × 30 m, an absolute horizontal accuracy ±20 m, and an absolute elevation accuracy ±16 m. The elevation and slope were extracted from the downloaded DEM. The socioeconomic data, namely, crop yield per unit area and sown area of crops, are mainly gathered from *China Statistical Yearbooks* and *Sichuan Provincial Statistical Yearbooks*. The food prices were obtained from http://www.scgrain.com/.

2.3. Methods. ESV. Ecosystem services refer to the life support products and services obtained directly or indirectly through the structure, process, and function of the ecosystem, which are usually evaluated by market valuation and consumer willingness to pay [5]. Costanza et al. divided the global ecosystem services into 17 different types of services and 16 biomes and calculated the global annual ESV, making the quantitative assessment of ESV a research hot topic. This method has been widely to evaluate the value of various ecosystem services [15]. However, their analysis is unfolded on the global scale. If their method is directly adopted, the ESV of the study area in this research will be estimated with large deviations.

Taking the situation in China as the baseline, Xie et al. [14] formulated the following calculation model of economic value, in reference to Costanza's research and the studies of ecological scholars in China [14, 16]:

$$VC_k = 1/7 \sum_{i=1}^{n} \frac{m_i P_i q_i}{M}, i = (1, 2 \cdots \cdots n), \quad (1)$$

where VC_k is the economic value of the food production function provided by a unit area of farmland ecosystem (yuan/hm^2); i is the type of crop; P_i is the man price of type i crop (yuan/kg); q_i is the per unit area yield of type i crop (kg/hm^2); m_i is the sown area of type i crop (hm^2); M is the total sown area of all grain crops.

The ESV in the upper reaches of the Minjiang River can be calculated by:

$$ESV = \sum (A_k \times VC_k), \quad (2)$$

where ESV is the total value of ecological services; A_k is the area of the kth type of land use.

To eliminate the ESV gap of different types of land use between the study area and China, this paper extracts slope and elevation from the DEM data on the upper reaches of the Minjiang River. Drawing on the socioeconomic data like grain yield per unit area and crop sown area, the economic

Table 1: Ecological value coefficients of various land use types in the upper reaches of the Minjiang River (yuan/hm^2).

Primary type	Secondary type	Farmland	Forest land	Grassland	Water area	Construction land	Unused land
Supply services	Food production	1109.63	404.69	130.55	1044.36	0.00	0.00
	Raw material production	522.18	926.87	182.76	300.25	0.00	0.00
	Water conservation	26.11	483.02	104.44	10822.18	0.00	104.85
Regulation services	Air regulation	874.65	3067.81	665.78	1005.20	0.00	33.88
	Climate regulation	469.96	9177.31	1749.30	2989.48	0.00	26.21
	Waste disposal	130.55	2597.85	574.40	7245.25	0.00	133.46
	Hydrological regulation	352.47	4582.13	1279.34	133469.21	0.00	383.80
Support services	Soil conservation	1344.61	3733.59	809.38	1214.07	0.00	25.14
	Nutrient recycling maintenance	156.65	287.20	65.27	91.38	0.00	0.00
	Biodiversity conservation	169.71	3394.17	731.05	3328.90	0.00	25.62
Cultural services	Entertainment culture	78.33	1488.21	326.36	2467.30	0.00	16.94

value equivalent factor per unit area of ESV in the upper reaches of the Minjiang River was solved and corrected as 1,305.45 yuan·hm^{-2}. On this basis, the authors derived the ESVs per unit area of different lands in the study area (Table 1).

ERI. Ecological risk refers the risk that an ecosystem and its components bear under the disturbance of natural or human activities. It refers to the possible adverse effects of uncertain accidents or disasters on the structure and function of ecosystems in a certain area. Numerous studies have shown a close correlation between land use change and ecological risk and considered land use change the greatest impactor of the ecosystem [5]. Using the area ratio of each land type, the authors constructed the ERI and built the empirical relationship between land use structure and regional ecological risk. The relationship was used to measure the relative magnitude of ecological risk in grid units [23]. The ERI can be calculated by:

$$ERI = \sum_{i=1}^{N} \frac{A_{ki}}{A_k} W_i, \tag{3}$$

where ERI is the ecological risk index; A_k is the total area of the kth sample plot; A_{ki} is the total area of type i land in the kth sample plot; W_i is the ecological risk intensity of type i land; N is the number of types of land use.

Comparing different grid sizes, it was found that a large grid size would sacrifice the coupling effect, and a small grid size would result in data redundancy. Finally, 1 km × 1 km was chosen as the optimal grid size. This paper sets the grid size to 1 km × 1 km, with a total of 24,927 grids. The ERI of each type of land use was determined through literature review, in consultation with experts on land management and ecological risk evaluation [28]. The mean ERI of each grid was solved. Through analytical hierarchy process (AHP), the ecological risk intensity W_i of different types of land use was solved: forest land 0.0427, farmland 0.1916, construction land 0.3934, water area 0.1425, grassland 0.0726, and unused land 0.1572 [28].

Coupling Coordination Degree (CCD) Model. The CCD model reflects the interplay and action mechanism, and coordination state among the systems in the study area. It is widely used in ecoenvironmental research. This paper adopts the CCD model to measure the coupling coordination relationship between the ESV and ERI in the upper reaches of the Minjiang River [27, 28]. The CCD can be calculated by:

$$C = \frac{ESV_i^{\,k} \times ERI_i^{\,k}}{(\alpha ESV_i + \beta ERI_i)^{2k}}, \tag{4}$$

$$D = \sqrt{C \times T}, \tag{5}$$

$$T = \sqrt{\alpha ESV_i \times \beta ERI_i}, \tag{6}$$

where C is the coupling degree index; D is the CCD index; T is the composite evaluation index of the two factors; ERI_i is the normalized ERI of the ith year; $ESVi$ is the normalized ESV of the ith year; α and β are coefficients to be determined. Here, $\alpha = \beta = 0.5$.

Exploratory Spatial Analysis (ESA). The spatial relationship between ESV and ERI in the upper reaches of the Minjiang River can be judged by the global spatial autocorrelation index [29]:

$$EBI = \frac{m}{\sum_{i=1}^{m}\sum_{j=1}^{m}} \frac{\sum_{i=1}^{m}\sum_{j=1}^{m}\omega_{ij}R_iR_j}{\sum_{i=1}^{m}\left(R_i - \bar{R}\right)^2}. \tag{7}$$

The EBI reflects whether the spatial values of the object are similar in space. If $EBI = 0$, the two values are randomly distributed. In formula (7), ω_{ij} is the spatial weight; R is the mean attribute value; R_i and R_j are the mean of factors i and j, respectively; n is the number of units. If $|Z| > 1.96$, the correlation is significant.

As a decomposed form of Moran's I, the local spatial autocorrelation reflects the internal correlation within the study area. The Moran's I index was corrected by

Table 2: ESVs in 2000–2020.

Time (year)	Statistical type	Farmland	Forest land	Grassland	Water area	Construction land	Unused land	Sum
2000	Value (10^8 yuan/year)	3.5264	339.2511	84.6721	6.5496	0.0000	0.0081	434.0073
	Proportion (%)	0.8125	78.1671	19.5094	1.5091	0.0000	0.0019	100
2005	Value (10^8 yuan/year)	3.5135	338.8580	84.7706	6.5965	0.0000	0.0081	433.7467
	Proportion (%)	0.8100	78.1235	19.5438	1.5208	0.0000	0.0019	100
2010	Value (10^8 yuan/year)	3.6680	350.5846	81.1639	19.5797	0.0000	0.0233	455.0195
	Proportion (%)	0.8061	77.0482	17.8374	4.2030	0.0000	0.0051	100
2015	Value (10^8 yuan/year)	3.6336	350.4870	81.1593	19.3758	0.0000	0.0233	454.6789
	Proportion (%)	0.7992	77.0845	17.8498	4.2614	0.0000	0.0051	100
2020	Value (10^8 yuan/year)	3.6332	350.0814	81.1945	20.7425	0.0000	0.0235	455.6751
	Proportion (%)	0.7973	76.8270	17.8185	4.5520	0.0000	0.0052	100

empirical Bayesian method to obtain the corrected local autocorrelation index EBI:

$$EBI_i = \left(R_i \sqrt{V_i} \sum_{j=1}^{m} \omega_{ij} \left(R_{ij} \sqrt{V_i} \right) \right). \quad (8)$$

3. Results

3.1. Spatiotemporal Evolution Features. The ESVs in the upper reaches of the Minjiang River in 1995–2020 were solved by formula (1), in reference to Table 1. The results are shown in Table 2.

As shown in Table 2, the total ESV of the study area was 4.34×10^{10} yuan, 4.33×10^{10} yuan, 4.55×10^{10} yuan, 4.55×10^{10} yuan, and 4.56×10^{10} yuan, respectively, in 2000, 2005, 2010, 2015, and 2020. The total value firstly decreased and then gradually increased, but the overall variation was small. The annual mean increase was merely 1.08×10^8 yuan. This is consistent with the conclusion of Xiang et al. [29].

Throughout the research period, the ESV proportion of each land use changed, but the changes did not affect the basic structure of ESV. The proportion of forest land in ESV was always more than 75% in the 25 years. The other types of land had a much smaller ESV than forest land. Hence, forest land is the dominant landscape in the upper reaches of the Minjiang River. Grassland is distributed more widely than any other type of land. However, the ESV per unit area of grassland was far smaller than that of forest land. That is why grassland ranked the second in ESV proportion throughout the study period.

In terms of the spatiotemporal variation in ESV, the ESV of the study area reduced by 2.61×10^7 yuan from 2000 to 2005. The main reason is the decline in the total ESV of forest land. Grassland was the land type with the largest ESV increment (5.72×10^4 yuan), while forest land was the land type with the largest ESV decrement (5.31×10^6 yuan).

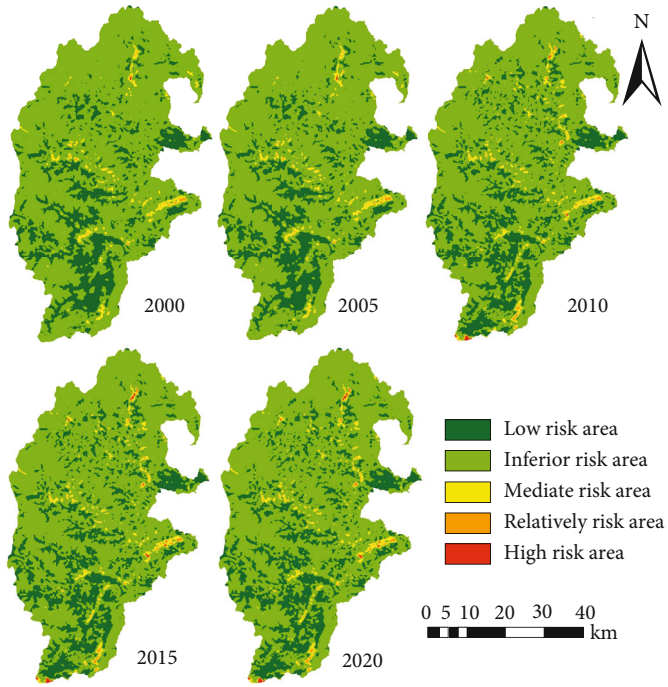
From 2005 to 2010, the ESV of the study area saw a net growth of 2.13×10^9 yuan, up by 4.9% from the previous period. The main contributor is the ESV growth (196.82%) of the water area. In this period, forest land also witnessed a rapid growth of total ESV. Both water area and forest land promoted the rapid growth of ESV.

From 2010 to 2020, the ESV of the study area increased rather slowly, up by only 0.14%, with a net increase of 6.56×10^5 yuan. In this period, the water area's ESV continued to increase, realizing a net growth of 1.16×10^6 yuan. On the contrary, the ESV of forest land dropped sharply by 5.03×10^5 yuan.

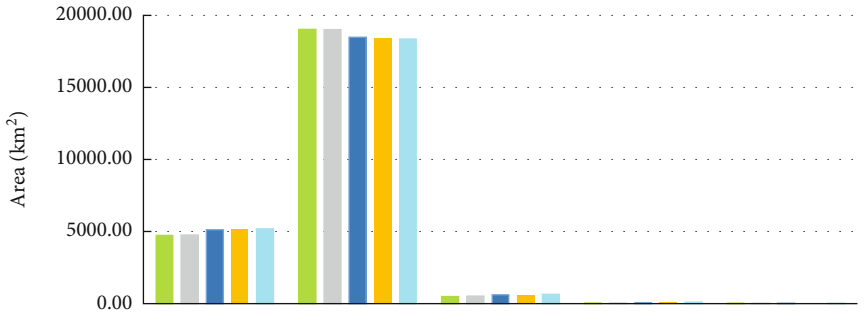
Although the uncontrolled expansion of farmland was controlled by the grain for green policy, the high ESV forest land shrunk in the period, owing to the complex topography and frequent disasters in the Minjiang River Basin. As a result, the ESV growth driven by the water area was offset by the ESV loss of forest land. Overall, the total ESV of the study area did not change much in the period. These results suggest that the relevant policies in the upper reaches of the Minjiang River benefit ESV increase, but the rapid loss of ESV in local areas calls for more attention.

3.2. Spatiotemporal Evolution Features of ERI. The stable model was used to perform ordinary kriging interpolation on the ecological risk values of 24,927 sample areas in the upper reaches of the Minjiang River during the study period, and the ERI was divided into strongly high ecological risk (≥0.20), slightly high ecological risk (0.15–0.20), medium ecological risk (0.10–0.15), slightly low ecological risk (0.05–0.10), and strongly low ecological risk (<0.05). The area of each level was counted by the spatial analysis tool of ArcGIS10.2. The results are shown in Figure 2.

As shown in Figure 2(a), there was a certain difference in the spatial distribution of ERI in the upper reaches of the Minjiang River from 2000 to 2020, but the overall change was not large. Most of the areas were strongly low and slightly low ecological risk areas. The strongly low ecological risk areas were relatively concentrated, while the strongly high and slightly high ecological risk areas were scattered and not connected. On the spatiotemporal variation of ecological risk, the trend of 2000–2005 is dominated by the change of strongly low-risk areas in the center of the study area, that of 2005–2010 is dominated by the change of strongly high risk areas in the north and south of the



(a) Ecological risk distribution map



Unit: km²	Low risk	Inferior risk	Mediate risk	Relatively risk	High risk
2000	4747.14	19027.10	505.85	35.95	1.81
2005	4755.56	19013.88	509.98	36.84	1.89
2010	5113.54	18495.65	617.41	74.27	17.21
2015	5165.28	18415.05	623.42	88.90	25.30
2020	5196.36	18374.17	632.19	90.02	25.34

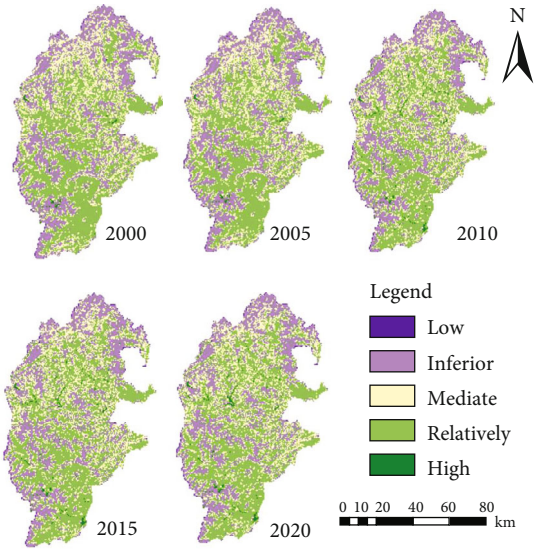
(b) Area statistics of each ecological risk level

Figure 2: Spatiotemporal distribution of ecological risks and the area statistics of each ecological risk level.

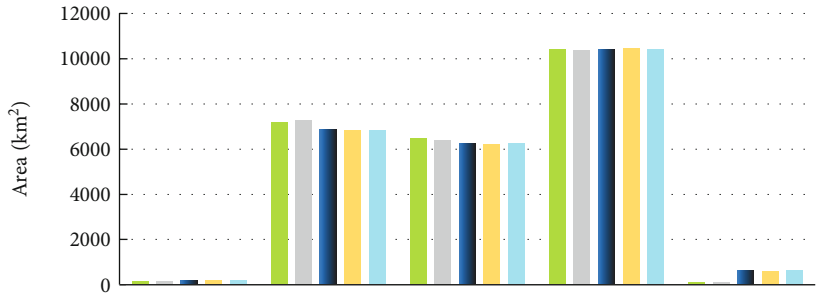
study area, and that of 2010–2020 is not significant. The slightly high and strongly high risk areas were located in Chuanzhusi Town and Jin'an Town in the north; Luhua Town, Weigu Township, and Seergu Town in the middle; Shunfu Township and Weimen Township in the east; and Xuankou Town and Sanjiang Town in the south. The strongly low ecological risk areas were relatively concentrated, mainly in Gengda Town, Caopo Township, Putou Town, and Puxi Township in the south, and Baiyang Township in the central and eastern part of the basin. The northern and southern margins of the study area were the main distribution areas of slightly low ecological risk areas, mainly involving Chuanzhusi Town, Caoyuan Township, Minjiang Township, Yanyun Township, Yinxing Township, and Wolong Town.

As can be seen from Figure 2(b), it should be noted that from 2020 to 2020, although the strongly low and slightly low ecological risk areas dominated the study area, the slightly low ecological risk areas decreased from 19027.1 to 18374.1 km^2. Meanwhile, the slightly high and strongly high risk areas in 2020 were 2.5 times and 14 times that in 2000, respectively. Overall, there was a continuous growth of ecological risks in local areas.

3.3. Spatial Relationship between ESV and ERI. The spatial coupling index between ESV and ERI was calculated by



(a) Coupling degree distribution map



Unit: km^2	Low	Inferior	Mediate	Relatively	High
2000	175	7187	6477	10393	107
2005	174	7264	6403	10390	108
2010	186	6819	6247	10471	616
2015	185	6847	6235	10469	603
2020	193	6837	6248	10435	626

(b) Total area of each coupling degree

Figure 3: Coupling relationship between ESV and ERI and total area of each coupling degree.

formula (4). Then, the coupling degree of each year was divided into five levels by the natural breakpoint method. The total area of each coupling degree was summarized by ArcGIS 10.2 (Figure 3).

As shown in Figure 3(a), the coupling degree of ESV and ERI in the upper reaches of the Minjiang River exhibited an obvious spatial differentiation, and the overall coupling degree was low in the north and high in the south. The areas with slightly high coupling degree were the most widely distributed. Such areas were mainly distributed like patches in the river valleys in Wenchuan County and Lixian County and scattered in other places. The slightly low coupling degree was mainly observed in the high-altitude areas; the medium coupling degree was mostly detected along the margins of the areas of strongly high coupling degree. In addition, the strongly high and strongly low coupling degrees were sporadically distributed.

As shown in Figure 3(b), the areas with strongly low or strongly high coupling degree occupied a very small portion of the study area. In the study period, however, both types of areas exhibited a growing trend. The areas of strongly low coupling degree expanded from 171 to 193 km^2, while those of strongly high coupling degree increased by nearly six times, from 105 to 626 km^2.

In general, the areas with slightly low, medium, and slightly high coupling degrees shrunk slightly in the study period. The areas with slightly high coupling degree boasted the highest proportion (43%), while the proportions of the areas with slightly low coupling degree and those with medium coupling degree did not change much, which remained at around 29% and 26%, respectively. Judging by the coupling between ERI and ESV, the high ESV areas are coupled closely with the low ERI areas, indicating the spatial correlation between ESV and ecological risk.

Further analysis of the CCD between ESV and ERI in the study area (Figure 4) shows that ERI and ESV were in coordinated development in most areas, but large stretches of uncoordinated development were observed. From 2000 to

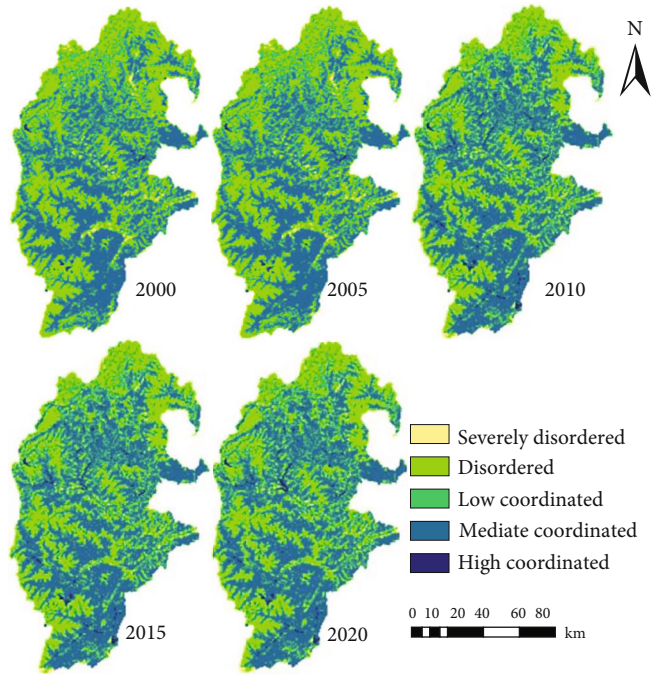


Figure 4: CCD between ERI and ESV.

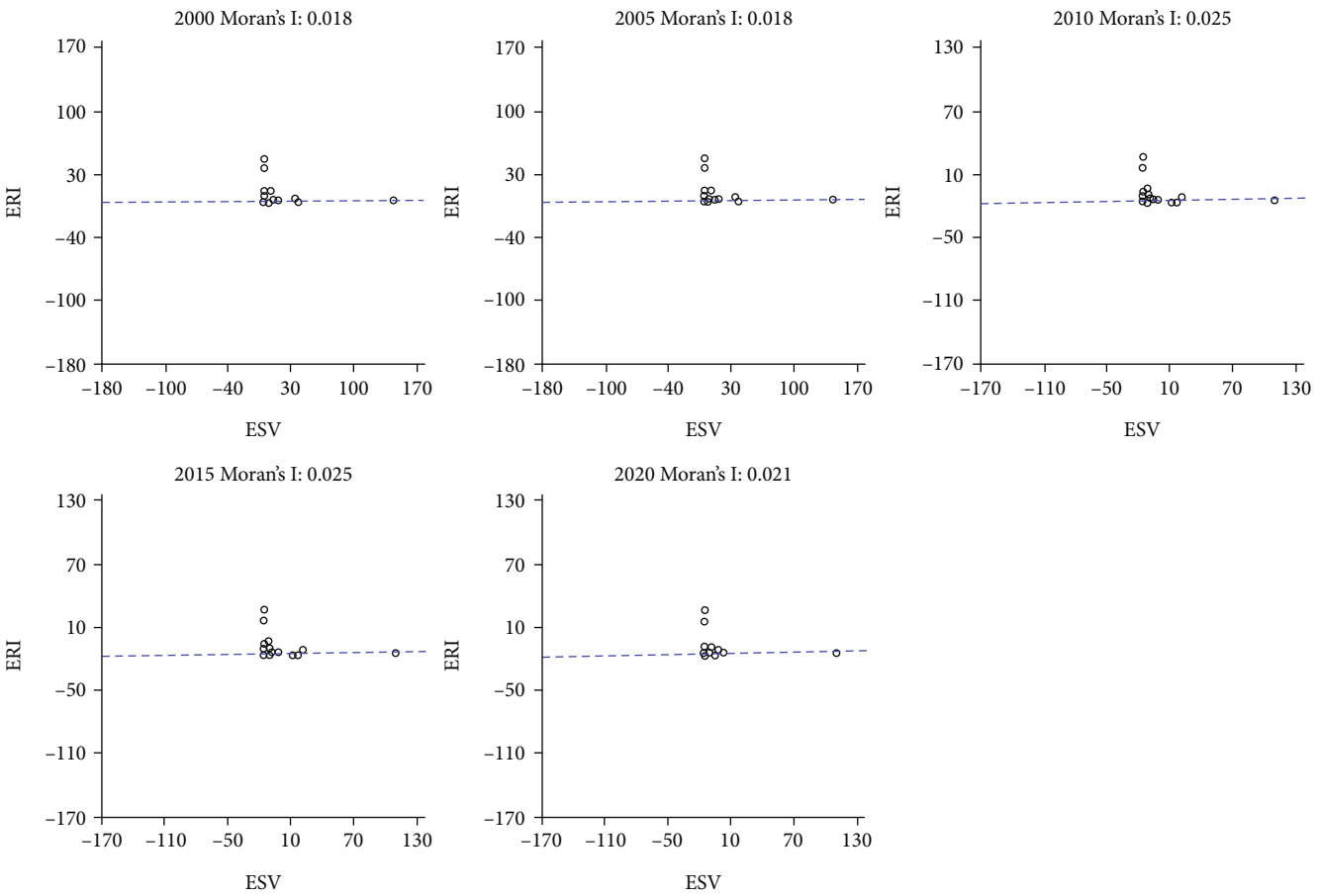


Figure 5: Scatterplot of Moran's *I*.

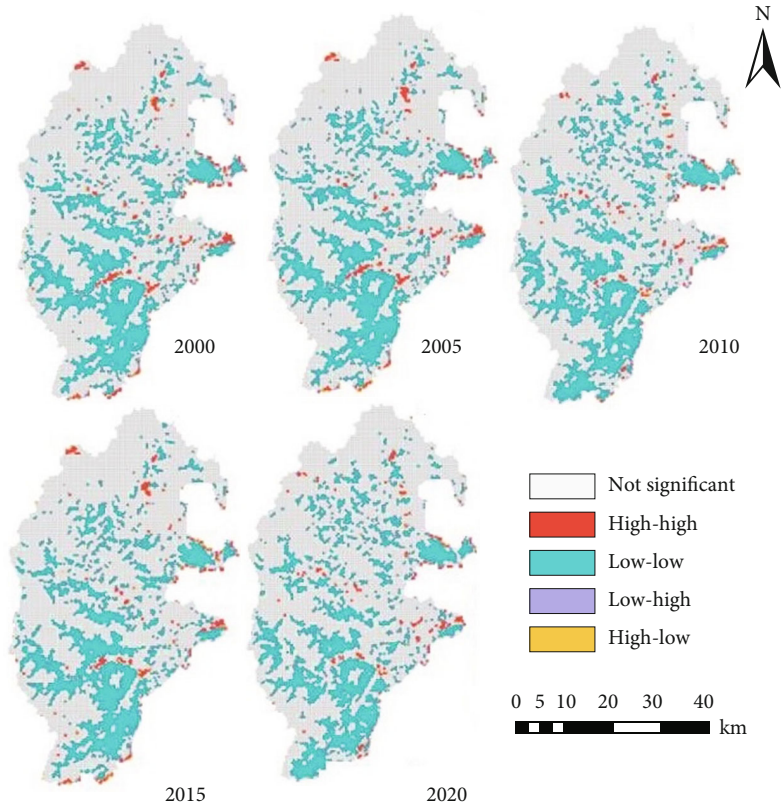


Figure 6: Scatterplot of local spatial autocorrelation.

2005, the CCD was high in the middle and south, forming patches in the south, and low and scattered in the north. From 2005 to 2020, the CCD in the north was optimized, and the strongly high coordinated areas increased along river valleys. In terms of the type of coupling coordination, the strongly high coordinated areas occupied a small portion, which increased significantly since 2010. The increase was mainly achieved in river valleys of Heishui County, Lixian County, and Wenchuan County. Many strongly uncoordinated areas existed in scattered form from 2000 to 2015. From 2005 to 2020, the strongly uncoordinated areas were generally on the decline.

Spatial Relationship Analysis Based on Autocorrelation Method. The spatial autocorrelation index between ESV and ERI was calculated by formula (7). The results in Figure 5 show that the Moran's I between ESV and ERI in the upper reaches of the Minjiang River was 0.018, 0.018, 0.018, 0.025, 0.025, and 0.021, respectively. EBI was always greater than 0, indicating that there was a certain spatial correlation. The overall correlation was not high. The global spatial correlation analysis shows that the spatial distribution of ERI and ESV in the upper reaches of the Minjiang River was not random. There was a certain correlation between ecological risk and ESV, but the relationship was relatively weak. After 2005, the degree of correlation continued to increase. However, the correlation started to weaken in 2020. Therefore, it is necessary to take targeted ecological restoration measures, optimize the ecosystem environment in discrete areas, and continuously enhance the ecosystem service capacity.

Further, the local spatial autocorrelation between ESV and ERI was calculated by formula (8). The results in Figure 6 show that the high-high and low-low cluster areas of ESV and ERI correlation in the study area were basically stable. The high-high cluster areas were scattered in the middle; the low-low areas were mostly concentrated in river valleys; the low-high and high-low areas were rather few. ESV and ERI were uncorrelated in most cases.

When it comes to the time-variation of the spatial correlation between ESV and ERI, after 2005, the high-high areas in the north declined clearly, while those in the south became less concentrated. This trend is closely associated with the grain for green project and mainly affected by human activities. Hence, the high-high areas largely fell to regions with intense human activities.

There were many low-low areas of ESV-ERI correlation, most of which belonged to the south and middle of the study area. A few low-low areas concentrated in the east. Thus, the low ERI areas have a slightly high ESV. The main reason is as follows: this area is mainly an ecological reserve, with a humid and mild climate. After the Wenchuan earthquake, ecological restoration and protection were accelerated, the vegetation coverage was fully restored, and the landscape was no longer fragmented.

4. Conclusions and Discussion

This paper targets the main ecoenvironmental problems in the upper reaches of the Minjiang River, a typical

mountain-plain transition zone in China, and quantifies the spatiotemporal evaluation features of ESV and ERI in the region, using the land use data, and, on this basis, explores the spatial relationship between the two factors. The main conclusions are as follows:

(1) From 2000 to 2020, the total ESV exhibited a fluctuating upward trend; the areas with a slightly high ESV increased with fluctuations and were distributed relatively concentratedly. In most towns and townships in the study area, the ESV belonged to the slightly low and slightly high levels. The spatial distribution of ESV was greatly affected by slope and altitude, which led to obvious differences in its spatial distribution

(2) The upper reaches of the Minjiang River had a strongly to slightly low ERI, and a slightly low ERI. The medium, slightly high, and strongly high risk areas took up small proportions in the study area, a sign of relatively good overall ecoenvironment. From 2005 to 2010, the ecological risk changed violently, owing to the Wenchuan earthquake and its secondary disasters. After 2010, slightly high and strongly high risk areas continued to widen. The new slightly high and strongly high risk areas mainly belonged to regions with frequent human activities, such as low altitude areas and river banks

(3) In the study area, very few regions had strongly low or strongly high coupling degrees between ESV and ERI, but more and more regions witnessed a strongly high coupling degree. The CCD was mainly strongly low, medium, and strongly high and went through violent spatial changes with the elapse of time. There was a certain spatial correlation between ESV and ERI. The low-low cluster feature was very prominent, suggesting that high ESV areas tend to have a slightly low ERI

(4) The research on the spatiotemporal relationship between ESV and ERI can better link human well-being with the sustainable development of the ecoenvironment and provide decision-making basis for regional ecoenvironmental protection and risk management. This paper focuses on the spatiotemporal relationship between ESV and ERI in the upper reaches of the Minjiang River. However, the changes of regional ESV and ERI are the combined results of multiple factors. Admittedly, this study focuses on the temporal and spatial relationship between ESV and ERI. Yet it fails to fully reflect the relationship and influence the mechanism and evolution trend of these two factors. To make up for the gap, the future research will build a more precise and applicable evaluation system, comprehensively evaluate regional ESV and ERI changes under the combined influence of multiple factors, provide inspiration for IPBES global ecosystem service assessment and IPCC AR6, and contribute more to the control of global warming

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Environmental Policy Selection and Town Resident Satisfaction Assessment: Under Governance of Localism

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Upper authorities have tightly controlled local budgets, especially at the administrative township level. Taiwan has been facing this particular phenomenon for a long period. This article explains how a township, before general elections, sees the choice of an improved environmental administrative work plan as a political advantage and uses simple and easy-to-use collective decision-making to assist. Then, survey residents' perceptions of implementing the new environmental policy. The research results are discussed not only as suggestions to improve the effectiveness of township public environmental policies and to respond to the needs of civilians appropriately but also to lead future research directions.

1. Introduction

The state determines all taxes, although many countries have developed new administrative measures that reconcile public services and funding while also considering the fairness of fiscal transfers, such as the introduction of specific local charges. For example, Horvat et al. [1] found that Slovenia's local governments could not raise public services funds. Nonetheless, Kirchgässner [2] argues that a stronger central government with a high degree of integration of administrative resources appears to increase the probability of ending the integration event in the context of high financial reliance on central government financing. However, this possibility can also easily lead to stagnation of local investment, especially in the absence of external funding [1]. As a result, public service resources lack professional governance and flexibility. In 2005, the Slovenian government amended the Financing of Municipalities Act. The five years following these amendments are worthy of attention—specifically, their impact on intergovernmental relationships and citizens' satisfaction with the loose budget allocation policy. For example, increasing the debt at the municipal level has even derived from the common phenomenon of "budget federalism" [3, 4].

A similarly interesting phenomenon has also occurred in Taiwan. The regional-level government revenue and expenditure expanded dramatically from 2010 to 2014, in which numerous county-level governments upgraded to a special municipal level because of public administrative and organizational reforms. The supreme administrative authority of Taiwan has granted extended powers to the local governments within 14 municipalities and 6 special municipalities. According to polls regarding citizen satisfaction with Taiwanese mayors, the chief administrative officers of the municipalities that had access to more financial resources did not always achieve the highest rankings. The lowest-ranked mayors predominantly came from regions affected or controlled by local political factions [5]. As the strategic selection of appropriate policies is the key to winning over voters, local administrative authorities must prioritize practical and essential issues for their residents instead of spending lavishly on projects just for face value.

In the previous discussion on this issue, very little literature discusses this issue in depth. Therefore, this empirical study attempts to reveal township governments' environmental administrative work factors that stimulate voter support before the general election. This study involved field-level governments adopting a multicriteria decision-making approach

(MCDM) in selecting focused environmental administrative work options. Then, half a year after the policy was implemented, a survey was conducted among the residents of the interviewed townships to survey perceptions of the new policy. The findings yielded several interesting results, particularly regarding the personal dynamics of township leaders in pushing for new administrative work policies. In addition, the phenomenon of "buying policy votes" has also been scrutinized.

This case study is aimed at solving the best township-level environmental administrative policy implementation system. Public administration problem-solving generally requires grasping principles that are easy to understand and use [6–8]. To this end, the ideal solution similarity ranking technique (TOPSIS) is introduced in this work rather than the commonly used qualitative decision-making techniques e.g., the Delphi, forced group discussion. We then analyze the results of resident satisfaction surveys in the case of the township and other highly homogeneous townships that have not implemented the new policy.

The following part introduces the TOPSIS to the problem of local administrative policy solution selection. Secondly, through descriptive statistical analysis, compare the differences in the satisfaction of township residents before and after the implementation of the new environmental policy, and discuss related phenomena. The final section concludes our findings.

2. TOPSIS-Selecting an Appropriate Policy in a Simple Way

Most optimization methods utilized in decision-making have been introduced as a response to the optimal solution to study a variety of administrative situations. However, simple and easy-to-use methods are still less discussed in environmental administration. TOPSIS was proposed by Chen and Hwang [9] and extended by Hwang and Yoon [10]. The rationale for the method is the option of the chosen choice closest to the ideal solution; the closer the two are the better. The main assumption of this model is to help decision makers avoid finding the maximum deviation from the negative ideal value (worst solution), and when the value is closer to the positive ideal value, it is the optimal solution [11]. The technique has been successfully applied to environmental improvement strategies [12], mass transportation fuel selection [13], large project solutions [14], highway bus route selection [15], and even at contributions for regional economic revitalization [16], as well as artwork surveys [17].

The TOPSIS procedure consists of the following six steps:

(1) Integrate the normalized decision matrix. The normalized value r_{ij} is calculated as

$$r_{ij} = f_{ij} / \sqrt{\Sigma_{j=1}^{j}, \mathrm{f}_{ij}^2}, j = 1, \cdots, J, \mathrm{i} = 1, \cdots \mathrm{n}. \quad (1)$$

(2) Measure the weighted normalized decision matrix. The normalized weighted value v_{ij} is calculated as

$$v_{ij} = w_i r_{ij}, j = 1, \cdots J\,; i = 1, \cdots, n, \quad (2)$$

where w_i is the weight of the ith attribute or criterion and $w_i = 1$

(3) Define the ideal and negative-ideal solution

$$A^* = \{\mathrm{v}_i^*, \cdots, v_n{}^*\} = \left\{ \left(\mathrm{j} \max v_{ij} \middle| i \in I' \right), \left(j \min v_{ij} \middle| i \in I'' \right) \right\}, \quad (3)$$

$$A^- = \{\mathrm{v}_i^-, \cdots, v_n{}^-\} = \left\{ \left(j \min v_{ij} \middle| i \in I' \right), \left(j \max v_{ij} \middle| i \in I'' \right) \right\}, \quad (4)$$

where I' is associated with benefit criteria and I'' is associated with cost criteria

(4) Determine the separation measures using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$D_{\mathrm{j}}^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^* \right)^2}, j = 1, \cdots, J. \quad (5)$$

Similarly, the separation from the negative-ideal solution is given as

$$D_{\mathrm{j}}^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^- \right)^2}, j = 1, \cdots, J. \quad (6)$$

(5) Calculate the relative closeness to the ideal solution. The proximity of the solution a_j concerning A^* is defined as

$$C_{\mathrm{j}}^* = \frac{D_j^-}{\left(D_j^* + D_j^- \right)}, j = 1, \cdots, J. \quad (7)$$

(6) Finally, rank the preference order

2.1. An Empirical Case

2.1.1. TOPSIS in Policy Selection. Township B has about 130,000 residents. As a satellite town near City A, it has a convenient transportation network and superior living functions. With a general election approaching, the current mayor of township B is fighting for re-election. In addition to implementing the previous political ideas, Town B's management must propose quick-acting short-term policy plans as a selling point to attract voters. After repeated arguments, four new policy options were offered as follows: increasing

Table 1: Evaluation of hierarchical structure for new policy solution selection.

Goal	Solution	Criteria
The optimal solution of strengthening the township office administrative work	Add the numbers of community park	Expected expenditure budget
	Add the numbers of library	Expected increase in public income
	Add the routes of free shuttle bus	Expected upper government grants
		Expected tax redistribution
	Add the garbage disposal routes	Expected self-fundraising
		Expected directly benefit the residents

Table 2: Collected data from each criterion.

Criteria	Solution			
	Add the number of community parks	Add the number of libraries	Add the routes of the free shuttle bus	Add the garbage disposal routes
Expected expenditure budget (Mn)	18.37	22.76	8.43	18.45
Expected increase in public income (Mn)	0.74	0.51	1.13	4.12
Expected upper government grants (Mn)	3.22	5.12	0.21	8.38
Expected tax redistribution (Mn)	9.81	4.73	1.87	6.66
Expected self-fundraising (Mn)	1.05	3.16	4.49	2.35
Expected directly benefit the residents (per 1,000 person)	7.23	10.44	12.68	19.53

Table 3: Criteria weights.

Criterion	Financial sector	Elected representative assemblies	Academic scholar	Average
Expected expenditure budget	0.2762	0.1984	0.1334	0.2027
Expected increase public income	0.1839	0.1098	0.1240	0.1392
Expected upper government grants	0.1998	0.1898	0.1498	0.1798
Expected tax redistribution	0.1081	0.1393	0.1201	0.1225
Expected self-fundraising	0.1234	0.1022	0.2090	0.1449
Expected directly benefit the residents	0.1086	0.2605	0.2637	0.2109

the number of parks, the number of libraries, the number of free shuttle buses, or the number of waste disposal routes. Administrative professionals and scholars jointly participated in the final choice based on township B's financial situation and expected residents' satisfaction (Table 1). Each data was collected in government public information (Table 2) based on the currently available budget and expected future fiscal policy. In the initial assessment of the weights of the various criteria, the relevant decision-making experts were government officials in the finance sector, members of the B township council, and public administration scholars.

Experts attempted to unearth the results through interviewing the results of a pair of questionnaires from the Analytical Hierarchy Process (AHP), giving some weight to the relative importance of each criterion, and are presented in Table 3. The most significant criteria for evaluating proposed new policy options are those that directly benefit residents, according to citizens' attitudes toward the management performance of incumbent townships. In addition, the expected budget support is also the focus of implementing the new policy; that is to say, the government's fiscal revenue and expenditure are also the focus of the expert group's consideration.

Table 4 shows the weighted normalized decision matrix Eq. (2).

For determining the optimal solution, the next is utilized by Eq. (3) and (4), the results that $A^* = \{0.068, 0.088, 0.089, 0.009, 0.014, 0.031\}$; $A^- = \{0.025, 0.011, 0.002, 0.052, 0.059, 0.083\}$. Then, this study employed Eq. (5) and (6) to measure the separation of each solution from the ideal solution (Table 5).

Finally, Table.6 indicates that the added garbage disposal routes at township B are the optimal solution for implementing a new environmental policy.

2.1.2. Descriptive Analysis Results. The researchers surveyed the township inhabitants joining the garbage disposal route policy in township B on January 1, 2022, observing the residents' satisfaction before and after the new policy. From July 1 to July 15, 2022, townships A, B, and C in the same

Table 4: Normalized matrix.

Solution	Criteria					
	Expected expenditure budget	Expected increase public income	Expected upper government grants	Expected tax redistribution	Expected self-fundraising	Expected directly benefit the residents
Add park numbers	0.054	0.016	0.034	0.052	0.014	0.031
Add library numbers	0.068	0.011	0.054	0.025	0.041	0.031
Add free shuttle bus routes	0.025	0.024	0.002	0.009	0.059	0.054
Add garbage disposal routes	0.055	0.088	0.089	0.035	0.031	0.083

Table 5: Separation measure of each alternative.

$Cj1^*$	0.069	$Cj1^-$	0.058
$Cj2^*$	0.064	$Cj2^-$	0.059
$Cj3^*$	0.089	$Cj3^-$	0.037
$Cj4^*$	0.043	$Cj4^-$	0.088

Table 6: TOPSIS ranking results.

Solution	Rank	Index
Add park numbers	3	0.457
Add library numbers	2	0.479
Add free shuttle bus routes	4	0.294
Add garbage disposal routes	1	0.671

municipal district were surveyed. Among them, townships A and C did not introduce new environmental policies. This study personally distributed 804 random questionnaires to the three surveyed township inhabitants who chose cluster sampling. After excluding unwilling and invalid respondents, 756 valid respondents ($n = 756$, about 94%) remained.

During the pretest phase from July 15 to July 31, each subdimension was from respondents' opinions. The administration performance design of township B managers has four components: public attention, regional development, policy satisfaction, and confidence in a future administration. We utilized a Likert 1 (extremely agree) to 5 (extremely disagree) rating scale. The questionnaire design considered reliability and validity (Cronbach's alpha value = 0.7). Bartlett's test was lower than 0.01, meaning higher significance, and the KMO value was 0.24. Each item reflects a list of selected topics with a significant difference of 5%. Table 7 shows that the respondents in township B were most recognized with the administrative satisfaction (79%) of the locality.

3. Discussions

Three parts will be discussed in this section. First, the benefits of the township-level government utilizing TOPSIS as an optimal group decision-making tool are described in the solution selection problem. Second, dynamic information is introduced along with the routing garbage collection truck of township B—the addition of the garbage disposal routes—which had the new policy implemented, unlike the previous static information. Finally, this study emphasizes an adverse phenomenon: policy vote buying at the local administrative level and existing coping strategies.

3.1. Simplifying the Policymaking. People's values, opinions, knowledge, abilities, and political systems influence policymaking. This diversity is destined to often conflict with each other, and different perspectives are often overlooked in decision-making. For the empirical cases of township election-driven decision-making procedures, resistance, or more complex situations often occur in the joint decision-making ways due to the interests of each faction. The TOPSIS method can help decision makers consider comprehensive alternatives and make better choices because it is introduced in this paper and can fully refer to the opinions of experts and representatives. In this way, even if there are differences between the decision-making options, they still focus on the problem.

3.2. A Powerful Promotional Tool for the Incumbent Township Mayor's Exposure. Unlike other areas where garbage is cleared and transported at designated locations, in Taiwan, due to the implementation of the policy of "no garbage on the ground", the government's environmental department is responsible for most garbage removal work. Garbage collection trucks will appear in residential areas daily to collect and process garbage.

Further, Taiwan is the world's reputable producer of light-emitting diodes (LEDs). [18]. Many garbage trucks in Taiwan's township cleaning unit install LED display boards to replace previous banner strip installations. Traditionally, the banner strip contains government propaganda in static form on the garbage trucks utilized by the daily routine township garbage disposal service. The new pattern uses an LED display board to illustrate the dynamic public information.

Interestingly, the most noted is that the personal mark of the incumbent mayor is presented with the dynamic public information while the garbage disposal truck is going through its route rather than only being presented at the township office. The incumbent mayor is receiving full publicity with the new policy of adding garbage truck disposal routes. The survey revealed that the exposure of the

Table 7: The administrative performance survey result.

	Administrative satisfaction				Public attention				Local construction				Confidence in future development			
	Satisfied		Unsatisfied		Attention		Ignore		Good		No-good		Confidence		Unconfidence	
Township A incumbent mayor ($n_1 = 271$)	(144)	53%	(73)	27%	(125)	46%	(43)	16%	(119)	44%	(57)	21%	(149)	55%	(70)	26%
Township B incumbent mayor ($n_2 = 263$)	(208)	79%	(32)	12%	(190)	72%	(13)	5%	(179)	68%	(26)	10%	(189)	72%	(29)	11%
Township C incumbent mayor ($n_3 = 222$)	(129)	58%	(31)	14%	(102)	46%	(16)	7%	(107)	48%	(25)	11%	(120)	54%	(53)	24%

incumbent mayor as a potential candidate for the next election had shown significant increases.

3.3. Avoiding 'Policy Vote Buying' and Strengthening Administrative Efficiency. As the survey revealed, it is worth mentioning that the attitudes of residents from township B toward the incumbent mayor are higher than in other towns where the new policy was not implemented as effectively as in township B. Can this kind of administrative work, especially in the preelection period, be considered policy vote buying? In general, Schaffer [19] defined "vote buying" as "In offering money, goods, or services selectively there are, broadly speaking, three ways in which givers might hope to get recipients to vote, or not vote, for a particular candidate."; Markovic [20] mentioned this phenomenon is easy to be manipulated by populism and social intervention, and it lacks long-term policy planning. Understandably, such behavior is against the law in countries or regions where free elections are implemented. Scholars have also pointed out that the township-level administrative works usually pay attention to visible items because of its policy scope approaching citizens directly [21]. In practical terms, township managements do everything possible to satisfy the demands and needs of the voter (i.e., if voters ask for a favor), even beyond the scope of the law. The only way for the voter to reciprocate is by voting for the candidate they deem the most responsive. Undoubtedly, beef politics impeded the normalization of the local administration.

To eliminate the drawbacks of vote-buying policy at the township level, the Taiwanese authorities restructured the local government during 2010-2014 in the four special municipalities: New Taipei, Taoyuan, Taichung, and Tainan. The changes to Taipei and Kaohsiung's two original special municipalities, commonly known as the "six metropolitans" (Liu du). Under the new municipalities, each township has become a district, and a district governor assigned by the upper authorities has replaced the existing township mayor. The original local representative assembly was integrated into the superior municipal council. Compared with the special municipality, only 36.4% of the overall annual budget in Taiwan can be assigned to the municipality and township government. The greatest advantage of these newly upgraded municipalities is tax redistribution, which accounted for 64.6% in 2015 [22]. A primary concern is whether the follow-up administrator at the district level can effectively shut down policy vote-buying.

Some other concerns regarding administrative efficiency arise when the original township administration transforms into a district administration under the new special municipality. This transformation changes the local political ecology and weakens the policy vote-buying phenomenon. A notable example occurred in Tainan, where a newly upgraded municipality suffered a deadly dengue fever outbreak between August and September 2015. Mosquitos predominantly spread this virus, is more likely to spread in hot weather, and may cause high fevers, headaches, itching, and joint pain [23]. At the onset of such an epidemic, a township authority can take immediate countermeasures such as fumigating, setting up a quarantine area, or providing vaccines. A district authority must first report the epidemic situation to the disease control center of the municipality. The center will then decide which measures to take. Opinion polls revealed that when the municipality administration officials of Tainan did not respond rapidly to the outbreak, satisfaction with the mayor declined (Taipei [24]). Changes to a municipality designation denote that a township acquires more financial resources. The rapid response of a municipality—in this case, spending available money on urgent needs—is a significant factor in resident satisfaction. As local administrative units are in close contact with residents, effective management of public funds is undoubtedly an issue of paramount importance for current local administrations.

4. Conclusions

Unlike other qualitative decision-making assistance methods, this study views the TOPSIS approach as a township-level preselection policy recommendation that plays an important role in MCDM by experts, scholars, and township representatives. Through exploratory case studies, despite cultural or geographical differences, this study explores new policies to increase waste disposal routes, which can help township management and residents' daily lives. The survey results showed that township residents agreed with the latest environmental policy. Further, many

of the implications led describe dynamic public information, including the current mayor's markings, while being displayed on routing garbage trucks and increasing visibility.

This study focuses on addressing policy-based vote buying at the township level and workarounds to address this phenomenon, but its follow-up effects remain to be seen. Future research could investigate whether higher-level local governments effectively avoided policy votes before elections and discover more convenient simple techniques used in environmental decisions. These questions are worthy of further exploration.

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.

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Research Article

The Panel Spatial Econometric Analysis for Development of Green Intensive Agriculture Based on Edge Computing and Internet of Things

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To further promote the modernization of agriculture and the prosperity of green industry, the analyses are made on the intensive level of agriculture by using spatial econometric model under the Internet of Things (IoT), and the optimal defense strategy is adopted for edge network equipment to ensure the security of agricultural information. Initially, the present work introduces the related concepts of agricultural intensive development and analyzes the important role of IoT in the development process of agricultural modernization. Next, it briefly explains the spatial econometric analysis method, introduces two basic spatial analysis models-spatial lag model (SLM) and spatial error model (SEM), and explains their principles in detail. Then, it signifies the characteristics of IoT and edge computing (EC) and designs the optimal defense strategy of edge network equipment from the perspective of IoT. Finally, the simulation experiment is carried out based on the edge network defense strategy, and the spatial econometric analysis is carried out by taking the agricultural intensive development of counties in a Chinese province as an example. The experimental results show that with the increase of the number of edge network devices, the optimal strategy of edge network defense can be adopted while consuming certain computing resources. The agricultural technology input and intensive level in the jurisdiction have high spatial correlation, so it is necessary to establish a spatial econometric model for analysis. Additionally, the statistics of SLM is higher than that of SEM, which shows that SLM can better reflect the technology investment and spatial correlation than SEM does. Both industrial and agricultural division of labor and agricultural production link division of labor can promote the level of intensification, among which the promotion of industrial and agricultural division of labor is not very significant, while the promotion of agricultural production link division of labor is very significant.

1. Introduction

The essence of the IoT is to let various sensing devices and intelligent terminals converge into a unified network system through a certain communication mode and connect the original independent carriers together, to realize barrier-free communication between things and people [1]. Edge computing (EC) is a hot term in recent years, which refers to the computing of data at the terminal close to the data source, the completion of traditional cloud data processing tasks at the edge, and the processing of computing and storage resources at the edge [2]. Traditional data processing mainly uses cloud computing. Now, it can sink to the edge, which will greatly reduce the pressure on the cloud. Of course, it can also be processed coordinated with other tasks. With the development and maturity of the IoT, the data volume of the central server is increasing. To reduce the huge computing pressure caused by the computing mode of a single mobile edge server, Lv et al. proposed a collaborative computing method to ensure the security and privacy of computer data [3]. For data collection or equipment monitoring, the ultimate purpose of data collection is to analyze

the data. If the computing power of the equipment close to the data source allows, it can be carried out at the edge, which will greatly reduce the pressure on the cloud and a conclusion can be drawn quickly and efficiently. At present, EC has become an important part of the current information infrastructure, and its future development can be expected. Chen et al. believed that although the development of modernization had brought better life experience and great convenience to people's life, there were also many network-security risks, including information leakage and malicious network attacks. The current network security development cannot keep up with the urgent adoption of global smart city technology. Therefore, the method based on IoT and EC is very important to protect network information security [4].

Agricultural intensive development is an important part of modern agricultural development [5], which is the basic path to rapidly improve the agricultural development and is of great significance in the development process of industrialization and urbanization [6]. Agricultural intensive development is the basis of agricultural modernization. In recent years, the pace of industrialization and urbanization has left many high-quality land and agricultural labor resources stranded in the mountainous areas. It is very necessary to develop modern agriculture in the mountainous areas [7]. Hence, intensive usage of modern agricultural technique investment should be promoted. Product factors in the mountainous areas should be made use of to promote the intensive development of their agriculture. It can both stimulate the inner requirements of the modern agriculture in the mountainous areas and coordinate the pace of reform in the mountainous areas with the space of industrialization and urbanization. It has high significance for the modernized development in the mountainous areas [8].

To sum up, from the perspective of agricultural intensive development, the information security strategy is upgraded by means of IoT EC, and then, a spatial econometric analysis model is established. Based on the combination of IoT technology and spatial econometric analysis, it realizes the scientific analysis of green agricultural development and improves the agricultural division system of intensive development. Taking the counties under the jurisdiction of the province as the actual case, the SLM and SEM are used to verify and analyze the collected data, respectively. There is very important guiding significance for the development of agricultural modernization and the improvement of intensive level.

2. Agricultural Intensive Development in the Context of IoT

2.1. Related Concepts of Agricultural Intensive Development. "Extensive" and "intensive" are a couple of relative concepts, which refers to investing in the production of materials and labor on the same land area and adopting the method of expanding the cultivated land area to improve agricultural products in the present work [9]. Intensive production information and labor force investment refer to the unit product amount of the invested product materials and accomplishment of agricultural business in the same land area. The concept involves of two corresponding agricultural management methods of "extensive" and "intensive," which is usually called intensive management of labor-intensive or intensive labor [10]. Extensive development and intensive development are two basic methods of economic development. Both methods are used by the agricultural economics department. Promoting the transformation of agricultural development into a broad intersection is both the inherent requirement of modern agricultural development and the basic path of transforming the mode of agricultural development. Agricultural intensive development is based on the operation mode of modern agricultural technology, which continuously improves the development process efficiency of agricultural strengthening level by promoting agricultural intensive enterprise activities and improving agricultural intensive operation effect [11].

Agricultural modernization is basically the modernization of science and technology, and agricultural production informatization is a direct reflection of the development of modern agriculture [12]. In the market exchange of domestic development, advanced agricultural knowledge should first be used in agricultural production [13] and agricultural information system. It is necessary to seamlessly mesh the advanced agricultural knowledge with other industry information systems, to realize agricultural modernization, including resource optimization and improvement of production, transportation, and sales efficiency [14]. The development of agricultural economy should improve efficiency and quality, reduce work intensity, and realize the sustainable development of agricultural production. Agricultural development contributes to the normal and stable development of domestic economy and plays an important role in promoting national competitiveness [15].

2.2. Overview of Spatial Econometric Analysis Methods. When there are similar values in a spatial field and there is a tendency of aggregation between these values, the spatial field will show a strong positive autocorrelation. On the contrary, if the spatial field has two values whose attributes are mutually exclusive, the spatial field will show negative autocorrelation [16]. Spatial autocorrelation represents the relationship between the observed values of two adjacent regions. The earliest spatial correlation is extended from spatial econometrics. After inheriting the classical panel econometric analysis method, the law is obtained by analyzing the spatial position and observation data between adjacent regions [17].

The spatial econometric model includes spatial autoregressive model (SLM) and SEM. The spatial autoregressive model mainly explains the spatial dependence caused by the interaction between variables such as spatial diffusion and spatial spillover, and the SEM is mainly used to reflect the impact of random impact on regional spillover [18]. There are usually two methods to establish spatial weight matrix: spatial weight matrix based on adjacency concept and spatial weight matrix based on distance. Assuming that the research object has n geographical regions, the spatial

weight matrix of these n geographical regions can be expressed as

$$W_{n\times n} = \begin{Bmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & w_{ij} & \vdots \\ w_{n1} & \cdots & w_{nn} \end{Bmatrix}. \quad (1)$$

In Equation (1), w_{ij} represents the neighbor relationship between area$i$ and area j. There are two ways to determine its standard. Equation (2) denotes the calculation of w_{ij} in a spatial weight matrix based on neighbor concept.

$$w_{ij1} = \begin{cases} 1, \\ 0. \end{cases} \quad (2)$$

In Equation (2), when area i is adjacent to area j, the value of w_{ij1} is 1, while, in other cases, its value is 0. Equation (3) signifies the calculation of w_{ij} in a spatial weight matrix based on distance.

$$w_{ij2} = \begin{cases} 1, \\ 0. \end{cases} \quad (3)$$

w_{ij2} is equal to 1 when the distance between area i and the area j is less than d, and it equals to 0 in other cases. Spatial econometric analysis can explain the law in parameter value changings and influencing factors of a common attribute in two adjacent regions, and it can analyze the relationship between the two spaces, which is also the biggest difference between spatial econometric analysis method and general econometric model [19]. The spatial econometric model studies the change of spatial attributes between different regions. Although spatial econometric models have many setting forms, SLM and SEM are the most common basic models [20]. Initially, a univariate linear cross-sectional data regression model without spatial effect is established as follows:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i. \quad (4)$$

In Equation (4), y_i is the observed value of the explained variable in the region, x_i stands for the observed value of the explained variable, β_0 and β_1 represent pending parameters, and ε_i refers to the random error [21]. Additionally, it is also necessary to transform the weight matrix in the spatial panel data and make the inner product of the matrix in time and the spatial weight matrix. Through the inner product transformation, the spatial panel data can be added with the time attribute [22]. Equations (5)–(7) illustrate the expressions of the transformed SLM and SEM.

$$y_{it} = \rho(I_T \otimes W_N)y_{it} + \beta x_{it} + \varepsilon_{it}, \quad (5)$$

$$y_{it} = \beta x_{it} + \varepsilon_{it}, \quad (6)$$

$$\varepsilon_{it} = \lambda(I_T \otimes W_N)\varepsilon_{it} + \xi_{it}. \quad (7)$$

In Equations (5)–(7), λ measures the impact of the random error of the explained variables in adjacent areas on the explained variables in the area. As the basic form of spatial econometric model, although the SLM and SEM reveal the spatial effects of the explained variables and random error terms in adjacent areas on the explained variables in the area, they cannot explain whether the explained variables in adjacent areas have spatial effects on the explained variables in the area [23]. To make up for this defect, it is necessary to further expand the data of spatial panel analysis and analyze the spatial lag term of explained variables and explanatory variables according to the spatial Dobbin model:

$$y_{it} = \rho(I_T \otimes W_N)y_{it} + \beta x_{it} + \theta(I_T \otimes W_N)x_{it} + \varepsilon_{it}. \quad (8)$$

In Equation (8), the purpose of spatial correlation test is to judge the selection of econometric model. Generally speaking, if the test results of correlation show that there is no spatial correlation, the ordinary econometric model is used for analysis. If there is spatial correlation, it is necessary to establish a spatial econometric model. Based on the ordinary least square regression of the panel data model without spatial effect, the Lagrange number multiplication (LM) statistics [24] is constructed. For the spatial correlation test of SLM and SEM, the calculations are shown in

$$\mathrm{LML} = \frac{\left[e'(I_T \otimes W_N)y/\widehat{\sigma}^2\right]^2}{J}, \quad (9)$$

$$\mathrm{LME} = \frac{\left[e'(I_T \otimes W_N)e/\widehat{\sigma}^2\right]^2}{T \times T_W}, \quad (10)$$

$$J = \frac{1}{\widehat{\sigma}^2}\left[(I_T \otimes W_N)x\widehat{\beta}'\left(I_{NT} - x(x'x)^{-1}\right)(I_T \otimes W_N)x\widehat{\beta} + TT_W\widehat{\sigma}^2\right], \quad (11)$$

$$T_W = \mathrm{tr}(WW + WW'). \quad (12)$$

In Equations (9)–(12), e represents the residual obtained after the ordinary least square's estimation of the panel data model without spatial effect, $\widehat{\sigma}^2$ expresses the variance of the random error term, and tr denotes the trace of the matrix [21]. Besides, Equations (13) and (14) demonstrate the robust tests of the two models.

$$\mathrm{robustLML} = \frac{\left[e'(I_T \otimes W_N)y/\widehat{\sigma}^2 - e'(I_T \otimes W_N)e/\widehat{\sigma}^2\right]^2}{J - TT_W}, \quad (13)$$

$$\mathrm{robustLME} = \frac{\left[e'(I_T \otimes W_N)e/\widehat{\sigma}^2 - TT_W/J \times e'(I_T \otimes W_N)y/\widehat{\sigma}^2\right]^2}{TT_W(1 - TT_W/J)}. \quad (14)$$

2.3. Overview of IoT and EC. The IoT is an integrated application of information technologies in the Internet era and one of the irreplaceable key technologies in the process of modernization [25]. Through the establishment of the IoT platform, applications like interconnection of everything and intelligent

operation can be realized, such as information storage, automatic positioning, intelligent management, and monitoring. The emerging industry team, which is based on the IoT, is also growing, such as smart home furnishing, automatic driving system, face recognition, and smart city construction. Simultaneously, the development of intelligent system extends many popular fields, such as cloud database, data mining, intelligent analysis, and intelligent decision making [26]. Though the IoT has spawned many popular industries and research fields, because the volume of data is too large, it also produces many security problems. The processing of a large amount of data makes the center equipment of the network overwhelmed. The long response time of the system and the consumption of computing resources are also tough problems. To help the central server reduce the pressure, improve the data processing efficiency, and ensure the security and timeliness of data transmission, EC has become one of the important improvement methods [27]. EC refers to the centralized processing and analysis of data on the edge side away from the central server. It is similar to the central server and includes the functions of computing, storage, classification, and so on. Moreover, because edge devices are generally far away from the central server, the data is stored in the local server and does not occupy the memory of the central server, which avoids the risk of data leakage caused by malware attack in the process of data transmission and guarantees the data security and user privacy [28].

Cloud computing service is the core technology to help cloud database process and analyze data. Its main function is to use network transmission to migrate data to cloud database for centralized processing. Although cloud computing services can process and integrate data in batches, with the huge volume of cloud resources, centralized processing is not easy to achieve. On the one hand, it will increase the burden on the central server. Too much memory will also affect the running speed, resulting in too slow response time. On the other hand, a large number of centralized data storage and transmission will also produce huge security risks, which are the main defects of cloud computing services [29].

To make up for the deficiency of centralized cloud computing, the concept of EC comes into being. It refers to a distributed open platform integrating the core capabilities of network, computing, storage, and application near the edge of the network or data source to provide edge intelligent services nearby. Due to the shortening of the transmission link, EC can quickly and efficiently respond to business needs on the data generation side, and the local processing of data can also improve the degree of user privacy protection. Additionally, EC reduces the dependence of services on the network and can also provide basic business services in the offline state [30].

Compared with traditional cloud computing, EC has obvious advantages, as follows:

(1) Low delay and high real-time performance

Generally speaking, the edge device is far away from the central server and at the boundary of the whole data system. Been put in another way to say, it is close to the data source. It can process the data immediately when receiving the data and then transmit it to the central server. EC's advantage is to reduce the pressure of the central server, speed up the data transmission time, and improve the operation efficiency of the central server.

(2) Less power consumption

The data preprocessing of edge devices can share part of the functions of the central server, greatly reduce the operation pressure of the central server and cloud database, and reduce the power consumption of network broadband [31].

(3) Reducing the risk of centralized data storage and improving the system's tolerance with fault

Since the data no longer needs to be uploaded to the EC for centralized processing, using EC can release some storage space and improve the operation speed of the system. When dealing with complex problems, it can free up more space, avoid the system locking phenomenon, improve the fault tolerance rate, and solve the security problem of data storage. Besides, because the edge device is far from the central server and the data is stored locally, the risk of data leakage can be greatly reduced.

(4) Security and privacy protection

EC can calculate and store the data on the edge device without uploading to the central server, so it can ensure the security and privacy of the data. Furthermore, EC can encrypt and desensitize the data through the key, which can realize the security authentication of the user's identity and ensure the privacy of the user's authority [32].

In general, EC can solve most of the problems existing in the IoT. With the help of EC, the IoT can develop faster and safer. Therefore, based on the large-scale edge network equipment, it is necessary to analyze the existence of the optimal solution. In the beginning, the total cost function of the edge network individual in time t is designed as

$$J_i = \min E\left\{\sum_{t=1}^{T}\left(|u_i(t) - f(r(t))|^2 + \alpha_i|x_i(t)|^2\right)\right\}. \quad (15)$$

In Equation (15), $u_i(t)$ represents the control variable when the edge device is optimal, $x_i(t)$ expresses the state variable, and $f(r)$ describes the time-varying mean field term, which can be transformed by LM.

$$L_1(u_1, ..u_n, \lambda) = E\left\{\sum_{i=1}^{N}\left(|u_i|^2 + \alpha_i|x|^2 + \lambda \bullet \frac{u_i}{N}\right)\right\}. \quad (16)$$

In Equation (16), λ stands for the Lagrange multiplier, which can be obtained after further resolution.

$$L_1^* = \min E\left\{\sum_{i=1}^{N}\left(\left|u_j^*\right|^2 + a_i\left|x_j^*\right|^2 + \lambda \bullet \frac{u_i}{N}\right)\right\}. \quad (17)$$

Then, u_i^* and L_1^* are the optimal solution of the function.

Table 1: Selection of control variables.

Research content of econometric model	Control variable selection	Control variable representation
The influence of the evolution of agricultural division on the degree of agricultural intensive management The influence of the evolution of agricultural division on the level of agricultural intensification	Farmers' income level Relative scarcity of agricultural production factors Characteristics of the production structure of the primary industry Agricultural infrastructure level Consumption level of urban and rural residents Characteristics of the production structure of the primary industry	Farmers per capita income level Representative production factors of cultivated land area The proportion of agricultural output value in the total output value of agriculture, forestry, animal husbandry, and fishery Per capita power consumption Per capita total consumption

According to the above analysis, the average field game algorithm steps of network security defense based on the IoT edge device environment are as follows:

(1) set the parameters: x, a_i, b_i, and c (parameter a_i indicates the influence factor of resource consumption of edge devices, and b_i refers to the influence factor of defense strength of edge equipment)

(2) set the number of iterations

(3) set time T

(4) calculate the status track of edge equipment x_i^*

(5) calculate the optimal conditions and optimal solutions

(6) analyze the relationship among optimal strategy, resource consumption, and attack intensity

(7) end "For"

(8) send back the track of cost function

2.4. Experiment Design. There are many influencing factors to be considered in the variable selection of spatial model. To make econometric analysis on the level of agricultural intensification, consideration should be both put into the specific quantification of these influencing factors, and whether the data is available and whether the source is reliable. These problems make the selection of control variables extremely difficult. After consulting the relevant literature and combining with the topographic characteristics of the studied area, the present work selects the control variables after comprehensive consideration: farmers' per capita income level; representative production factors of cultivated land area; the proportion of agricultural output value in the total output value of agriculture, forestry, animal husbandry, and fishery; per capita power consumption; and per capita total consumption.

Table 1 demonstrates the various control variables used in the spatial econometric model that analyzes the impact of the evolution of agricultural division of labor on the development of agricultural intensification.

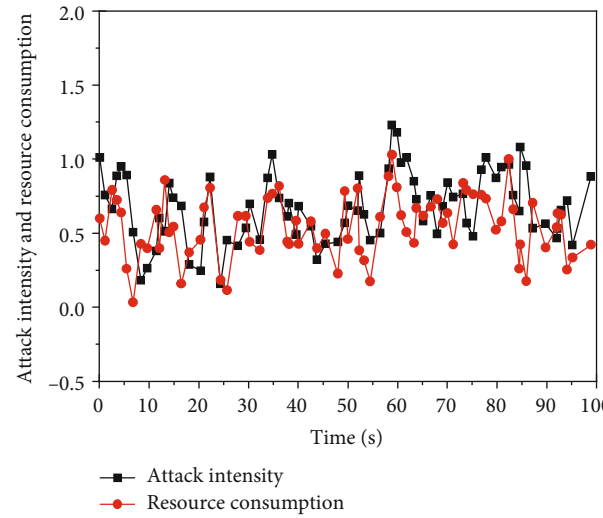

Figure 1: Relationship between the intensity of malicious attack on edge network devices and the consumption of computing resources.

The relevant data to calculate the above control variables are from the provincial data part of the *Statistical Yearbook*. A common panel data model is established based on these control variables:

$$J_{it} = \alpha + \beta_1 F(1) + \beta_2 F(2) + \beta_3 F(3) + \beta_4 I_{it} + \beta_5 S_{it} + \beta_6 E_{it} + \varepsilon_{it}. \quad (18)$$

In Equation (18), J_{it} represents the agricultural technology investment in region i, during period t. $F(1)$, $F(2)$, and $F(3)$, respectively, describes the division of agricultural industry, the division of agricultural products, and the division of agricultural production links in the region i, during period t. I_{it} denotes the income level of farmers, S_{it} refers to the characteristics of the production structure of the primary industry, and E_{it} stands for the scarcity of agricultural production factors.

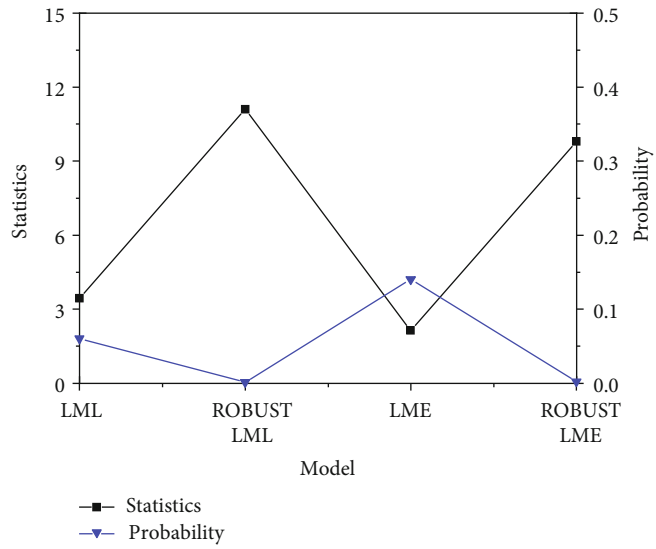

Figure 2: Results of spatial correlation tests of agricultural technology investment degree in investigated areas.

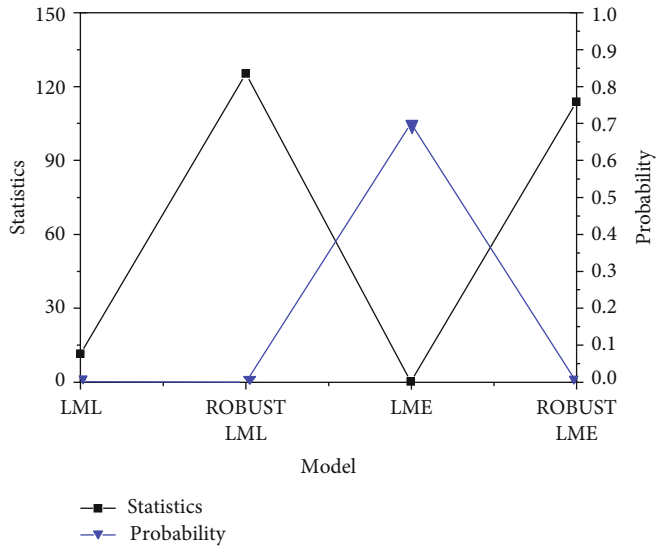

Figure 3: Results of spatial correlation test of agricultural intensification level in the areas.

Based on this model, the relevant programs in the spatial metrology toolbox are used in MATLAB software, and the Lagrange multiplication lag model (LML), Lagrange multiplication error model (LME), and robust test models (robustLML and robustLME) are adopted to carry out the spatial correlation test on the development of agricultural green intensification in 36 counties and districts under the jurisdiction of the province.

3. Experiment and Result Analysis

3.1. Defense Strategy Analysis of Edge Equipment. Figure 1 manifests the relationship between defense response time and computing resource consumption of edge network devices.

Figure 1 indicates that when edge network devices are attacked by malware, the computing resource consumption of defense measures will change with the change of attack intensity. The higher the attack intensity, the higher the consumption of computing resources, but the overall maintenance is in a fixed interval. This is because edge network devices contribute some computing resources to deal with malware attacks to maintain the response time at a low level. With the increase of the number of edge network devices, the optimal strategy of edge network defense can be adopted while consuming certain computing resources.

3.2. Spatial Correlation Tests of Agricultural Intensive Development. Figure 2 displays the spatial correlation test of agricultural development technology investment in the investigated province.

Figure 2 shows that the agricultural intensification level in the jurisdiction has high spatial correlation, so it is necessary to establish a spatial econometric model for analysis. Additionally, the statistics of LML are higher than LME.

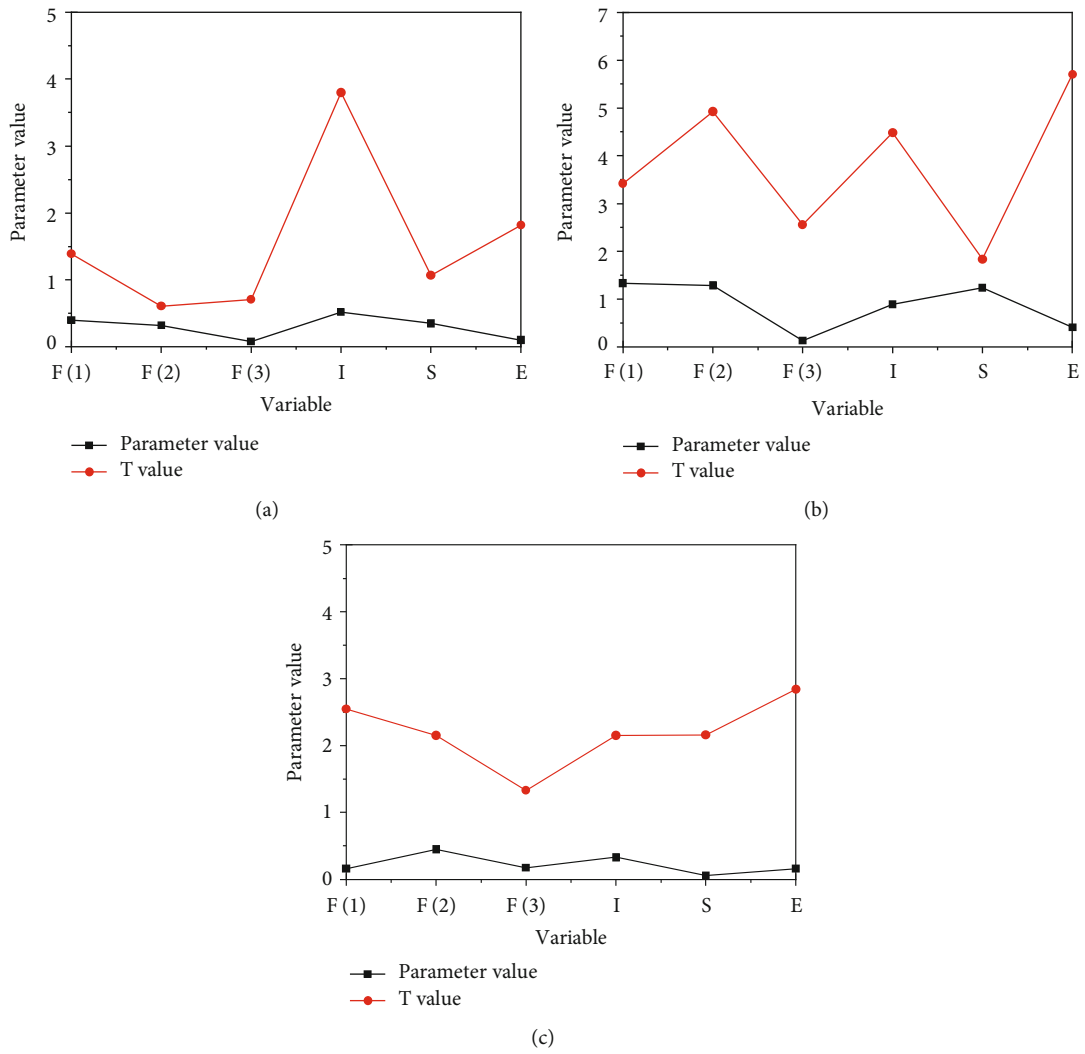

Figure 4: Results of spatial econometric analysis of agricultural production technology investment: (a) individual fixed effect, (b) time fixed effect, and (c) two-way fixed effect.

This shows that the SLM can better reflect the relationship between technology investment and spatial correlation than the SEM. Meanwhile, the robust LML statistic of stability test is higher than the LML of model test, indicating that the effect of stability test is more significant.

Figure 3 demonstrates the spatial correlation test of agricultural development intensification level in this province.

Figure 3 shows that the agricultural intensification level in the jurisdiction has high spatial correlation, so it is necessary to establish a spatial econometric model for analysis. Additionally, the statistics of LML are higher than LME. This shows that the SLM can better reflect the relationship between technology investment and spatial correlation than the SEM. Meanwhile, the robust LML statistic of stability test is higher than the LML of model test, indicating that the effect of stability test is more significant.

Based on the SLM, the maximum likelihood estimation method is used to estimate the three fixed effect models, respectively. Figure 3 presents the final spatial results of econometric analysis.

Figure 4 reveals that the estimation effect of the parameter values of the time fixed effect model is adverse, while the estimation results of the parameter values of the other two models are relatively significant. As for the fitting degree of the model, the fitting degree of the time fixed effect is the worst, and the fitting degree of the individual fixed effect is the best. Therefore, the individual fixed effect model is selected to analyze the intensification level. Figure 4 also bespeaks that both industrial and agricultural division of labor and agricultural production link division of labor can promote the level of intensification. Among them, the promotion from industrial and agricultural division of labor is not very significant, while the promotion from agricultural production link division of labor is very significant. The possible reason is that the division of labor between industry and agriculture is not obvious in the peasant class, and farmers can also engage in nonagricultural production process in the process of agricultural production. Under the condition of both, there is limited impact from industrial and agricultural division of labor on the level of agricultural

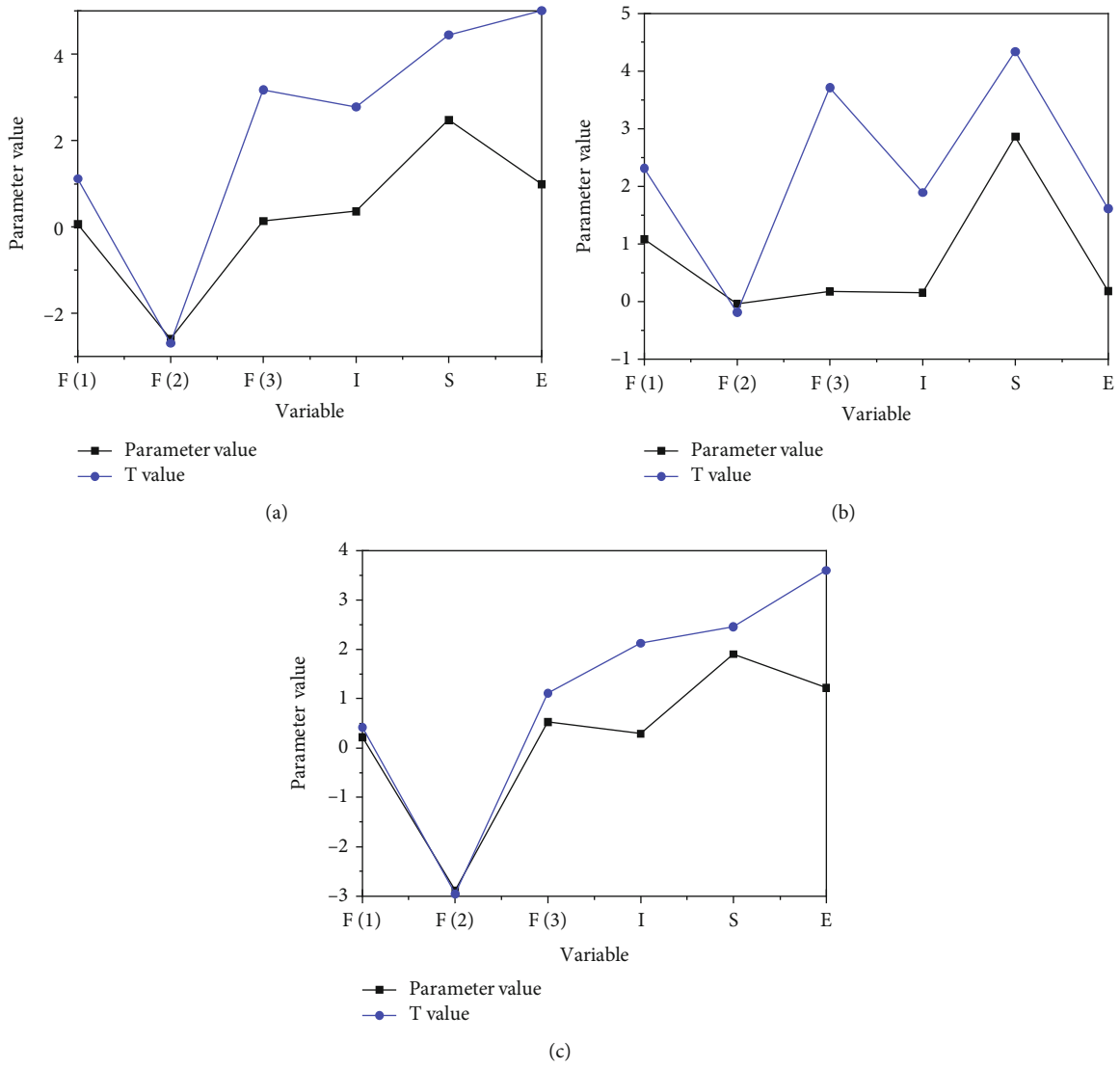

Figure 5: Spatial econometric analysis of agricultural intensification level in the jurisdiction: (a) individual fixed effect, (b) time fixed effect, and (c) two-way fixed effect.

intensification. For farmers, the balanced management of industry and agriculture is neither conducive to the production of agricultural products, nor able to meet the growing market demand. If the production model of self-sufficiency of agricultural products is maintained, the market transaction of agricultural products will stagnate. Even if the market demand is large and the technology investment is large, the intensive level cannot be improved. Moreover, farmers' balanced management cannot change the scarcity of means of production and factors of production. Although the production mode of "going out to work in idle time and going home to work in busy time" is a manifestation of reasonable time management and resource allocation for farmers and can also increase farmers' income to a certain extent, it cannot fundamentally change the scarcity of agricultural factors of production, which is impossible to realize the intensive development of agriculture and substantially to improve the quality of life of farmers.

For agricultural production, industrial and agricultural division, production link division, and agricultural product classification can promote agricultural technology investment. Among them, industrial and agricultural division and agricultural product classification have the highest significance, while the significance of production link division is lower. This may be because the division of labor between industry and agriculture promotes the transfer of productivity, and the transfer of labor can accelerate the internal digestion of the agriculture industry. The classification of agricultural products can accelerate the formation of a stable industrial chain and provide a realistic basis for technology investment. Because different types of agricultural products need different production technologies, specialized classification processing depends more on technology investment. Meanwhile, the income of most farmers is low, which makes farmers lack the ability to buy means of production, which is also one of the reasons for the overall low technology investment. The

government's support and material subsidies can help farmers improve their technical investment to a great extent.

Figure 5 illustrates the spatial econometric analysis results of agricultural intensification level.

Figure 5 reveals that the estimation effect of the parameter values of the time fixed effect model is adverse, while the estimation results of the parameter values of the other two models are relatively significant. As for the fitting degree of the model, the fitting degree of the time fixed effect is the worst, and the fitting degree of the individual fixed effect is the best. Therefore, the individual fixed effect model is selected to analyze the intensification level.

Figure 5 also bespeaks that both industrial and agricultural division of labor and agricultural production link division of labor can promote the level of intensification. Among them, the promotion from industrial and agricultural division of labor is not very significant, while the promotion from agricultural production link division of labor is very significant. The possible reason is that the division of labor between industry and agriculture is not obvious in the peasant class, and farmers can also engage in a nonagricultural production process in the process of agricultural production. Under the condition of both, there is limited impact from industrial and agricultural division of labor on the level of agricultural intensification. For farmers, the balanced management of industry and agriculture is neither conducive to the production of agricultural products, nor able to meet the growing market demand. If the production model of self-sufficiency of agricultural products is maintained, the market transaction of agricultural products will stagnate. Even if the market demand is large and the technology investment is large, the intensive level cannot be improved. Moreover, farmers' balanced management cannot change the scarcity of means of production and factors of production. Although the production mode of "going out to work in idle time and going home to work in busy time" is a manifestation of reasonable time management and resource allocation for farmers and can also increase farmers' income to a certain extent, it cannot fundamentally change the scarcity of agricultural factors of production, which is impossible to realize the intensive development of agriculture and substantially to improve the quality of life of farmers.

Additionally, there is a negative correlation between the type division of agricultural products and the level of intensification, which may be because the level of type division of agricultural products is not high, which hinders the development of agricultural intensification. Finally, there is a positive correlation between the agricultural intensive development level and space, indicating that the agricultural intensive level of the areas with higher intensive level is also higher in the adjacent areas. Hence, a regional collaborative development model was formed. The agricultural technology between different regions can spill over to the adjacent areas to promote the intensive development of regional agriculture.

4. Conclusion

Under the IoT, the present work uses the SLM and SEM to conduct panel spatial econometric analysis on the development of agricultural intensification and adopts the EC theory to defend the security of network equipment in the digital information environment, to ensure the information security in the development of agricultural modernization. Simultaneously, the security of defense strategy of edge network equipment is verified by simulation experiment, and the spatial econometric analysis of technology investment and intensive level development is carried out by taking the agricultural development in the province as an example. The results reveal that (1) when edge network devices are attacked by malware, the computing resource consumption of defense measures will change with the change of attack intensity. The higher the attack intensity, the higher the consumption of computing resources. (2) The level of agricultural technology input and intensification in the province has significant spatial correlation, which needs to be analyzed by establishing a spatial econometric model. (3) From the time fixed effect model, industrial and agricultural division of labor, production link division of labor, and agricultural product classification can promote agricultural technology investment. (4) From the individual fixed effect model, both industrial and agricultural division of labor and agricultural production link division of labor can promote the level of intensification, among which the promotion of industrial and agricultural division of labor is not very significant, while the promotion of agricultural production link division of labor is very significant. The deficiency is that the spatial econometric model proposed here only makes analyzation from the county level. To obtain accurate data, it also needs to be analyzed from the aspect of farmer. With the continuous development of IoT technology, EC will be more widely used, the data source of spatial measurement model will be timelier and more accurate, and the green intensive development of agriculture will be further improved.

Data Availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

All authors declare that they have no conflict of interest.

Acknowledgments

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Retraction

Retracted: An Empirical Study on the Relationship among Mental Health, Learning Engagement, and Academic Self-Efficacy of Senior High School Students

Journal of Environmental and Public Health

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

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

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

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

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] L. Wu and C. Ma, "An Empirical Study on the Relationship among Mental Health, Learning Engagement, and Academic Self-Efficacy of Senior High School Students," *Journal of Environmental and Public Health*, vol. 2022, Article ID 4253142, 8 pages, 2022.

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Journal of Environmental and Public Health
Volume 2022, Article ID 4253142, 8 pages
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Research Article

An Empirical Study on the Relationship among Mental Health, Learning Engagement, and Academic Self-Efficacy of Senior High School Students

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This study examines the mediating role of the academic self-efficacy of high school students in Tibetan and Qiang areas of China on the relationship between their mental health and learning engagement, as well as their gender and grade-specific differences in mental health, learning engagement, and academic self-efficacy. The authors drew 600 valid samples in Tibetan and Qiang areas of China, built a measurement model and a structure model, established a structural equation model comprising the mental health scale, the learning engagement scale, and the academic self-efficacy scale, and conducted an independent sample t-tests and a one-way analysis of variance. The questionnaires took the form of the 5-point Likert scale. This research shows that the mental health of high school students in Tibetan and Qiang areas of China has a significant positive impact on their learning engagement and academic self-efficacy and that their academic self-efficacy has a significant positive impact on their learning engagement. Academic self-efficacy produces an overwhelming mediating effect on the ways mental health influences learning engagement. High school students, male and female, in Tibetan and Qiang areas of China show no marked gender-specific differences in mental health, learning engagement, and academic self-efficacy, while junior high school students show marked grade-specific differences in mental health, and senior high school students show marked grade-specific differences in learning engagement and academic self-efficacy. This article concludes that improving the academic self-efficacy of high school students in Tibetan and Qiang areas of China can boost their learning engagement.

1. Introduction

Many parts of China are inhabited by Tibetans, some parts are inhabited by the Qiang people. Aba Tibetan and Qiang Autonomous Prefecture in western China's Sichuan Province is the only region of the country that is inhabited by both Tibetans and the Qiang people. It has a population of 904,900 including 536,300 Tibetans; 167,800 Qiang people; 170,500 Han Chinese; 28,400 Hui people; and 1,700 people of other ethnicity. Tibetans, Qiang people, and Han Chinese form the majority of the total population, as shown in Figure 1. Aba Tibetan and Qiang Autonomous Prefecture is an outlying area of Sichuan Province. The lack of adequate educational facilities and the relative limited learning engagement on the part of high school students in this region have gravely impaired education development, leading to comparatively low performance in the National College Entrance Examination (NCEE) for years. Therefore, efforts must be made to improve the academic performance of the high school students in Tibetan and Qiang areas of China. Many scholars who study high school students in Tibetan and Qiang areas of China focus on the ways to motivate the students to do physical exercise and improve health, totally ignoring their learning engagement. Active learning engagement is fundamental to learning efficiency—the primary goal of education. This research is a case study involving high school students in Aba Tibetan and Qiang Autonomous Prefecture, a typical Tibetan and Qiang area of China. It studies the factors that

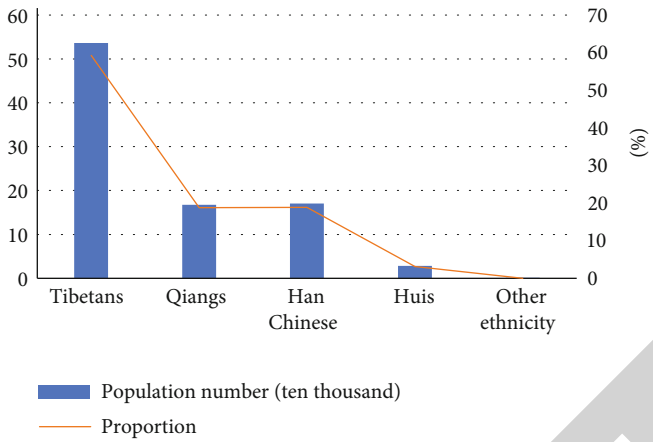

Figure 1: Proportions of ethnic populations in Tibetan and Qiang areas of China.

might influence the learning engagement of high school students in Tibetan and Qiang areas of China and how to boost their learning engagement to improve their learning efficiency.

In Tibetan and Qiang areas of China, less than 40% of junior high school students pass the Senior High School Entrance Examination (SHSEE) to go on to senior high school, and less than 40% of senior high school students pass the National College Entrance Examination (NCEE) to go on to college. To reverse this situation, efforts must be made to boost the learning engagement of high school students in these regions. These students can gain a competitive edge by actively developing their mental competencies and boosting their learning engagement. Adolescents go into different emotional states and develop diverse motives during learning, and these states and motives play a fundamental role in their personal development and academic performance [1]. Mentally healthier adolescents display higher academic self-efficacy [2]. Moreover, Kakoschke et al.'s and Siu et al.'s experiment [3, 4] confirms the correlation between mental health and learning engagement.

Frail mental health can result in school dropout [5], and good mental health can increase concentration and focus in the process of learning [6]. The latest research results confirm that good mental health translates to active learning engagement, and active learning engagement translates to better academic performance [7–10].

Academic self-efficacy is an individual's beliefs about their academic performance and assessment of their level of confidence in finishing school work on their own. It is a subjective judgment on their ability to determine their learning behavior and academic performance. Academic self-efficacy determines academic and career choices, contributes to academic success, and helps to develop learning strategies [11]. At the same time, academic self-efficacy has a positive impact on the academic performance of adolescents [1]. Previous studies show that there is a close relationship between academic self-efficacy and academic performance. Mornar et al.'s studies [12] show that academic self-efficacy plays a mediating role in academic performance. Later, other scholars also find that academic self-efficacy is a positive and important predictor of learning engagement [13]. Wang, et al. [14] use academic self-efficacy as a mediating variable, and Parmaksiz [15] and Affuso et al. and Wang and Gao [16, 17] also use academic self-efficacy as a mediating variable in their research.

The above studies show that mental health, academic self-efficacy, and learning engagement are closely related variables. However, these variables were seldom considered together in prior research. Therefore, it is necessary to comprehensively analyze the relationships between mental health, academic self-efficacy, and learning engagement.

2. Hypothetical Model

The authors construct a hypothetical model based on previous research [18], and under the framework of this model, propose that mental health is a positive predictor of learning engagement. In addition, the authors make the hypothesis that academic self-efficacy plays a mediating role on the relationship between mental health and learning engagement [13, 14, 16]. Figure 2 is an illustration of the hypothetical model. After designing the research tools and collecting relevant data, the authors used the structural equation model (SEM) to test if the hypothetical model is valid. And put forward the following research hypotheses. The following research hypotheses are constructed based on a review of previous research:

H1: Mental health has a significant positive impact on learning engagement;

H2: Academic self-efficacy plays a mediating role on the relationship between high school students' mental health and learning engagement.

2.1. Objects and Methods of Research

2.1.1. Objects of Research. The objects of this study were 617 high school students randomly selected in Tibetan and Qiang areas of China. 100% of the questionnaires were returned, of which 17 were invalid and 600 were valid. 414 (69%) of the respondents live with their parents, and 186 (31%) of them do not live with their parents. 257 of them are boys, accounting for 42.46%, and 343 of them are girls, accounting for 57.54%.

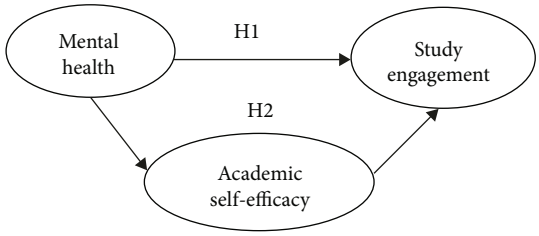

Figure 2: Hypothetical Model.

343 of them are junior high school students, accounting for 57.2%, and 257 of them are senior high school students, accounting for 42.8%. Table 1 provides the details.

2.1.2. Research Tools. The mental health scale in this research is based on the Mental Health Scale for High School Students compiled by famous Chinese psychologist Wang Jisheng [19]. Modified to suit this particular survey, it is classic and geared specifically towards Chinese high school students. The original scale contains 60 questions about 10 dimensions. Considering that too many questions might cause boredom in the students and that boredom might result in data distortion, only four out of the 10 dimensions—interpersonal tension and sensitivity, anxiety, learning stress, and psychological imbalance—were selected in the test which asked 24 questions.

The learning engagement scale is Li Xiying and Huang Rong's translated and revised version of the learning engagement scale developed by Schaufeli and others. Applicable to Chinese students [20], it asks 15 questions about the three dimensions of vigor, dedication, and absorption.

The academic self-efficacy scale is Li Wei and Bai Yingying's revised version [21]. It asks 20 questions about the two dimensions of learning ability self-efficacy and learning behavior self-efficacy.

The above three scales are based on the structure of the 5-point Likert scale, in which responders specify their level of agreement to a statement typically in five points: (1) strongly disagree; (2) disagree; (3) neither agree nor disagree; (4) agree; (5) strongly agree. The higher the total score, the more active the learning engagement and the higher the academic self-efficacy. The mental health scale is a reverse-scoring scale. Therefore, the higher the mental health score, the lower the mental health level. All the above scales have been proved in actual use to be reliable and valid.

2.2. Data Analysis. SPSS 22.0 and AMOS 23 were used for data analysis and data processing, and *t*-tests, variance analysis, and structural equation model were used for analysis.

2.3. Research Results

2.3.1. The Relationships between Mental Health, Academic Self-Efficacy and Learning Engagement. To explore the relationships between the mental health, academic self-efficacy, and learning engagement of high school students in Tibetan and Qiang areas of China, the authors analyzed the correlation among the three variables and used the means that the respondents obtained from the mental health questionnaire, learning engagement questionnaire, and the academic self-efficacy questionnaire to produce descriptive statistics and conduct correlation analysis. The descriptive statistics and correlation matrix of the variables under this research are shown in Table 2. The results show that the mental health of high school students in Tibetan and Qiang areas of China is negatively correlated with their learning involvement and academic self-efficacy. This is because the mental health questionnaire is a reverse-scoring questionnaire. There is a positive correlation between the academic self-efficacy and learning engagement of high school students in Tibetan and Qiang areas of China; the value of the correlation coefficient ranges from -0.177 to 0.641.The mental health of high school students in Tibetan and Qiang areas of China is negatively correlated with their learning engagement and academic self-efficacy; the values of the correlation coefficients are -0.185 and -0.177, respectively. There is a positive correlation between academic self-efficacy and learning investment, and the correlation coefficient is 0.641. The correlation of the variables is significant at the 0.01 level.

There is a significant negative correlation between the mental health, academic self-efficacy, and learning engagement of high school students in Tibetan and Qiang areas of China. That is to say, the mentally healthier the students, the more active their learning engagement and the higher their academic self-efficacy. There is a significant positive correlation between their academic self-efficacy and learning engagement; the higher their level of academic self-efficacy, the more active their learning engagement.

Table 1: Sample demographics.

Characteristic	N	%
Male	257	42.46
Female	343	57.2
Grade		
Junior high school	343	57.2
High school	257	42.8
A home with parents or a home without parents		
A home with parents	414	69
A home without parents	186	31
Total	600	100

Table 2: Correlation between mental health, academic self-efficacy, and learning engagement.

M ± SD	Mental health	Academic self-efficacy	Learning engagement
Mental health			
1.9977 ± .68,873	1.		
Academic self-efficacy			
3.1563 ± .69,742	−.177**	1.	
Learning engagement			
3.2078 ± .73,129	−.185**	.641**	1

Note: $^{**}p < 0.01$.

Table 3: t-test on gender-specific differences in mental health, learning engagement, and academic self-efficacy.

	Mean (standard deviation)		Degree of freedom	t value	p
	Male ($N = 257$)	Female ($N = 343$)			
Mental health	2.0198 (.73983)	2.0522 (.69288)	598	-.551	.582
Learning engagement	3.1582 (.77022)	3.2288 (.59176)	464.511	-1.222	.222
Academic self-efficacy	3.0905 (.74068)	3.1022 (.60899)	487.410	-.207	.836

Table 4: t-test on differences between students living together with parents and those not living together with parents in mental health, learning engagement, and academic self-efficacy.

	Mean (standard deviation)		Degree of freedom	t value	p
	Students not living together with parents ($N = 186$)	Students living together with parents ($N = 414$)			
Mental health	2.0477 (.72464)	2.0341 (.68802)	598	-.216	.275
Learning engagement	3.1853 (.66677)	3.2045 (.67838)	598	.322	.747
Academic self-efficacy	3.0527 (.64514)	3.1171 (.67785)	598	1.093	.829

2.4. Analysis of Gender-Specific Differences. The authors conducted the independent sample t-test to investigate whether there are any gender-specific differences between high school boy and girl students in Tibetan and Qiang areas of China in mental health, learning engagement, and academic self-efficacy. The results are shown in Table 3. The gender-specific difference in mental health is expressed as $t = -0.551$ ($p > 0.05$), and those in learning engagement and academic self-efficacy are expressed as $t = -1.222$ ($p > 0.05$) and $t = -.207$ ($p > 0.05$). This shows that there is no significant difference between male and female students in Tibetan and Qiang areas of China in mental health and that the difference in learning engagement and academic self-efficacy is not significant. That is to say, there is no difference between male and female students in Tibetan and Qiang areas of China.

2.5. Differences between Students Living Together with Parents and those Not Living Together with Parents. The authors conducted the independent sample t – test to investigate whether there are any differences between students living together with parents and those not living together with parents in Tibetan and Qiang areas of China in mental health, learning engagement, and academic self-efficacy. The results are shown in Table 4. The difference between students living together with parents and those not living together with parents in mental health is expressed as $t = -0.216$ ($p > 0.05$), and those in learning engagement and academic self-efficacy are expressed as $t = 0.322$ ($p > 0.05$) and $t = -1.093$ ($p > 0.05$). This shows that there is no significant difference between students living together with parents and those not living together with parents in Tibetan and Qiang areas of China in mental health and that the difference in learning engagement and academic self-efficacy is not significant. That is to say, there is no difference between students living together with parents and those not living together with parents in Tibetan and Qiang areas of China.

2.6. Grade-Specific Differences. To investigate whether there are any grade-specific differences in the mental health, learning engagement and academic self-efficacy of high school students in Tibetan and Qiang areas of China, the authors conducted a one-way analysis of the variance of the data. As shown in Tables 5 and 6, senior high school students of all three grades show significant differences only in academic self-efficacy and learning engagement, and the academic self-efficacy and learning engagement of grade One and grade Two senior high school students are significantly lower than those of grade Three senior high school students. There is no significant difference in the mental health of high school students in Tibetan and Qiang areas of China. This is different from Andersen et al.'s findings that the mental health of Danish high school students varies with the grade [5]. However, there are significant differences in the mental health of junior high school students of all three grades in Tibetan and Qiang areas of China. The post-hoc test shows that grade two junior high school students are mentally the healthiest, and grade three junior high school students are mentally the least healthy. All junior high school students show no significant differences in learning engagement and academic self-efficacy.

2.7. Mediating Effect

2.7.1. Measurement Model. As shown in Figure 3, the factor loading of all items reaches 0.7 due to factor loading in the measurement model. So all the questions have been retained.

The standardized factor loading of the three variables ranges between 0.711 and 0.903. The factor loading of all items and the t value of all variances have statistical significance. In addition, the absolute value of the kurtosis and deviation ranges from 0.03 to 0.504 and from 0.187 to 0.833, respectively. The absolute values of kurtosis and skewness are less than 2. So the samples have single-variate and multivariate normality [22]. The Mardia coefficient is 24.117, lower than

Table 5: Grade-specific differences in the mental health, learning engagement, and academic self-efficacy of senior high school students.

Grade	Mental health learning engagement				Academic self-efficacy	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Grade one	2.1487	.77602	3.1796	.51307	2.9903	.55148
Grade two	2.0750	.73054	3.1753	.61813	3.0149	.63609
Grade three	1.8750	.73519	.36515	.18257	3.6750	.80571
F value		427		2.214*		2.351*
LSD			Grade one, grade two< grade three; grade one, grade two< grade three			

*represents $p < 0.05$.

Table 6: Grade-specific differences in the mental health, learning engagement, and academic self-efficacy of junior high school students.

Grade	Mental health		Learning engagement		Academic self-efficacy	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Grade one	2.0219	.71305	3.1477	.75793	3.1209	.72429
Grade two	1.8180	.61126	3.2972	.72626	3.2674	.72815
Grade three	2.2050	.68481	3.2044	.67623	3.0704	.57296
F value		7.527*		1.513		2.179
LSD			Grade two < grade one < grade three			

*represents $p < 0.05$.

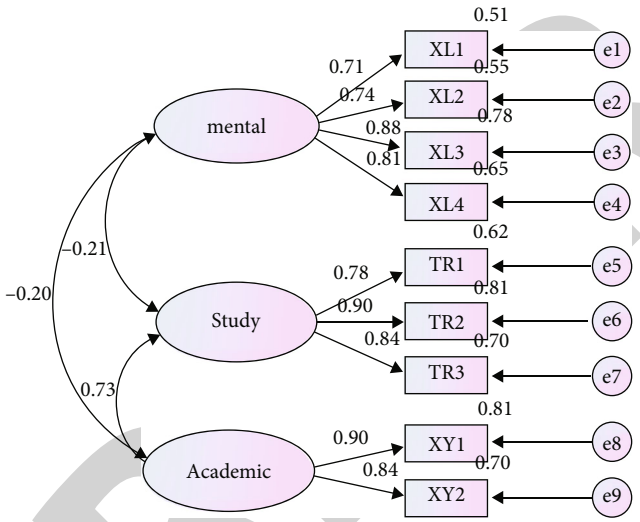

Figure 3: Measurement Model.

$p(P + 2) = 99$ [23]. Mardia coefficient shows that the sample satisfies multivariate normality. Second, model fitting shows that the samples fit the measurement model $\chi 2 = 99.755$ ($p < .001$), $\chi 2/\mathrm{df} = 4.156$, RMSEA = 0.073, CFI = 0.975, NFI = 0.967, GFI = 0.967, TLI = 0.962, and PNFI = 0.645 [23, 24].

Cronbach's alpha, CR, and AVE of each variable range from 0.86 to 0.943, 0.867 to 0.912, and 0.5108 to 0.711, respectively (Table 7).

The Bootstrap method was used to draw observations for 2,000 times. The 95% confidence interval was computed for estimation purposes. It can be seen from Table 7 that Cronbach α of three potential variables exceeds 0.8, which indicates that the three variables have high reliability, and the combination reliability of all three variables exceeds 0.7, which also indicates that the internal consistency of the three variables is high, and the average variation extraction exceeds 0.5, which indicates that the potential variables have high reliability and convergence validity. It can be seen that the measurement model has reasonable reliability and validity, because the factor load, model fitting, reliability, convergence validity, and discriminant validity are acceptable. In addition, the Harman single-factor analytic approach was used to test the common method bias. 22 items have a characteristic root greater than 1. The first factor explains that the 26.185% variance is lower than the 40% critical value, meaning that there is no serious common method bias in the study.

Table 7: Cronbach's alpha, CR and AVE.

Index	Mental health	Learning input	Academic self-efficacy
Cronbach's alpha	0.866	0.877	0.943
CR	0.867	0.880	0.912
AVE	0.622	0.711	0.5108

2.7.2. Main Effect. The main effect is constructed upon mental health and learning engagement. The standardized regression coefficient of the main effect ranges from -0.213 to 0.928, the error variance ranges from 0.147 to 0.358, and the standard error ranges from 0.017 to 0.028. All the t values are significant. The main effect fits the sample data to a reasonable degree and has the following values:

$\chi 2 = 75.959$ ($p < .001$), $\chi 2/\mathrm{df} = 5.843$, RMR = .028, GFI = 0.968, CFI = 0.971, NFI = 0.966, TLI = 0.954, PGFI

= 0.450, and PNFI = 0.598 [23, 24]. Furthermore, mental health explains the 5% difference in learning engagement ($\gamma = -0.21$, $p < 0.001$), as shown in Figure 4.

2.7.3. Structure Model. Figure 5 shows a structure model with path coefficients and explains the differences. The standardized regression coefficient of the structure model ranges from -0.198 to 0.903, the error variance ranges from 0.092 to 0.357, the standard error ranges from 0.013 to 0.031. All the t values are significant. The model fitting of the structure is acceptable, with the following values: $\chi 2 = 99.755$ ($p < 0.001$), $\chi 2/df = 4.156$, RMR = 0.027, GFI = 0.967, CFI = 0.975, NFI = 0.967, NNFI(TLI) = 0.962, PGFI = .516, and PNFI = .645 [23, 24]. In addition, mental health explains the 4% academic self-efficacy ($\gamma = -0.2$, $p < 0.001$), and academic self-efficacy ($\gamma = 0.71$, $p < 0.001$) explains the 53% difference in learning engagement.

2.7.4. Mediating Effect. First, the main effect of the mental health of high school students in Tibetan and Qiang areas of China on their learning engagement is -0.21 ($t = -4.581$, $p < 0.001$) in the absence of self-efficacy as the moderator. Second, the direct effect of mental health on learning engagement is reduced to -0.07 ($t = -1.845$, $p > 0.05$) in the presence of self-efficacy as the moderator. The total effect, direct effect, indirect effect, and the structure model (Table 8) show that the academic self-efficacy of high school students in Tibetan and Qiang areas of China plays an overwhelming mediating role on the relationship between mental health and learning engagement.

In Table 8, the total effect and indirect effect do not include 0, indicating that their parameters are all statistically significant. The 95% confidence interval of the indirect effect does not include 0 (significant), while the 95% confidence interval of the direct effect includes 0 (not significant). According to the Bootstrap method, academic self-efficacy now becomes a complete mediating variable. Hypothesis 2 is thus verified.

3. Discussions

The above research results are summarized as follows:

3.1. Structure Model. Hypothesis 1 has been proven to be the main influencing factor in this study. This finding is consistent with the study by Chen [18]. It suggests that the mental health of high school students in Tibetan and Qiang areas of China is a positive predictor of their learning engagement. Hypothesis 2 has also been validated because in the structure model, the adjusting, mediating effect of the academic self-efficacy of high school students in Tibetan and Qiang areas of China has led to the disappearance of the main effect. The mediating role of academic self-efficacy on the main effect reveals that high school students in Tibetan and Qiang areas of China affirm the formulation and fulfillment of their learning plans, thereby weakening the main effect and providing a strong guarantee for their learning engagement.

3.2. Mediating Effect. The mediating effect of the structure model shows that the learning engagement of high school students in Tibetan and Qiang areas of China is above

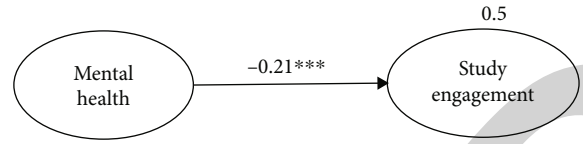

Figure 4: Main effect.

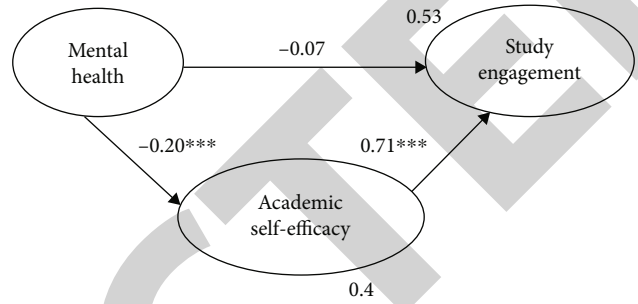

Figure 5: Structure model.

average because their academic self-efficacy is above average. In addition, it is often neglected that the state attaches great importance to education in areas inhabited by minority ethnic groups. In May 2016, the General Office of the State Council issued the "Guidelines on Accelerating the Development of Education in the Midwest", which stressed the importance of achieving the rapid development of education in areas inhabited by minority ethnic groups. The state's close attention to education and its relevant policies have given a boost to the learning engagement of high school students in areas inhabited by minority ethnic groups.

3.3. Correlation Analysis. Correlation analysis shows that the mentally healthier students in Tibetan and Qiang areas of China are, the more engaged they are in learning, and that the higher their academic self-efficacy, the more engaged they are in learning.

3.4. Mental Health. The mental health of high school students in Tibetan and Qiang areas of China is above average. There is no significant difference in mental health between junior and senior high school students regardless of gender. This shows that since the 2008 Wenchuan Earthquake, the region has attached great importance to educating students about mental health and related ongoing efforts are effective. There is no significant difference in the mental health of senior high school students of all three grades. This discovery is slightly different from the findings of Li et al. [25]. The parents of the students experienced the 2008 Wenchuan Earthquake. As a natural outcome, they are very concerned about the health of their children but do not care if their children can go on to college. In addition, high school students tend to be more mentally sound and resilient, so there is no significant difference across the three grades. grade three junior high school students in Tibetan and Qiang areas of China are about to take the Senior High School Entrance Examination (SHSEE), which might reduce their opportunities to go on to senior high school. Without

Table 8: Bootstrap estimation of the 95% confidence interval.

Total, direct, and indirect effect	Path coefficient	Bias-corrected		Percentile	
		Lower	Upper	Lower	Upper
Indirect effect (XL ⟶ XY ⟶ TR)	−.141***	-.216	-.064	-.216	-.064
Direct effect (XL ⟶ TR)	-.068	-.137	.003	-.135	.005
Total effect (XL ⟶ TR)	−.209***	-.315	-.103	-.311	-.099

**$p < .01$.

exception, all parents expect their children to enter high schools instead of vocational high schools. In view of this, grade three junior high school students are generally under great pressure. This is manifested as poorer mental health in comparison with grade one and grade two students. Such a phenomenon is reflective of the actual conditions. This shows that schools and parents should give more care and love to grade three junior high school students, modify their understanding of the Senior High School Entrance Examination (SHSEE), and help them adopt a healthy and positive attitude.

4. Conclusions

The academic self-efficacy of high school students in Aba Tibetan and Qiang Autonomous Prefecture plays an adequate mediating role between their mental health and learning engagement.

5. Research Significance

This study provides a theoretical framework for boosting the learning engagement of high school students in Tibetan and Qiang areas of China. Its findings can basically enhance the understanding of the mental health of the high school students, offer effective ways to boost their learning engagement, and improve their learning efficiency. This model applies to high school students in Tibetan and Qiang areas of China as well as those in other regions of China and even in other countries. The respondents can be high school students, primary school students, college students, or vocational college students. Different respondents may produce different yet interesting results.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Solving the Location Selection Problem of Self-Service Stores from the Perspectives of Sustainability and Uncertainty

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This paper presents an improved method for selecting a specific location in the development of convenience stores in municipal areas. This method solves the problem of self-service store location from the perspective of sustainability and uncertainty and adequately considers the characteristics of individual locations with the proposition of an improved grey wolf optimization algorithm. The example presented shows that the improved algorithm has obvious advantages in facilitating the selection of convenience stores with respect to the search precision, stability, and convergence. Based on the macroenvironment, income, and cost, this work establishes a relatively complex, complete, and targeted mathematical model. Finally, taking the Xiaonanzhuang area of Suzhou Street in Beijing as an example, the scientificity, feasibility, and sustainability of the location model are verified.

1. Introduction

The self-service model has been studied since 2010 [1–3]. Buell et al. [4] investigated the impact of self-service technology usage on customer satisfaction and retention. Self-service terminals are used as part of a customer's checkout process in retail operations. Li et al. [5] proposed that inter-customer interactions are important for the operation of self-services in retail settings. Weretecki et al. [6] studied the impact of intercustomer interactions at retail self-service terminals on service quality perceptions and repeat purchase intentions at retail stores. Self-service stores are retail outlets in which machines replace humans in providing customers with specific services to reduce the cost of delivery and purchasing through service standardization [7, 8]. Compared with traditional retail stores, self-service stores have numerous benefits, including the use of small retail space, low inventory, the provision of convenience, and reduced operation costs [9, 10]. As a result, self-service stores have developed rapidly. The rapid development of self-service stores requires the adequate evaluation and selection of store locations in specific situations. The store location is one of the most important factors in the operation of unattended convenience stores and is directly related to their profitability. Consequently, evaluating and selecting the best store location is a critical problem that needs to be adequately addressed.

Much research has benefited from the development of specific methods for solving the site selection problem under various circumstances. Huang et al. [11] reported an analytical approach to select expansion locations for retailers selling add-on products. Moreover, the authors built predictive models for understanding the derived demand of the add-on product and established an optimization framework for automating expansion decisions to maximize expected sales. Zhao et al. [12] presented a data-driven approach to allocating 'taxi canteens' throughout a city and proposed a constrained optimization model to select locations for these services. Mohammad and Morteza [13] presented a fast, constructive heuristic algorithm based on priority rules to determine the optimal location for storage facilities.

Rao et al. [14] proposed a fuzzy multiattribute group decision-making (FMAGDM) technique based on linguistic tuples to evaluate potential alternative CLC locations. Birol

[15] proposed the Fuzzy Preference Ranking Organization method for enrichment evaluation to evaluate the potential location of logistics centers. Such methods in general can be classified as multiple criteria decision-making (MCDM) methods, mathematical methods, and intelligent methods. MCDM methods always involve multiple objectives, there are contradictions and incommensurability among objectives, and the qualitative and quantitative indicators are mixed [16–18]. The multicriteria decision siting model often contains some specific constraints, can satisfy multiple objectives, and focuses on comprehensively considering multiple criteria for nuclear site selection [19]. Rouyendegh and Savalan [20] combine multiple-criteria decision-making with an analytic hierarchy process and fuzzy sets to establish a hybrid model to provide decision support for the selection of sustainable solutions to agricultural problems. Ghosh et al. [21] studied the application of the hexagonal fuzzy multicriteria decision-making method in the location of charging stations for electric vehicles. Erol et al. [22] proposed a new decision-making framework based on fuzzy MCDM to sort the site selection of alternative nuclear power plants in Turkey. As a result of the existence of qualitative indicators, this method is greatly influenced by subjective factors. In actual decision-making, these qualitative indicators must be treated with fuzzy quantification.

Mathematical methods are used to solve location selection problems by quantifying factors such as costs and expenses, defining definite assumptions, setting parameters and variables, and establishing a mathematical model for optimization [23, 24]. The entropy weight method and TOPSIS model are used to determine distribution center locations in cold-chain logistics. From the perspective of quantitative analysis, how comprehensive factors influence the site selection problem is difficult to consider by establishing a mathematical model for solving it, such as topography, land appreciation, urban development, environment, traffic, pollution, and the impact on the user, which usually cannot be quantified and ignored. The use of mathematical methods to solve practical problems with large amounts of data is often difficult. Mathematical models are always ideal and precise.

The emergence of intelligent algorithms has greatly enriched modern optimization technology and provided practical solutions for combinatorial optimization problems that are difficult to solve using traditional optimization techniques, such as genetic algorithms, particle swarm algorithms, and differential evolution algorithms [25, 26]. These methods share many of the same characteristics: (1) all indeterminate algorithms; (2) global optimization algorithms; (3) excellent distributed computing mechanisms; (4) self-organization and evolution; and (5) strong robustness; however, some defects exist, such as (1) the accuracy of the solution results is often sacrificed for the efficiency of the solution; (2) it easily falls into the local optimal solution; and (3) the selection of algorithm parameters is based mainly on experience.

As a new type of offline retail business, there are few research papers on unmanned convenience stores, and few researchers participate in the study of the operation and management of unmanned convenience stores. At present, the existing research articles on unmanned convenience store mainly focus on analyzing its market positioning and its own operating characteristics and summarize the current development of the industry. Based on this, a self-service store location model is proposed, and an improved grey wolf optimization (GWO) algorithm is proposed to solve the model. Aiming at the improvement strategy of global optimization algorithm, an endogenous improvement method is proposed to optimize the application of global optimization algorithm in linear programming computational problems. The factors affecting the location of self-service stores are analyzed. Seven representative influencing factors are proposed, and two hypotheses are put forward: store rent is the revenue factor, and daily flow is the cost factor. Horizontal competitors in the surrounding area assist in the operation of self-service stores. These hypotheses are verified by practical cases, and their rationality and practical significance are demonstrated.

The remainder of the paper is divided into four sections. The next section describes the location problem and the associated factors. The improved grey wolf algorithm is introduced to solve the mathematical model of the location problem and runs tests using the class functions. A location model of convenience stores is established against this improved algorithm backdrop. This step is followed by selecting the location of two convenience stores in Beijing, and the results of the location model are analyzed. Finally, the concluding section details some practical suggestions for improving future site planning.

2. Formulating the Selection Problem

After analyzing many references and conducting field research in Beijing, the following factors influencing the location selection of self-service stores were summarized to establish the location selection model:

2.1. Environmental Factors. Environmental factors should include the specific location of the reserved location, specific area, degree of policy support, degree of macroregional development, and degree of development of social law and morality [27]. These factors are generally predetermined.

2.2. Revenue Factor. The revenue factor is an important factor that can, directly and indirectly, influence the operating profit of self-service stores. Profit is how much revenue exceeds the cost [28]. The profit of the enterprise comes directly from consumers' consumption in the store.

2.3. Cost Factors. The cost factors generally include the site cost, goods loss cost, maintenance and replacement cost, depreciation cost, and manpower cost [29, 30]. The model of this paper should include the daily flow of people, distance from dangerous areas, maintenance distance, and several peripheral competitors. Self-service stores prefer small numbers of customers with high net worth and long-term stable demand. Therefore, too much traffic does not have a positive effect on these stores. In contrast, due to its limited space, limited reception capacity, and the consumption of hardware facilities and products, too much traffic will have

a highly negative impact. Therefore, the people flow is a cost factor with a large changed weight.

Location in a potentially dangerous area is a serious cost factor. Such an area can attract people who do not intend to shop at the convenience store, create discomfort, and feature low-quality facilities and the potential harm to the store or customers. This factor should therefore be heavily weighted. Surrounding competitors represent the competition factor. Peripheral competitors will inevitably affect the store's income level, but there are no convenience stores with general offline retail stores. Sales are not repelled but increased around a certain number of traditional offline retail stores, as the presence of competitors increases the main demand of passenger flow and disperses them; therefore, this cost factor has a smaller weight. Maintenance distance is the distance from the warehouse to the location of the staff responsible for maintaining the self-service store. The space affects warehouse sales and self-service stores and is affected by the total number of warehouses. Then, the model should consider all preexisting warehouses and no convenience store randomness. The characteristics of the high-frequency replenishment and exchange of goods mean that the distance should be as low as possible. Thus, this factor is a cost factor.

2.4. Correlation Factors. Correlation factors refer to the interactions between factors. The main correlation factors are as follows;

2.4.1. Associated Effects of the Master Stream Band. When the site location is closer to the mainstream of people, away from residential and office areas, the income-weighted rent cost for peripheral small village land is low, and the weight of the cost factor of daytime traffic is large. Conversely, when the location is away from the mainstream of people and close to residential and office areas, the income-weighted rent cost for peripheral districts is larger, with a smaller value for the weight of the cost factor of daytime traffic.

2.4.2. Associated Effects of Risky Areas. When a location is too close to a dangerous area, the weight of daytime human flow and the distance to the dangerous area will correspondingly increase. In contrast, when the location's proximity to a dangerous area meets the specified limit, the weight of the daytime human flow and the distance to the dangerous area will correspondingly decrease.

2.4.3. Associated Effects of Distance to the Maintenance Area. When the location is too far from the maintenance area, the weight of the daytime human flow and distance to the maintenance area will correspondingly increase. In contrast, when the location's distance to a dangerous area meets the specified limit, the weight of daytime human flow and distance to the maintenance area will decrease.

3. Formulating the Site Selection Problem

The objective function of the optimal location is expressed as follows:

$$P_{\text{best}} = \text{MAX}(P_i), \tag{1}$$

where P_i is the optimal location searched by the algorithm in each iteration, which can be expressed as

$$P_i = \text{LP}_i + R_i + \text{DF}_i + \text{NF}_i + \text{DZ}_i + \text{CN}_i + \text{MD}_i + Z_i, \tag{2}$$

where LP_i, R_i, DF_i, NF_i, DZ_i, CN_i, MD_i, and Z_i are represented as different total weight values at position i, which are detailed as follows:

(1) LP_i is the total weight value of the land price in the neighbourhood of the community at position i, which should be expressed as

$$\text{LP}_i = \text{LP}_w \times \text{LP}_{c_i} \times \text{LPK}_i \times \text{DPa}_i, \tag{3}$$

where LP_w is the default weight of the land price, LPc_i is the normalized value of the practical land price at position i, and LPk_i is the dependency coefficient of the actual location on the land price, which can be expressed as

$$\begin{aligned} \text{LPK}_i &= \begin{cases} \omega_1 & \text{dd} \le \text{DD}, \\ \theta_1 & \text{dd} > \text{DD}, \end{cases} \\ \text{DPa}_i &= \begin{cases} \alpha_1 & \text{pp}_i \subset \text{DP}, \\ \beta_1 & \text{pp}_i \not\subset \text{DP}, \end{cases} \end{aligned} \tag{4}$$

where ω_1 and θ_1 are different constants. dd is the distance from the location to the nearest master stream belt, and DD is the default distance limit. DPa_i is the influence coefficient of the closed area on the surrounding land price, while α_1 and β_1 are different constants, pp_i is the location of the prelocation, and DP is the closed area.

(2) R_i is the total weighted value of the store's rent in location i, which can be expressed as

$$R_i = R_w \times \text{Rc}_i \times \text{Rk}_i, \tag{5}$$

where R_w is the default weight of the store's rent, Rc_i is the normalized value of the actual rent, and Rk_i is the dependency coefficient of the actual location on the rent, which can be represented as

$$\begin{aligned} \text{RK}_i &= \begin{cases} \omega_2 & \text{dd} \le \text{DD}, \\ \theta_2 & \text{dd} > \text{DD}, \end{cases} \\ \text{DPb}_i &= \begin{cases} \alpha_2 & \text{pp}_i \subset \text{DP}, \\ \beta_2 & \text{pp}_i \not\subset \text{DP}, \end{cases} \end{aligned} \tag{6}$$

where ω_2 and θ_2 are different constants. DPb_i is the influence coefficient of the closed area on the surrounding land price, while α_2 and β_2 are different constants.

(3) DF_i is the total weighted value of the daytime flow of people at position i, which can be expressed as

$$DF_i = DF_w \times DFc_i \times DFk_i \times CO_i, \quad (7)$$

where DF_w is the fixed weight of the daytime flow, DFc_i is the normalized value of actual daytime flow at position i, DFk_i is the dependence coefficient of the actual location on the flow of people at position i, and CO_i is the influence coefficient of the number of competitors on the daytime flow, which can be described as

$$DFK_i = \begin{cases} \omega_3 & dd \le DD, \\ \theta_3 & dd > DD, \end{cases}$$
$$CO_i = \begin{cases} 1 & \sum cn_{ic} = 0, \\ \mu_1 & \sum cn_{ic} = 1, \\ \mu_2 & \sum cn_{ic} = 2, \end{cases} \quad (8)$$
$$cn_{ic} = \begin{cases} 1 & dcc_i \le dcd, \\ 0 & dcc_i > dcd, \end{cases}$$
$$DPc_i = \begin{cases} \alpha_3 & pp_i \subset DP, \\ \beta_3 & pp_i \not\subset DP, \end{cases}$$

where ω_3 and θ_3 represent different constants. CO_i is the influence coefficient of the number of competitors on the daytime flow. $1 < \mu_1 < \mu_2$, and they are all constants. cn_{ic} is the number of competitors in the default distance dcc_i of position i. DPc_i is the influence coefficient of the closed area on the daytime flow, and α_3 and β_3 are different constants.

(4) NF_i is the total weighted value of the night flows at position i, which should be expressed as

$$NF_i = NF_w \times NFc_i, \quad (9)$$

where NF_w is the default weight of the flow of people at night, and NFc_i is the normalized value of the actual night flow at position i. Because the stream of people at night is relatively lower than that during the day and the service objects are mostly local residents, the cost of loss is lower. In this context, because of the sudden demand of customers and the irreplaceability of self-service stores for general stores, the store earnings rise as the number of customers increases.

(5) DZ_i is the total weighted value of dangerous areas at position i, which can be expressed as

$$DZ_i = Rw \times Rc_i \times DZk_i, \quad (10)$$

where Rw is the default weight of the store's rent, Rc_i is the normalized value of the actual rent, and DZk_i is the dependency coefficient of the actual location on the dangerous area, which can be represented as

$$DZK_i = \begin{cases} \omega_4 & ddz_i \le DDZ, \\ \theta_4 & ddz_i > DDZ, \end{cases} \quad (11)$$

where ω_4 and θ_4 represent different constants. ddz_i is the distance between location i and the nearest dangerous area, and DDZ is the default distance limit.

(6) CN_i is the total weighted value of regional competitors in position i, which can be expressed as

$$CN_i = CN_w \times CNc_i, \quad (12)$$

where CN_w is the default regional competitor weight and CNc_i is the normalized value of the actual number of regional competitors in position i.

(7) MD_i is the total weighted value of the maintenance distance at location i, which can be expressed as

$$MD_i = MD_w \times MDc_i \times MDk_i, \quad (13)$$

where MD_w is the weight of the default maintenance distance and MDc_i is the normalized value of the actual maintenance distance at position i. MDk_i is the dependence coefficient of the actual location on the distance to the maintenance area, which can be represented as

$$MDK_i = \begin{cases} \omega_5 & ddm_i \le DDM, \\ \theta_5 & ddm_i > DDM, \end{cases} \quad (14)$$

where ω_5 and θ_5 represent different constants. ddm_i is the distance between location i and the nearest dangerous area, and DDM is the default distance limit.

4. A New Method

Grey wolves are highly intelligent social animals and have long been considered a dangerous top predator, which means they are at the top of the food chain. Most grey wolves like to live in a small cluster.

The leader of the herd can be a male wolf or a female wolf, which we call the alpha (α) wolf. Alpha (α) wolves are mainly responsible for making decisions about where the population hunts, where they sleep, when they wake up, and so on. The decision of the alpha (α) wolf depends on individual thinking and decision-making behaviour [31]. However, biologists have also observed some kind of democratic behaviour; that is, alpha (α) wolves sometimes follow other subordinate wolves. In the group, the whole population recognizes the alpha (α) by raising its tail. The alpha (α) wolf is also called the dominant wolf because his or her orders should be obeyed by the whole pack. Alpha (α) wolves are only allowed to mate and reproduce in their own population. It is worth noting that alpha (α) wolves are not necessarily the strongest and most ferocious members of the pack, but they are the best at managing the pack

[32]. This shows that for the first wolf, that is, alpha (α) wolf, organizational ability and discipline are much more important than their individual strength in status evaluation.

The second level of the grey wolf class is the beta (β) wolf. Beta (β) wolves are subordinate wolves to help alpha (α) wolves make decisions or leaders of other ethnic activities. Beta (β) wolves can be either male or female, and he or she may be the best candidate for alpha (α) wolves to prevent the death or aging of alpha wolves. Beta (β) wolves should respect the alpha (α), but also command and command other lower-level wolves. It plays the role of consultant and trainer. Beta (β) wolves play a role in strengthening the alpha (α) command and providing feedback to the alpha (α) in the whole population [33, 34].

The lowest ranking grey wolf is the omega (ω) wolf. Omega (ω) plays the most passive role of scapegoat. Omega wolves always have to obey all other higher-level dominant wolves. They are the last wolves allowed to hunt and feed. Omega (ω) wolves may not seem like a very important hierarchy, but biologists have observed the problems caused by internal fighting and the loss of omega (ω) wolves in the entire population [35]. This is because omega (ω) wolves mainly perform the function of violence and destruction at all levels of the pack. This helps to meet the needs of the whole ethnic group and maintain the dominant structure. In some cases, omega (ω) is also a maintainer in the community.

If the selected grey wolf is not an alpha (α) wolf, a beta (β) wolf, or an omega (ω) wolf, then he or she is called a delta (δ) wolf. Delta (δ) wolves must obey the alpha (α) wolves and the beta (β) wolves, but they will dominate the omega (ω) wolves. Scouts, sentinels, elders, hunters, and guards belong to the role of this type of wolf. The scouts are responsible for monitoring the boundaries of the territory and warning the guard in the event of danger. The sentry protects and ensures the safety of the packing [36]. Elders are experienced wolves who used to be alpha (α) wolves or beta (β) wolves. Hunters help the alpha (α) wolves and the beta (β) wolves when hunting prey and providing food. Finally, the guards are responsible for taking care of the weak, sick, and injured members of the pack. In the GWO algorithm, the hunter-gatherer (optimization) is always led by α, β, and δ. The rest of the wolves follow these three wolves. According to the description of Muro et al. [37] the main stages of grey wolf hunting are as follows:

(1) Tracking, chasing, and approaching prey

(2) Pursuing, surrounding, and harassing the prey until it stops moving

(3) Attacking the prey

Grey wolves surround their prey during hunting. To simulate surrounding behaviour mathematically, the following equation is proposed:

$$\begin{aligned} \vec{D} &= \left| \vec{C} \times \overrightarrow{X_p}(t) - \vec{X}(t) \right|, \\ \vec{X}(t+1) &= \overrightarrow{X_p}(t) - \vec{A} - \vec{D}, \end{aligned} \tag{15}$$

where t represents the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p(t)$ is the position vector of prey, and $\vec{X}$ indicates the position vector of grey wolves.

$$\vec{A} = 2\vec{a} \times \overrightarrow{r_1} - \vec{a}, \tag{16}$$

$$\vec{C} = 2\overrightarrow{r_2}. \tag{17}$$

In the iterative process, the convergence factor decreases linearly from 2 to 0, and the vector r is the random number between 0 and 1. Grey wolves can update the position in the surrounding space of their prey at any random position using equations (16) and (17).

We save the first three best solutions so far and ask the other search agents (including the omega wolf) to update their location X_α, X_β, and X_δ according to the position of the optimal search agent:

$$\begin{aligned} x_{i,\alpha}^d(t+1) &= X_\alpha^d(t) - A_{i,1}^d \left| C_{i,1}^d X_\alpha^d(t) - X_i^d(t) \right|, \\ x_{i,\beta}^d(t+1) &= X_\beta^d(t) - A_{i,2}^d \left| C_{i,2}^d X_\beta^d(t) - X_i^d(t) \right|, \\ x_{i,\delta}^d(t+1) &= X_{\alpha\delta}^d(t) - A_{i,3}^d \left| C_{i,3}^d X_{\alpha\delta}^d(t) - X_i^d(t) \right|, \\ X_i^d(t+1) &= \frac{X_{i,a}^d(\mathrm{t}+1) + X_{i,\beta}^d(t+1) + X_{i,\delta}^d(t+1)}{3}, \end{aligned} \tag{18}$$

where $X_i^d(t+1)$ represents the fitness value of the individual grey wolf i in generation $t+1$.

To solve the problem that the basic GWO easily falls into a local optimum, this paper improves two aspects:

4.1. Convergence Factor Strategy Based on Nonlinear Decline. In GWO, the default convergence factor decreases linearly from 2 to 0 as the number of iterations increases; however, in using the actual algorithm and solving the function, the algorithm convergence trend is not linear. Therefore, the linear decreasing strategy of convergent factor in the basic algorithm is not completely suitable for the actual algorithm when searching and calculating the optimal value of the function. Therefore, a new nonlinear convergence method is proposed in this paper:

$$a = 2 - 2\left(\frac{l}{n}\right)^2, \tag{19}$$

where l is the current iteration number; n is the default maximum number of iterations; and a is a nonlinear convergence factor.

The nonlinear convergence of convergence factor a is shown in figure 1.

When the maximum number of iterations is 500, the blue function curve represents the speed of basic GWO convergence, and the red function curve represents the speed of optimized algorithm convergence. The improved convergence factor a presents the curve convergence with the

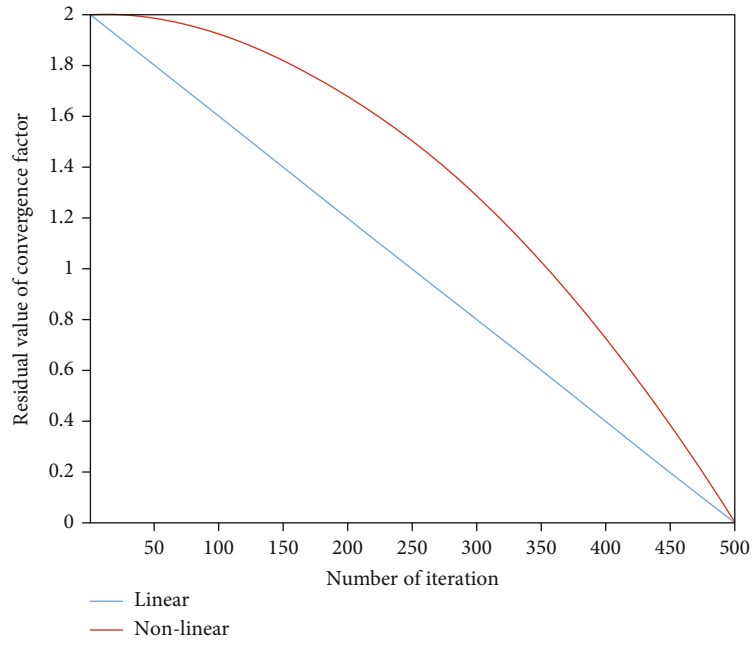

Figure 1: Comparison of convergence factors.

iterations; in the short term, a slow convergence speed can interact with the GWO to determine a better global optimal solution, and in the medium term, the convergence of the algorithm is accelerated. The convergence speed of a accelerates at the later stage, which helps the algorithm find the local optimal solution quickly.

4.2. Fixed Penalty Function Method for Multisegment Association Mapping. Because GWO is an optimization algorithm search technology based on an unconstrained function, it is necessary to combine an appropriate constraint treatment when solving the optimization problem of the constrained function with GWO. The penalty function method is most commonly used to handle a series of unconstrained optimization algorithm technologies.

As shown in equation (20), the constraint optimization problem is as follows:

$$\begin{aligned} &\mathrm{Min} f(x), \\ &\mathrm{s.t.} g_j(x) \le 0 \quad j = 1, 2, 3, \cdots, p, \\ &h_j(x) = 0 \quad j = p+1, p+2, p+3, \cdots, m, \\ &l_i \le x_i \le u_i \quad i = 1, 2, 3, \cdots, d, \end{aligned} \tag{20}$$

where $f(x)$ is the target function, $g_j(x)$ is the constraint condition of the inequality, $h_j(x)$ is the constraint condition of the equation, and l_i and u_i are the upper and lower bounds of the variable x_i, respectively.

This equation can be translated into the following form:

$$\begin{aligned} h_j(x) - \varepsilon \le 0, \\ -h_j(x) - \varepsilon \le 0, \end{aligned} \tag{21}$$

where ε is called the tolerance value, which is generally taken as a small positive number. The general form of the constructed generalized objective function is as follows:

$$F(x) = f(x) + \partial(t) H(x), \tag{22}$$

where $F(x)$ is the original target function, partial $\partial(t)H(x)$ is called the punishment term, partial $\partial(t)$ is expressed as the punishment intensity, and $H(x)$ is called the punishment factor.

During the whole process of solving the optimization problem of constraints, if the partial (t) in equation (22) is fixed, it is called the fixed penalty function method; otherwise, it is called the nonfixed penalty function method. The fixed penalty function method will be determined by a set of preset parameters in accordance with the actual situation or theoretical situation and will not change due to changes in the number of iterations. Multisegment mapping is when the function value or variable value changes, and the default constraint function will have different constraint effects on the original function, which is expressed as:

$$\begin{aligned} H_1(x) &= A(x) \times B(x), \\ A_1 \quad & A(x) \le r_1, \\ A_2 \quad & r_1 < A(x) \le r_2, \\ A_3 \quad & r_2 < A(x) \le r_3, \end{aligned} \tag{23}$$

where $H_1(x)$ is the target punishment function; $A(x)$ is the punishment intensity; $B(x)$ is the punishment degree; A_1, A_2, and A_3 are the punishment intensity set; and r_1, r_2, and r_3 are the upper and lower bounds of different sections.

The correlational penalty function can be expressed as

$$\begin{aligned} H_2(x) &= A_2(x) \times B_2(x), \\ H_3(x) &= A_3(x) \times B_3(x), \\ \mathrm{AX}_2 &\quad x < e_1, \\ \mathrm{BX}_2 &\quad x \geq e_1, \\ \mathrm{AX}_3 &\quad H_2(x) < e_2, \\ \mathrm{BX}_3 &\quad H_2 \geq e_2, \end{aligned} \tag{24}$$

where $H_2(x)$ and $H_3(x)$ are objective functions; $A_2(x)$ and $A_3(x)$ are weights of punishment; $B_2(x)$, $B_3(x)$, and r are the reference boundary of the independent variable x; AX_2 and BX_2 are variable values of presupposed $A_2(x)$; and e_2 is the reference boundary of the dependent variable$H_2(x)$. AX_3 and BX_3 are the variable presupposed values of dependent variable $H_2(x)$.

According to the above ideas and formulas, a new grey wolf optimization algorithm is proposed in this paper, and its process can be summarized as follows. The flow chart is shown in Figure 2.

Step 1. Initialize the grey wolf population, that is, randomly generate the position of n intelligent individuals; initialize a, A, and C; initialize the value of X_α, X_β, and X_δ.

Step 2. The transboundary intelligent individual is processed, and the fitness value of each intelligent individual is calculated.

Step 3. Compare the fitness of each individual of intelligence, and determine the optimal solution, optimal solution, sub-optimal solution, and X_α, X_β, and $X_\delta$in the current iteration.

Step 4. For each intelligent individual, the strategy is adjusted nonlinearly according to the control parameters, and the parameters a are obtained by optimization, and then A and C are obtained.

Step 5. According to the optimized position determination method and the nonlinear penalty function, the position of the intelligent individual is redetermined.

Step 6. Then, determine the fitness of the new generation of individuals and update the population level.

Step 7. If the end condition (maximum number of iterations) is reached, the end is finished and the optimal solution is output, otherwise go to Step 2.

5. Simulation Study

To test the feasibility and practical reliability of the IGWO, we used classic test functions, including unimodal functions and multipeak functions. Each function was used to extract three sample tests and was compared with GWO and PSO. The details are shown in Tables 1 and 2:

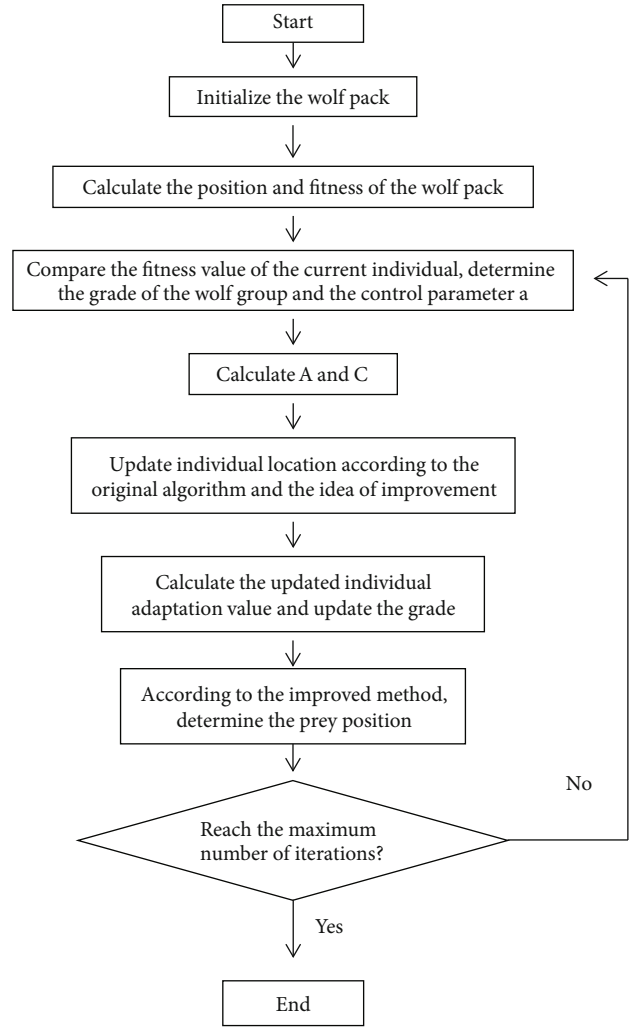

Figure 2: Flow chart of improved grey wolf optimization algorithm.

Table 1: Unimodal function.

Function	Dim	Range	$f_{\min}$
$f_1 = \sum_{i=1}^{n} x_i^2$	30	[-100,100]	0
$f_2 = \sum_{i=1}^{n} \lvert x_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$	30	[-10,10]	0
$f_3 = \sum_{i=1}^{n} \left(\sum_{j-1}^{i} x_j \right)^2$	30	[-100,100]	0

Each test function was tested at least 50 times, and the representative image was taken for display. The details are shown in Figures 3–8.

As shown, compared to PSO, IGWO has obvious advantages in terms of speed and precision and does not easily fall into the local optimum. IGWO shows clear superiority of the functional testing results shown in Table 3.

Table 3 shows the following aspects in detail:

Table 2: Multimodal function.

Function	Dim	Range	$f_{\min}$
$f_4 = \sum_{i=1}^{n}[x_i^2 - 10\cos(2\pi x_i)] + 10$	30	[-5.12,5.12]	0
$f_5 = -20\exp\left(-0.2\sqrt{\frac{1}{n}\sum_{i=1}^{n}x_i^2}\right) - \exp\left(\frac{1}{n}\sum_{i=1}^{n}\cos(2\pi x_i)\right) + 20 + e$	30	[-32,32]	0
$f_6 = \frac{1}{4000}\sum_{i=1}^{n}x_i^2 - \prod_{i=1}^{n}\cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$	30	[-600,600]	0

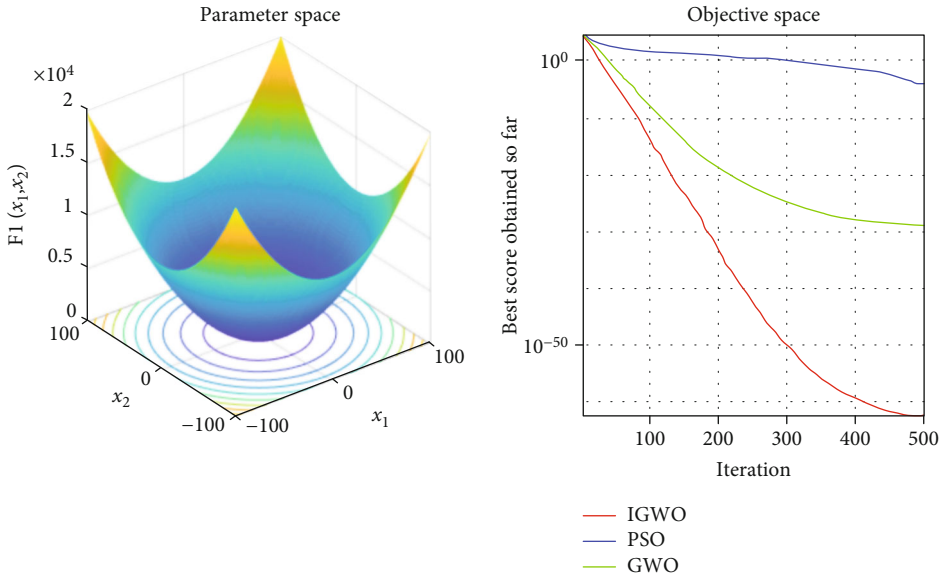

Figure 3: $f_1 = \sum_{i=1}^{n}x_i^2$ test function.

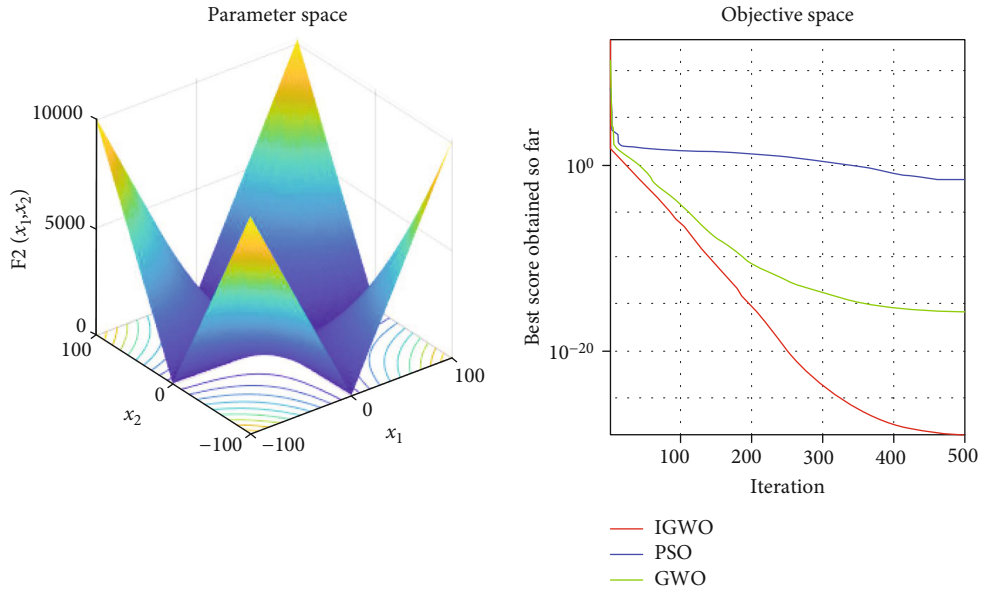

Figure 4: $f_2 = \sum_{i=1}^{n}|x_i| + \prod_{i=1}^{n}|x_i|$ test function.

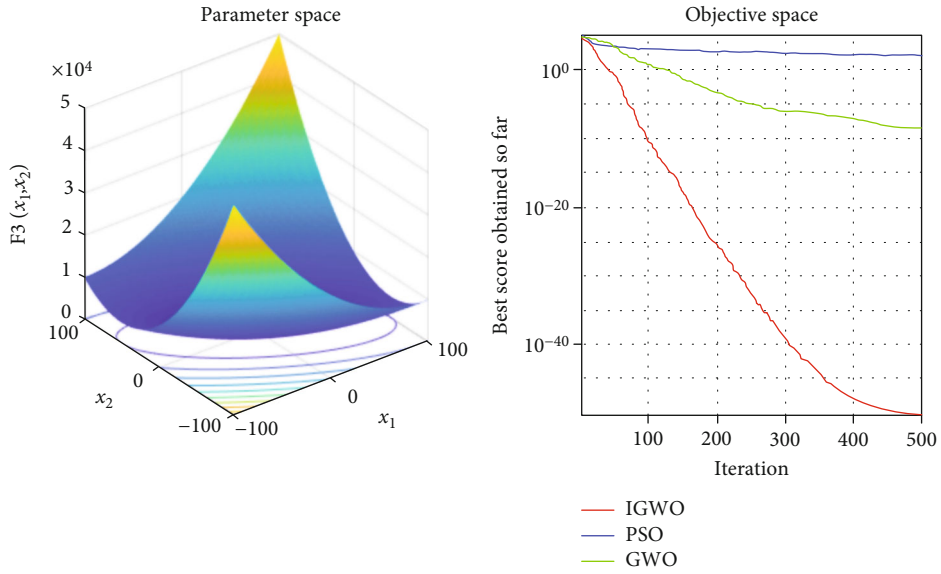

Figure 5: $f_3 = \sum_{i=1}^{n} (\sum_{j-1}^{i} x_j)^2$ test function.

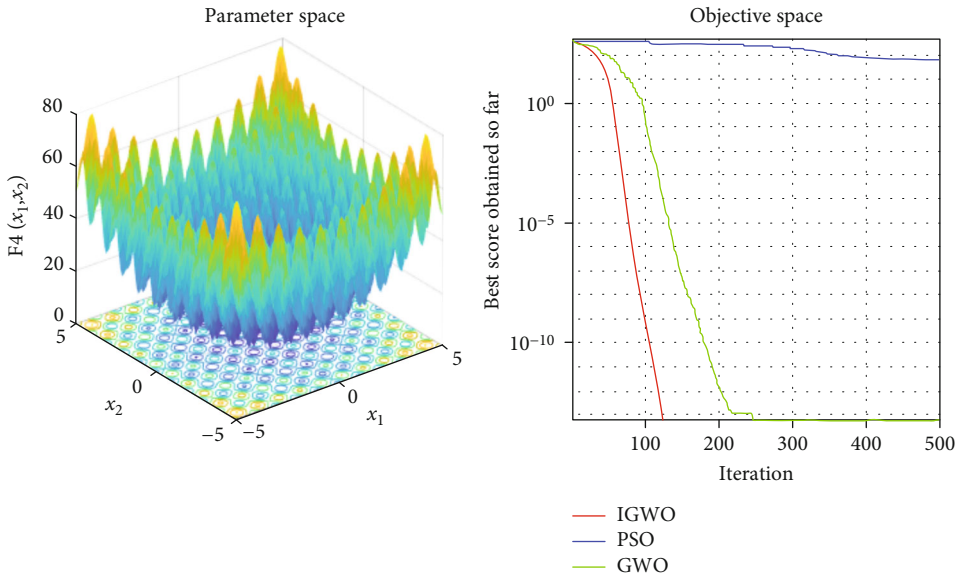

Figure 6: $f_4 = \sum_{i=1}^{n} [x_i^2 - 10 \cos(2\pi x_i)] + 10$ test function.

5.1. Evaluation of exploitation capability (functions F_1–F_3). Functions F_1–F_3 are unimodal with only one global optimum, which can evaluate the exploitation capability of the investigated metaheuristic algorithms. According to the results in the table, the present algorithm provides very good exploitation.

5.2. Evaluation of exploration capability (functions F_4–F_6). To evaluate the exploration capability of an optimization algorithm, we used multimodal functions. These functions include many local optima whose number increases exponentially with the problem size (the number of design variables).

In terms of quantitative analysis, on the premise of keeping the original search time unchanged, the improved grey wolf optimization algorithm improves the search accuracy by 100%. The search accuracy of all test functions of PSO, PSO, and GWO can only be maintained to about e^{-28}, while the improved grey wolf optimization algorithm can stably improve the search accuracy to about the maximum e^{-60}, and performs well in several test functions, significantly leading the accuracy of GWO and PSO. In fact, because the algorithm slows down the convergence speed of the convergence factor in the early stage, the algorithm actually searches more possible solutions and traverses more possibility intervals, so the actual operation speed of the

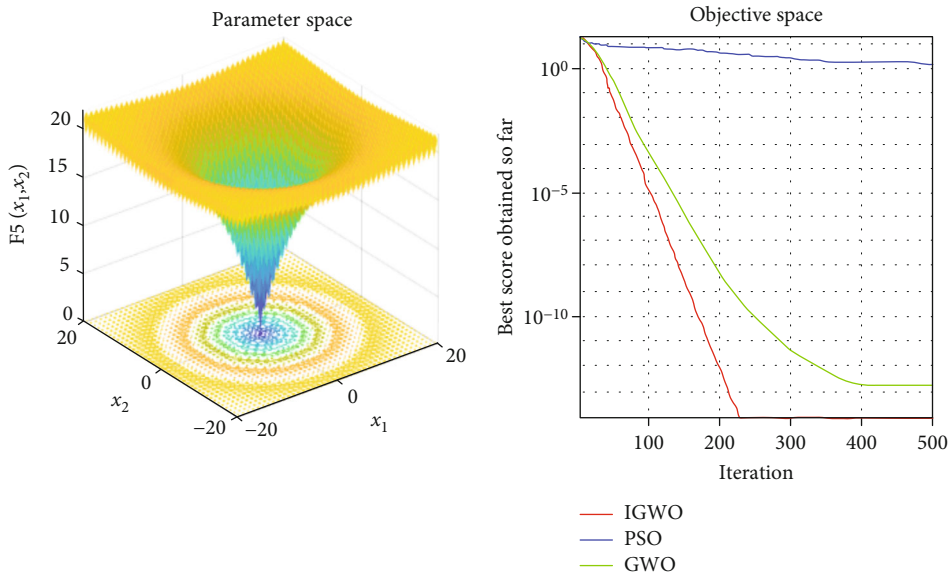

Figure 7: $f_5 = -20\exp\left(-0.2\sqrt{(1/n)\sum_{i=1}^{n}x_i^2}\right) - \exp\left((1/n)\sum_{i=1}^{n}\cos(2\pi x_i)\right) + 20 + e$ test function.

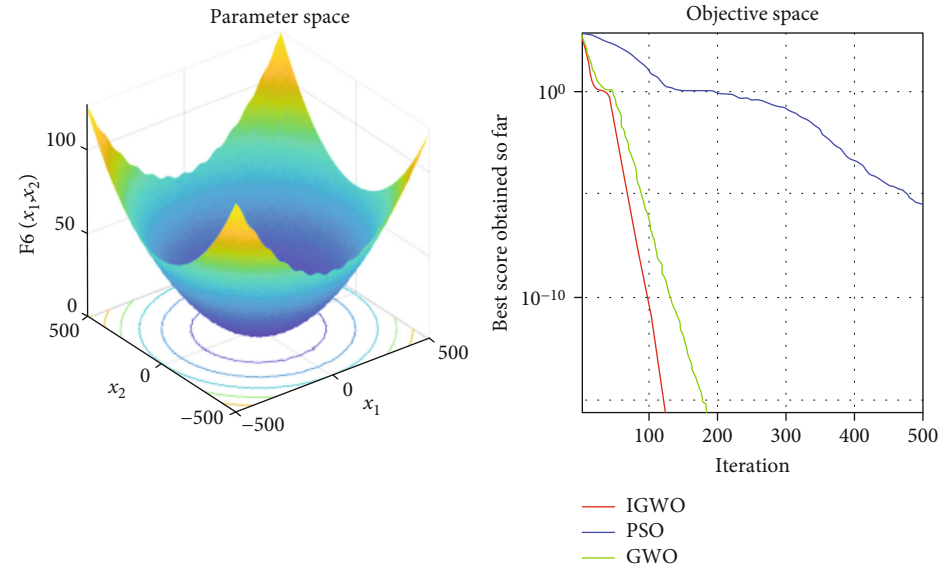

Figure 8: $f_6 = (1/4000)\sum_{i=1}^{n}x_i^2 - \prod_{i=1}^{n}\cos\left(x_i/\sqrt{i}\right) + 1$ test function.

Table 3: Comparison of optimization results.

F	IGWO			GWO			PSO		
	Avg	Std	f_{min}	Avg	Std	f_{min}	Avg	Std	f_{min}
F_1	6.5991E-61	1.0803E-60	9.0538E-64	1.2038E-27	2.154E-27	7.1046E-30	1.62E-04	0.00025071	5.8104E-06
F_2	1.541E-28	1.3769E-28	8.8133E-30	1.54E-16	9.9257E-17	7.461E-17	4.31E-02	0.02528922	0.00568909
F_3	2.0747E-46	5.1803E-46	1.0348E-53	6.71E-05	0.00014031	1.0995E-07	8.68E+01	54.2280091	50.162977
F_4	0	0	0	3.45E+00	3.64620894	5.6843E-14	1.10E+00	0.15524199	0.15523653
F_5	15.8452336	8.35507149	7.99E-15	9.68E-14	1.35024E-14	7.5495E-14	1.15E+02	136.910361	136.487454
F_6	0	0	0	2.86E-03	0.00619638	0	9.62E-03	0.0094064	4.2541E-06

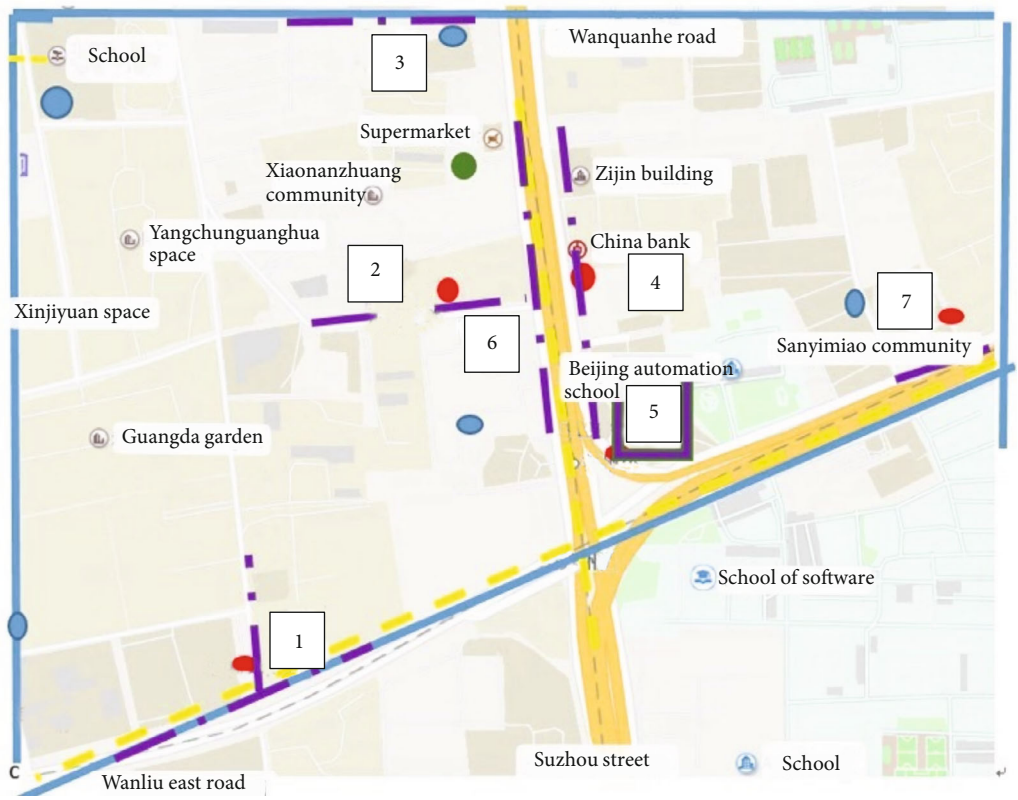

Figure 9: Location map for Xiaomai (Suzhou Street).

algorithm is accelerated. It shows its extremely high precision and not easy to fall into the local optimal performance.

In terms of qualitative analysis, the improved grey wolf optimization algorithm further improves the convergence speed and the smooth degree of convergence in the second half of the algorithm on the premise of keeping the original convergence curve from deterioration. IGWO further maintains and improves its own characteristics of fast iteration speed, fast convergence speed, and fast search speed in the process of comparing PSO and GWO.

6. Examples

6.1. Case Analysis. The case area is zoned from the auxiliary road of Wanquanhe Road in the north to Suzhou Street in the south and from western Sanyimiao Community in the east to Wanliu East Road in the west. The area is 1.2 km long from east to west, the longest distance from north to south is 900 m, and the shortest is 650 m. The case area contains a total of eight residential areas, including Guangda Garden, Xiaonanzhuang Community, and Xinjiyuan Space, two primary schools, two secondary schools, and a floating population area. An illustration of the area is shown as Figure 9.

To build the model, the area was transformed into a rectangle with a length of 120 and a width of 80, and each optional location in the region was marked. The dangerous area is marked in blue, the maintenance area is marked in green, and surrounding competitors are marked in red. The approximation is as follows Figure 10.

Through the measurement of the actual model described in the previous chapter, we obtained seven kinds of data for seven areas, as shown in Table 4, then, we normalized the data.

We then introduced a linear normalization formula to normalize the data used in this paper:

$$P_i^* = \frac{P_i - P_{\max}}{P_{\min} - P_{\max}}, \tag{25}$$

$$P_i^* = \frac{P_i - P_{\min}}{P_{\max} - P_{\min}}, \tag{26}$$

where P_i is the i-th value of the P class data. $P_{\max}$ refers to the maximum value of the P class data, $P_{\min}$ refers to the minimum value of the P class data, and P_i^* is the normalized value of the i-th value of the P class data. Formula (25) is used when P_i is smaller and closer to the expected situation. Formula (26) is used when P_i is larger and closer to the expected situation.

In practical application, taking area 1 (Xiaomai) as an example when calculating the land price factor, this factor increases as it becomes closer to the expected value, which can be written as

$$A_1^* = \frac{4.6 - 5.5}{4.3 - 5.5} = 0.25, \tag{27}$$

However, when normalizing the value of the distance from the danger area, this factor decreases as it becomes closer to the expected value, which can be written as

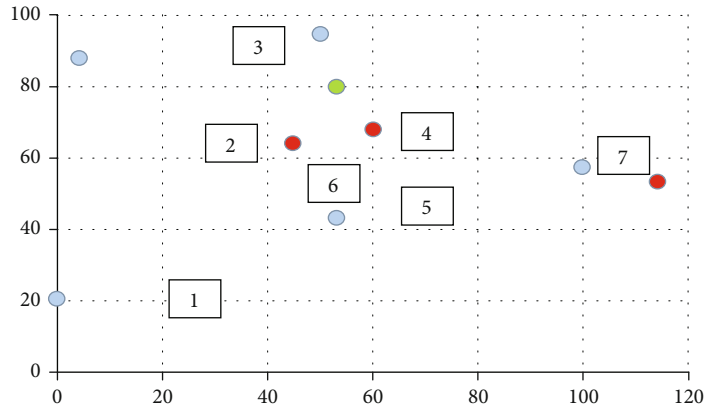

Figure 10: Segmentation of the Xiaomai site selection area.

Table 4: Site selection factor measurements.

	Land price	Rent	Daytime flow	Night flow	High risk area	Number of competitors	Maintenance distance
1	3100	9	9	2	7	1	9
2	2700	7	8	2	7	1	3
3	2500	10	9	2	1	0	2
4	3500	12	2	1	6	2	2
5	2900	12	10	2	5	2	7
6	2900	11	10	2	6	2	2
7	2700	12	10	2	1	1	10

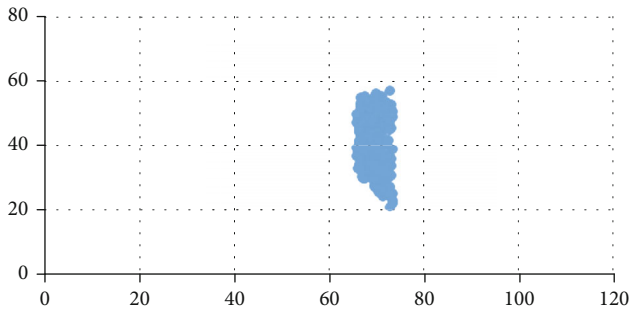

Figure 11: Site selection result for Xiaomai (Suzhou Street).

$$E_1^* = \frac{5-5}{1-5} = 0. \quad (28)$$

This process is similar to the remaining data.

6.2. Analysis of the Model Calculation Results. MATLAB software was used for 200 tests (as in the previous procedure) to form the scatter diagram of location selection shown in Figure 11; that is, the optimal solution to the location selection problem. The optimal locations are mainly concentrated in the Youth Apartment area (enclosed residential area) in area 4 and the office building in area 5. In these areas, the floating population is low, which guarantees that the customer source is active and stable; however, the land price of the neighborhood around area 7 is high, as the area features mainly residents with higher incomes. The area is close to the planned maintenance location for urban and rural storage, which helps to reduce maintenance costs. Conforming with the self-service retail industry in Beijing before the existing location mode emphasizes the main principles to "avoid crowds, implement closed-end management, serve select customer groups, implement low flow operations, and be close to maintenance areas;" this approach can ensure the long-term stable development of self-service stores.

7. Conclusion

In this paper, IGWO is proposed. This approach features high stability, high speed, accuracy, and global scope, can solve the optimal search problem of the related functions involved in the general swarm intelligence optimization algorithm, and has good adaptability and reliability for common functions. This paper also tries to solve the problem of convenience store location from the perspective of sustainability and uncertainty, and explores the development history of the unmanned retail industry in China, focuses on the development process of the self-service store industry in Beijing, and analyses the development of several typical self-service stores in Beijing and the location of these sites.

Based on research and analysis, three categories of dimensions are summarized:

(1) Macroenvironmental factors, which include policy factors, legal and quality factors, macroeconomic development factors, and the specific circumstances of the selected regions

(2) Income factors, which include land price, shop rent, and night flow

(3) Cost factors, which include daytime flow, risk zone distance, maintenance area distance, and surrounding competitors

Through these dimensions, a relatively complex, sustainable, complete, and targeted mathematical model has been established. Finally, we selected Suzhou Street in the Xiaonanzhuang area as a case area and verified the scientific feasibility of the location model.

7.1. Managerial Insights. The problem of determining the location of convenience stores has often been mentioned by previous researchers but without a scientific, systematic, visual, and quantifiable description or calculation method to address it. In response, an effective, targeted, systematic, and practical location method is proposed in this paper. In terms of optimization and improvement strategies for the grey wolf optimization algorithm, some endogenous improvement methods are provided, and the calculation of the linear programming problem is optimized. These advancements offer innovation, pertinence, and practicability. For the establishment of the location model for convenience stores, seven representative important influencing factors are put forward, and two hypotheses are proposed: store rent is a factor of income, and the flow of people in the daytime is a factor of cost, and competitors in the surrounding industry are helpful for the operation of the convenience store. Using an actual case to verify these assumptions, we proved their rationality and practical significance.

7.2. Opportunities for Future Research. This paper focuses on improving the internal mechanism of the GWO algorithm. The algorithm's optimization speed is not optimal and thus room for improvement remains to avoid falling into local optimization. At present, the most popular method is to use two or more hybrid algorithms, such as hybrid difference algorithms and genetic algorithms, to improve this optimization. Future research can integrate multiple algorithms to overcome the problem of easily falling into local optimization.

For convenience, this paper focuses mainly on factors that can be simply quantified and have fixed values. For some content, it is difficult to investigate and collect information, including the impact of the population age ratio on consumption in the convenience store, the consumption tendency of customers at the convenience store, and the subjective attraction of the location to the crowd. These factors have not been investigated, analyzed, and evaluated in depth, which makes the evaluation ability of the mathematical model in the subjective direction insufficient. Future researchers can conduct more in-depth analyses of these aspects.

Data Availability

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

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

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Research Article

Impact of Low-Carbon City Policy on Enterprise Investment Efficiency: Based on the Heterogeneity of Chinese Urban Culture

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Based on panel data of Chinese listed companies, this paper estimates the impact of low-carbon city policy (LCCP) on enterprise investment efficiency (EIE) by the heterogeneous timing difference in differences (HTDID) method and examines the heterogeneous effect of urban culture on the impact. The results show that LCCP improves EIE, and the research conclusion passes the robustness tests. Mechanism analysis reveals that LCCP mainly acts on EIE along two paths: promoting enterprise technological innovation and easing financing constraint. But the LCCP does not have a significant effect on resource allocation. On urban culture heterogeneity, the ecological wisdoms of green urban culture and Confucian culture, such as benevolence to all beings and the harmony between man and nature, help to enhance the promoting effect of LCCP on EIE. From the perspectives of the synergistic development between formal and informal institutions and of urban cultural governance, this research provides important reference and data support to EIE improvement.

1. Introduction

Global warming, a consequence of greenhouse gas emissions, exposes human beings to multiple risks, including sluggish economic growth and worsening living environment. To address these risks, the National Development and Reform Commission of China issued the *Notice on Launching the Pilot Program of Low-Carbon Provinces and Low-Carbon Cities* in 2010, kicking off the piloting of low-carbon city development. In the meantime, the Chinese economy is moving from the high-speed growth stage to the high-quality development stage. The further decline of industrial production efficiency has severely bottlenecked the macroeconomic growth of China in recent years. The low-carbon city policy (LCCP) requires cities to clarify their development strategies, principles, and directions during the pursuit of low-carbon development; accelerate the research and development, promotion, and application of low-carbon technologies; build a low-carbon industrial system characterized by greenness, environmental friendliness, and high recyclability; and implement the industrial policies, fiscal and tax policies, and technology promotion policies for low-carbon development, aiming to strengthen the driving role of low-carbon technology innovation on economic development. Enterprises are the most important participant and contributor in the construction of low-carbon cities. Being major emitters of carbon dioxide, enterprises are the core organizers of low-carbon product research and development and need to improve investment efficiency, one of the most effective ways to reduce carbon emissions and lead the construction of low-carbon cities. In the context of China's economic transformation, culture lies at the core of the informal institution and significantly affects economic and social development. The implementation of the LCCP is inseparable from the cultural foundation at the city level. Therefore, it is particularly important to explore the impact of LCCP on enterprise investment efficiency (EIE) and consider the role of urban culture for the implementation of policies. Facing the realistic needs of ecological protection and high-quality development, this paper is aimed at answering

the following questions: does China's LCCP help improve EIE? Under the influence of culture, an important informal institution, does the relationship between LCCP and EIE varies with the culture of specific cities?

Rich results have been drawn on the evaluation of the effect of LCCP. Many scholars used the data of Chinese listed companies to evaluate the impact of LCCP on the total factor productivity [1]. For example, Song et al. [2] measured the impact of LCCP on energy efficiency. Cheng et al. [3] discussed the effect of low-carbon city construction on green growth. Chinese scholars have also explored the relationship between LCCP and economic efficiency extensively. For instance, Z. Wang and H. Wang [4] found that the LCCP can significantly promote the high-quality development of enterprises, both in terms of the total factor productivity and sustainable development. Zhao et al. [5] and Guan et al. [6] proved the positive effect of LCCP on the total factor productivity of enterprises. Fan and Liu [7] discovered that the LCCP has significantly improved the total factor energy efficiency. The existing literature provides profound insights for the effect evaluation of LCCP. But there are some shortcomings. Firstly, the existing research on LCCP emphasizes environmental performance and economic performance, over the impact of LCCP on EIE. To enhance the development resilience and core competitiveness of enterprises, it is crucial to take low-carbon city piloting as a strategic opportunity to inject new vitality into the improvement of EIE, by boosting the enthusiasm and creativity of implementing the climate action vision. Therefore, it is important to explore the impact of LCCP on EIE, a weak link in the existing research. Secondly, the piloting effect of LCCP is closely associated with the urban culture, yet the factors of urban culture have not been thoroughly investigated. Thus, it is of great academic value to systematically evaluate the action and effect of China's LCCP on EIE and examine the effects of urban cultural factors.

Based on the above analysis, this paper intends to reveal the impact mechanism of LCCP on EIE and to empirically test that impact. Taking the LCCP as a quasinatural experiment, the authors estimated the impact of LCCP on EIE, using the heterogeneous timing difference in differences (HTDID) method, and alleviate the endogenous bias through a series of robustness tests. In addition, urban green culture and Confucian culture were taken as examples; the heterogeneous impact of urban culture was examined, revealing the key role of cultural governance in the implementation of LCCP. This is another defining feature of this research. The research findings help to examine the achievements of low-carbon city construction, deepen the understanding of the factors affecting EIE, and provide reliable suggestions for promoting high-quality economic development while implementing low-carbon governance.

The main contributions are as follows: firstly, scholars have not reached a consensus on how environmental regulation affects economic efficiency of enterprises [8–11]. At the same time, the existing literature only focuses on the overall impact of environmental regulation intensity on EIE, without going to the details. This paper examines the implementation effect of LCCP from the perspective of investment efficiency and expands the research framework for scientifically quantifying the implementation effect of the policy on the basis of overcoming self-selection of samples, thereby alleviating endogeneity and eliminating other policy interference. Secondly, the mechanism of LCCP on EIE is verified; that is, LCCP will affect EIE through technological innovation effect and alleviating financing constraint effect, and LCCP does not produce resource allocation effect. Thirdly, the analysis on urban culture heterogeneity discovers that both urban green culture and Confucian culture offer a favorable environment for the orderly promotion of LCCP.

2. Theoretical Analysis and Hypotheses

2.1. LCCP and EIE. Under the global trend of carbon reduction, China launched the first batch of low-carbon pilot projects in 2010. Each pilot region was required to explore a low-carbon development model according to its own conditions. Subsequently, the second and third batches of pilot projects were determined in 2012 and 2017, respectively. The pilot regions need to complete the following tasks: establishing a responsibility system for carbon control target, setting up a carbon emission data statistics and management system, formulating supporting policies for low-carbon development, constructing a low-carbon industrial system, and advocating the low-carbon green lifestyle. This paper intends to demonstrate the impact of LCCP on EIE from three aspects: technological innovation effect, financing constraint effect, and resource allocation effect.

Specifically, the technological innovation effect refers to the influence of LCCP over EIE via technological innovation. LCCP is an environmental regulation policy proposed by China at the city level to reduce carbon emissions [12]. The influence of LCCP over enterprise technological innovation is mainly theorized based on the Porter's hypothesis, which holds that environmental regulation has two impacts on enterprise decision-making: (1) environmental regulation will push up the production cost of enterprises and squeeze their profit margin, forcing them to cut research and development (R&D) expenditure and increase financial investment. In this way, environmental regulation will eventually suppress EIE. (2) Environmental regulation stimulates enterprises to invest more on R&D [13, 14], forcing them to improve profitability by upgrading equipment or investing in relevant technologies. These means help to offset the extra expenditure brought by environmental regulation [15, 16]. In this case, the enterprises will become more efficient in production and investment [17, 18]. In addition, Porter's hypothesis believes that environmental regulation can manifest as an external pressure, which encourages enterprises to overcome investment inertia and complements with the internal governance mechanism, exerting an incentive effect on EIE [19]. The key areas of low-carbon city construction are industry, construction, transportation, energy supply, and waste management. Therefore, LCCP mainly guides these industries to achieve low-carbon development, so as to control greenhouse gas emissions at the city level. In this process, enterprises are guided to implement technology

research and development, in order to make energy use more efficient. In addition, the central government treats local pilot programs seriously. Being selected as a piloting site is both an honor and a responsibility. Thus, local government is enthusiastic about environmental governance, once the region is selected for the piloting of low-carbon cities. Enterprises are encouraged to improve technology to achieve green and low-carbon development, which in turn enhances enterprise technological innovation and thus improves EIE. There are different views on the features of China's LCCP. Some hold that the LCCP is China provides weak incentives, and some argue that it exists as weak constraints. The pilot capacity-building projects only receive a small amount of financial support. The local governments do not receive additional financial and policy resources from the competent national authorities. Neither do they face assessment pressure like performance evaluation and project review. As a result, some pilot work fails to achieve the desired results. Therefore, it is difficult to improve EIE by promoting technological innovation. The above analysis shows the needs to verify the technological innovation effect of LCCP on EIE.

The financing constraint effect refers to the influence of LCCP over EIE via easing the financing constraint. To integrate the concept of low-carbon development into the production and operation of enterprises, the government has continuously stepped up its support for enterprises. Local governments have made bold explorations and attempts with the help of the autonomy granted by their superiors, such as tax relief, financial subsidies, loan discounts, special funds, and talent incentives, aiming to help enterprises to expand financing channels. Banks and other financial institutions regard the government support and subsidies as implicit guarantees and lower the credit threshold for the enterprises receiving such support and subsidies. For example, the low-carbon urban plans of the pilot regions all cover various financial policies, namely, the special funds for low-carbon development, subsidies for specific industries, preferential loan interest rates, and tax reductions and exemptions. Through capital allocation, these financial policies guide enterprises to reduce investment in polluting projects and invest more funds in green industries and environment-friendly production processes [20], thereby alleviating the financing constraint and enhancing EIE.

The resource allocation effect refers to the influence of LCCP on EIE by affecting enterprise resource allocation. On the one hand, the implementation of LCCP, whether it is the formulation of emission reduction requirements, the collection of pollution taxes, or the trading of pollution rights, will generate new costs, which will cause enterprise production to deviate from the original optimal state. The reason is that environmental regulation will increase the corporate cost of pollution control and system compliance [21]. Some enterprises may reduce production activities and even shut down the production facilities [22, 23]. In other words, environmental regulation will disrupt the normal investment of enterprises and reduce investment efficiency. On the other hand, the theory of bounded rationality says that low-carbon city piloting can strengthen the awareness of resource allocation efficiency among enterprises, pointing out the possible direction for improving that efficiency. Under the constraints of the low-carbon city pilot policy, the carbon reduction cost of enterprises with high emissions and low production efficiency may approach or even exceed their normal operating income. At this time, the enterprises face multiple pressures, such as relocation, merge, transfer, shutdown, or withdrawal, in order to utilize resources more efficiently. In the light of long-term economic benefits, a rational enterprise will choose to improve the efficiency of resource allocation and thus reduce or eliminate the pressure from environmental costs. Meanwhile, low-carbon city piloting provides preferential policies and fund supports to enterprises in various forms. Enterprises can seize the opportunities and utilize the favorable conditions to optimize the internal organizational structure, improve coordination and cooperation, and enhance the ability to identify investment opportunities, thereby improving EIE.

Through the above analysis, the following hypotheses were presented.

Hypothesis 1. LCCP can promote EIE.

Hypothesis 2. LCCP can suppress EIE.

Hypothesis 3. LCCP influences EIE via technological innovation effect.

Hypothesis 4. LCCP influences EIE via financing constraint effect.

Hypothesis 5. LCCP influences EIE via resource allocation effect.

2.2. Heterogeneity of Urban Culture. Urban culture is mainly defined in two ways: deducing from the definition of culture and defining by the features of the city itself. Concerning the first way, urban culture is defined as the sum of material and spiritual wealth created by people in the city and is the overall form of their living conditions, behavior patterns, spiritual characteristics, and urban features. Concerning the second way, urban culture is defined as a cultural model with urban characteristics jointly created by citizens in the long-term life process and is the sum of urban living environment, lifestyle, and living habits, according to the *Chinese and Foreign Urban Knowledge Dictionary*. It is a rather complex and diversified issue. Urban culture, as a way of communication between people and cities, is rooted in the soil of urban historical development and is the characteristic gene of a city. Urban culture has strong regional characteristics, and its development is largely affected by administrative division. Therefore, different cities may vary significantly in terms of culture. As an informal system, culture has an important impact on the economy and enterprise behavior. Urban green development is impossible without the support and guidance of culture. The promotion and implementation of LCCP cannot be detached from the special "soil" of urban culture, especially the green gene in culture. Urban green culture is the value and philosophy of ecoenvironment

protection and resource utilization with urban characteristics, both of which gradually form in the process of urban operation and management. As the main body of Chinese traditional culture, Confucian culture has a subtle influence on the behavior of Chinese people. Its ecological ethics and wisdom are highly consistent with modern concepts like ecological civilization and green development. Both urban green culture and Confucian culture carry the gene of green culture, exerting an important impact on the implementation of LCCP. Therefore, this paper takes urban green culture and Confucian culture as examples to explore the different roles of urban culture differences in the implementation of LCCP.

Confucian culture has a long history of development. After more than two thousand years, Confucian culture has gradually established the core values and moral norms of Chinese culture and has become the ethics of "daily use without knowing." With a low per capital ecological wealth, China faces a growing mismatch between the public's pursuit of high-quality life and the insufficient supply of urban development resources. *The Outline of the Tenth Five Year Plan for National Economic and Social Development* proposed to break the extensive "black" development model with GDP growth as the fundamental goal, switching to a resource-saving, environment-friendly, and green path towards sustainable development. Since then, urban green culture has been gradually formed through urban green operation and management and imperceptibly affected the public's values and decision-making. Therefore, Confucian culture and urban green culture are the representatives of traditional culture and emerging culture, respectively, and carry the very gene of green culture. Meanwhile, the two cultures vary greatly from city to city.

Urban green culture refers to the values and philosophy of ecoenvironmental protection and resource utilization with urban features. These values and philosophy are formed gradually during urban operation and management. Firstly, urban green culture can promote enterprises to generate cohesive and centripetal forces, which are friendly to the environment. By giving play to the guiding role of culture, the awareness of environmental protection can be formed subtly, and employees are encouraged and instructed to care for the environment and make concerted efforts for environmental protection. Secondly, urban green culture will form a binding force in enterprises through institutional norms and responsibility requirements. The social and environmental responsibilities that enterprises should undertake in production and operation will be stressed, motivating enterprises to develop the relevant institutions. Hence, urban green culture will lay a good basis for the promotion and implementation of LCCP and actively shape the influence of LCCP over EIE.

The behavior of enterprises is affected by the institutional environment [24]. China is currently going through a period of economic transformation. The formal institution in the country is not yet perfect, giving informal institution an important position. Culture, the core of the informal institution, significantly affects economic and social development. Here, Confucian culture is included in the research framework of the impact of LCCP on EIE, mainly for two considerations: firstly, Confucian culture is the merit of Chinese traditional culture, which has imperceptibly influenced the people's behavior for thousands of years [25], and shapes the values and business philosophy of Chinese entrepreneurs [26]. It is unsurprising that the business decisions of enterprises are, to a certain extent, affected by Confucian culture. In addition, China has been actively promoting its traditional culture in recent years, which deepens the influence of Confucian culture in the contemporary era. Secondly, Confucianism embodies rich ecological ethics. The modern concepts of ecological civilization and green development are highly consistent with the Confucian ideas of "harmony between man and nature" and "benevolence for all things." The ecological wisdom advocated in Confucian culture cultivates the green development awareness among enterprises and drives the green transformation from the inside. The Confucian concepts of righteousness and profit guide enterprises to sacrifice interest for righteousness, actively undertake social responsibilities, and move away from the extensive growth model of the economy. The ideas of prudence and introspection make enterprises more aware of environmental self-discipline, forming an internal self-supervision mechanism, and promote them to actively practice the development of low-carbon cities. Therefore, Confucian culture will play a role in the influence of LCCP over EIE.

To sum up, the following hypotheses were presented.

Hypothesis 6. The stronger the urban green culture, the more LCCP improves EIE.

Hypothesis 7. The stronger the Confucian culture, the more LCCP improves EIE.

3. Empirical Design

3.1. Identification Strategy. Taking the low-carbon city piloting policy of China as an example, this paper explores how LCCP affects EIE. Since the piloting program starts from different years in different cities, the HDID method was adopted to recognize the influence of LCCP over EIE. The benchmark econometric model can be designed as

$$\begin{aligned} Investeff_{i,t+1} = {} & \alpha + \beta LCC_{i,t} + X_{i,t}{}'\gamma + \mu_i + \sum Year \\ & + \sum Industry + \sum Province + \varepsilon_{i,t}, \end{aligned} \tag{1}$$

where i and t are the serial numbers of enterprises and years, respectively; $Investeff_{i,t+1}$ is EIE; $LCC_{i,t}$ is the low-carbon piloting state of the registered city of the enterprise; $X_{i,t}$ is a series of control variables; μ_i, $\sum$Year, $\sum$Industry, and $\sum$Province are the fixed effects of individuals, years, industries, and provinces, respectively; $\varepsilon_{i,t}$ is a random error; and β is the estimate of HDID, the key index of this research.

3.2. Samples and Data Sources. The research samples are the nonfinancial Chinese enterprises listed in the A-share board of Shanghai and Shenzhen stock exchanges from 2007 to

2016. Financial enterprises were excluded from the samples, mainly for the following two reasons: firstly, the financial industry, especially the banking industry, is more special than general industries. For example, many banks earn profits from off-balance sheet businesses. Bias is unavoidable if listed banks are analyzed based on the three major financial statements. Secondly, the financial enterprises have different financial statement requirements different from nonfinancial enterprises, because of the difference in business model between the financial industry and other industries. The statement structure and main accounting items of the financial industry are also different from those of general industries. The following samples were also excluded: the samples receiving special treatment (ST) or facing delisting risk (∗ST), the enterprises issuing both A-shares and B-shares, and the enterprises with key variables missing. The relevant data were collected from China Stock Market & Accounting Research (CSMAR) database and WIND database.

3.3. Important Variables and Measurements

3.3.1. Measurement of Low-Carbon City Piloting. The low-carbon city piloting (LCC) is defined as follows: if the registered city of a listed enterprise implements low-carbon piloting, LCC = 1 in the current and following years; otherwise, LCC = 0. During the sample period, two batches of pilot cities were announced. Hence, the first and second batches of pilot cities were selected as the treatment group. Some cities belong to both batches. As a result, the start time of piloting of a province was taken as that of every city administered by that province.

3.3.2. EIE Measurement. The EIE was measured mainly referring to the research of Biddle et al. [27] and Choi et al. [28]. Using the enterprise expected investment model of Richardson [29], this paper first calculates the normal investment level expected by the enterprise and then measures the EIE with the regression residual of the model.

The model can be expressed as follows:

$$\begin{aligned} \mathrm{Inv}_{i,t} = {} & \beta_0 + \beta_1 \mathrm{Growth}_{i,t-1} + \beta_2 \mathrm{Lev}_{i,t-1} + \beta_3 \mathrm{Age}_{i,t-1} \\ & + \beta_4 \mathrm{Size}_{i,t-1} + \beta_5 \mathrm{Cash}_{i,t-1} + \beta_6 \mathrm{Ret}_{i,t-1} + \beta_7 \mathrm{Inv}_{i,t-1} \\ & + \sum \mathrm{Year} + \sum \mathrm{Industry} + \varepsilon_{i,t}, \end{aligned} \tag{2}$$

where $\mathrm{Inv}_{i,t}$ is the investment level of the enterprise in year t, which is measured by the ratio of the cash paid for the purchase and construction of fixed assets, intangible assets, and other long-term investments to the total assets at the beginning of the period, and $\mathrm{Growth}_{i,t-1}$, $\mathrm{Lev}_{i,t-1}$, $\mathrm{Age}_{i,t-1}$, $\mathrm{Size}_{i,t-1}$, $\mathrm{Cash}_{i,t-1}$, $\mathrm{Ret}_{i,t-1}$, and $\mathrm{Inv}_{i,t-1}$ are the growth capacity, debt rate, listing period, company scale, cash holding ratio, stock return, and investment level of the enterprise in year $t-1$, respectively.

The regression residual $\varepsilon_{i,t}$ reflects the inefficient investment expenditure of the enterprise. If $\varepsilon_{i,t} > 0$, then the investment is excessive; if $\varepsilon_{i,t} < 0$, then the investment is insufficient. The absolute value of the residual $\varepsilon_{i,t}$ was taken to measure the EIE (Investeff). This value reflects how much the enterprise investment deviates from the theoretical expectation. The greater the value, the larger the deviation and the lower the EIE.

3.4. Control Variables and Measurement. The HDID model controls the key explanatory variables and solves the endogeneity induced by the correlation between time-invariable individual features. But the time-varying individual features should be controlled to reduce the estimation inconsistency arising from missing variables. Referring to the literature, this paper selects the following control variables: enterprise size (Size), price-earnings ratio (PE), government subsidy change (Subchange), holding concurrent positions of chairman and general manager (Dual), industry concentration (Hhi), and sustainable growth rate (Sgr). In addition, industrial and provincial dummy variables were included. Reasons for choosing the control variables are as follows: firstly, the existing research has shown that enterprises of different scales have different financing constraints, which affect EIE differently. Secondly, *price-earnings ratio* has been used as a key variable to measure investor sentiment, which has been proved to bear on the investment behavior of enterprises through equity financing, catering, manager optimism, debt financing, and other channels. Thirdly, the local government would intervene in the economic operation of enterprises by means of government subsidies, guiding local investment, and changing the investment direction and level of enterprises. Fourthly, the duality of chairman and general manager, as an important allocation mechanism of decision-making power, directly affects EIE. Fifthly, market competition can improve information sharing. In a fully competitive market, owners will have reliable information of managers. Thus, the information asymmetry between shareholders and management is mitigated, so that executives will not expand blindly or get complacent, and the enterprises will invest more efficiently. Sixthly, the sustainable growth rate reflects the sustainability of enterprises. The sustainable growth rate can affect EIE through earnings retention and financial structure.

4. Empirical Results and Analysis

4.1. Benchmark Regression. Table 1 lists the regression results of LCCP on EIE. The results show that the regression coefficient of LCCP on EIE is significantly negative, regardless of whether the time fixed effect, industry fixed effect, provincial fixed effect, and control variables are controlled. Since *Investeff* represents the deviation of enterprise investment from the theoretical expectation, the greater the deviation, the lower the EIE. Hence, the empirical results reveal that LCCP significantly enhances EIE. According to column (5) of Table 1, after controlling time fixed effect, industry fixed effect, provincial fixed effect, and control variables in the model, the regression coefficient of LCCP on EIE was -0.005 (significant at the level of 5%), which indicates that the EIE in low-carbon city pilot areas is 0.5% higher than

Table 1: Benchmark regression results.

Variables	(1) HTDID	(2) HTDID	(3) HTDID	(4) HTDID	(5) HTDID
LCC	-0.004***	-0.004**	-0.008***	-0.008***	-0.005**
	(-2.60)	(-2.30)	(-4.04)	(-3.91)	(-2.25)
Size					-0.008***
					(-3.74)
PE					0.000
					(1.23)
Subchange					0.008
					(1.34)
Dual					0.008**
					(2.27)
Hhi					0.061
					(1.15)
Sgr					0.010
					(1.48)
Constant	0.046***	-0.007	0.047***	-0.040	0.026
	(8.04)	(-0.29)	(26.44)	(-1.34)	(0.64)
Observations	18,569	18,604	14,846	14,823	10,951
R-squared	0.004	0.009	0.001	0.017	0.024
Control variables	No	No	No	No	Yes
Time fixed effects	No	No	Yes	Yes	Yes
Enterprise fixed effects	Yes	Yes	Yes	Yes	Yes
Province fixed effects	No	Yes	No	Yes	Yes
Industry fixed effects	Yes	No	No	Yes	Yes

Note: robust t-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

that of enterprises in non-low-carbon city pilot areas. Hypothesis 1 was therefore validated.

Next, EIE was divided into excessive investment and insufficient investment and treated as the explained variable separately. On this basis, model (1) was regressed again. The empirical results are shown in Table 2. It can be seen that LCCP mainly affects EIE by solving the insufficient investment, without easing excessive investment.

4.2. Parallel Trend Testing. Parallel trends are the premise of DID. In view of the relevant studies, this paper adopts event-based analytics to test the parallel trends [30, 31]. The model can be expressed as

$$\begin{aligned} \text{Investeff}_{i,t+1} = \alpha + \sum_{k\geq -5}^{6} \beta_k D_{i,t}^{k} + X_{i,t}{}'\gamma + \mu_i + \sum \text{Year} \\ + \sum \text{Industry} + \sum \text{Province} + \varepsilon_{i,t}, \end{aligned} \tag{3}$$

where Investeff is EIE; $D^{k}_{i,t}$ is a series of dummy variables, indicating the k-th year since the implementation of low-carbon city piloting ($k \in [-5, 6]$ and $k \neq 0$). This paper mainly

Table 2: Influence of LCCP on excessive and insufficient EIEs.

Variables	(1) Excessive investment	(2) Insufficient investment
LCC	-0.006	-0.005***
	(-0.88)	(-3.30)
Constant	0.154*	-0.005
	(1.85)	(-0.22)
Observations	3,900	7,051
R-squared	0.054	0.036
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Enterprise fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes

Note: robust t-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

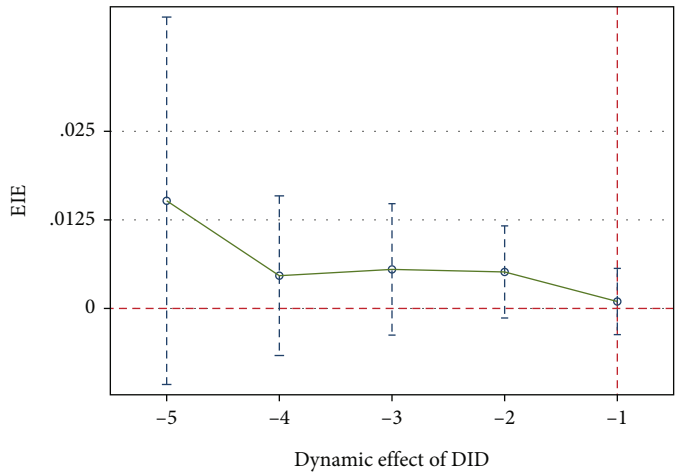

Figure 1: DID parallel trend testing results.

considers parameter β_k ($k \in [-5,-1]$). The other variables in formula (3) are configured consistently as those in benchmark model (1). If $k < 0$ and if β_k is not significantly different from zero, then parallel trends are satisfied.

Figure 1 reports the estimated value of β_k and the confidence interval of 95%. It can be seen that when $k < 0$, the null hypothesis that estimated value of β_k is zero cannot be rejected. This mean, before low-carbon city piloting, the treatment group and the control group meet the parallel trend hypothesis after the relevant variables are controlled.

4.3. Robustness Tests. The following robustness tests were carried out.

4.3.1. Nonrandom Selection of Samples. The first batch of low-carbon pilot cities in China was designated by the superior government. As for the second and third batches, application and expert review were added as necessary links of determining low-carbon pilot cities. Thus, the list of low-carbon pilot cities is not determined purely by random. To mitigate the negative effect of nonrandom selection on estimation results, this paper adds the cross-term $\mathrm{Sc} \cdot f(t)$ between city attribute and time trend to the benchmark regression model, where Sc is the city attribute (whether the city is the provincial seat or a special economic zone) and $f(t)$ is the first-order term of the time trend. The cross-term controls the time-varying influence of the intrinsic difference between city attributes over EIE. The regression results are recorded in column (1) of Table 3.

4.3.2. Placebo Test. The approval time of low-carbon pilot cities was moved ahead by 3 years, and variable Before_3 was added to model (1). The regression results are displayed in columns (2) and (3) of Table 3. It can be seen that the variable did not significantly affect excessive or insufficient investment.

4.3.3. Abnormal Value Removal. Considering the effect of its abnormal value, the explained variable was censored at the 1% and 99% quantiles. The regression results are displayed in column (4) of Table 3.

4.3.4. Controlling the Influence of the Level of Economic Development in the Registered City on EIE. Per capita gross domestic product (GDP) was added to the benchmark model. The regression results are shown in column (5) of Table 3.

4.3.5. Influence of the Other Policies. Two cross-terms were designed: the cross-term between whether the city is a new energy demonstration city and the time of approval (Ncity) and the cross-term between the city environmental protection criticized by superiors and the time of criticized (HBYT). The two terms were introduced to model (1). The regression results are given in columns (6) and (7) of Table 3.

4.3.6. Removal of Provinces without Pilot Cities. To increase the similarity between treatment group and control group, this paper further removes the provinces without any pilot cities. The regression results are displayed in column (8) of Table 3. After a series of robustness tests, the main conclusions of this paper still hold.

5. Heterogeneity Analysis

5.1. Urban Green Culture. Regarding the measurement of urban green culture, this paper selects the actual year-end number public vehicles and trams/(the actual year-end number public vehicles and trams+the actual year-end number of taxis) to depict the green consumption concept of residents. The samples were grouped by the median of the variable and tested separately. The results are shown in columns (1) and (2) of Table 4. The results show that, in areas with strong green culture, LCCP has a positive effect on EIE. Hypothesis 6 is thereby testified.

To rule out the possibility that the above results are caused by government intervention, this paper uses the government-market relationship index compiled by Fan et al. [32] to measure the degree of intervention of Chinese local governments and divides the samples into high intervention group and low intervention group by the median of the variable. The regression results are shown in columns

Table 3: Regression results of robustness tests.

Variables	(1) Nonrandom selection of samples	(2) Placebo test	(3) Placebo test	(4) Abnormal value removal	(5) Controlling level of economic development	(6) New energy demonstration city	(7) Environmental criticism	(8) Removal of provinces without pilot cities
LCC	-0.005**			-0.005**	-0.005**	-0.007***	-0.005**	-0.006**
	(-2.32)			(-2.36)	(-2.30)	(-2.80)	(-2.31)	(-2.40)
Before_3		-0.020	-0.004					
		(-1.17)	(-1.55)					
PGDP					0.000			
					(0.59)			
Ncity						0.002		
						(0.60)		
HBYT							-0.007*	
							(-1.75)	
Constant	0.027	0.168*	-0.001	0.016	0.024	0.041	0.026	0.010
	(0.66)	(1.88)	(-0.02)	(0.43)	(0.58)	(1.02)	(0.64)	(0.22)
Observations	10,951	3,900	7,051	10,951	10,894	9,724	10,951	9,840
R-squared	0.024	0.054	0.034	0.023	0.024	0.020	0.024	0.023
$Sc \cdot f(t)$	Yes							
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: robust t-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

(3) and (4) of Table 4. It can be seen that the effect of LCCP on EIE is significantly negative in the low intervention areas, but not significant in the high intervention areas. The impact of government intervention is thus excluded.

Compared with non-resource-based cities, many resource-based cities in China lag behind in the construction of urban green culture, due to their long-term dependence on resources. According to the *National Sustainable Development Plan for Resource-Based Cities (2013-2020)*, this paper divides cities into resource-based cities and non-resource-based cities and performs regression on each group. The results are shown in columns (5) and (6) of Table 4. It is found that, in resource-based cities, low-carbon pilot policies have no significant impact on EIE, while in non-resource-based cities, these policies have a significant positive impact on EIE. This further demonstrates the positive role of urban green culture.

5.2. Urban Confucian Culture. Referring to the research of Du [33], this paper selects the distance between the enterprise's registered place and the seven existing Confucian cultural centers in China to measure the influence of Confucian culture. These centers were gradually formed by the spread of Confucianism in China for more than 2,500 years, including Qilu in Shandong, Chengdu in Sichuan, Luoyang in Henan, Sanming and Longyan in Fujian, Dongtai in Jiangsu, and Ningbo and Shaoxing in Zhejiang. Referring to Baidu Map, the authors collected the longitude and latitude coordinates of the above seven Confucian centers, as well as the longitude and latitude coordinates of the registration places of all A-share listed companies. These data were used to calculate the mean distance between the registration places of each listed company and each Confucian center. The larger the value of Confucian culture (Confu), the higher the degree of influence of Confucian culture on the enterprise.

Table 4: Regression results of green culture heterogeneity.

Variables	(1) Strong green culture	(2) Weak green culture	(3) High intervention	(4) Low intervention	(5) Resource-based city	(6) Non-resource-based city
LCC	-0.011**	-0.007*	-0.003	-0.007**	-0.005	-0.006**
	(-2.53)	(-1.73)	(-0.69)	(-2.35)	(-0.46)	(-2.29)
Constant	0.054	0.061	0.058	-0.044	0.040	0.044
	(1.31)	(1.49)	(1.38)	(-1.42)	(0.84)	(1.10)
Observations	4,896	4,498	4,792	6,116	1,109	9,842
R-squared	0.014	0.067	0.041	0.016	0.032	0.025
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Note: robust *t*-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

Table 5: Regression results of Confucian culture heterogeneity.

Variables	(1) Weak Confucian culture	(2) Strong Confucian culture
LCC	-0.004	-0.008**
	(-1.07)	(-2.41)
Constant	0.030	0.016
	(0.64)	(0.37)
Observations	5,194	5,757
R-squared	0.035	0.023
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Enterprise fixed effects	Yes	Yes
Province fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes

Note: robust *t*-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

The samples were grouped by the median of Confu and divided into a weak Confucian culture group and a strong Confucian culture group. The two groups were regressed separately, and the results are shown in Table 5. It was found that in weak Confucian culture areas, LCCP has no significant effect on EIE, while in strong Confucian culture areas, LCCP significantly improves EIE. Hypothesis 7 is therefore verified.

5.3. Industrial Heterogeneity of Carbon Emissions. Under the influence of green culture and Confucian culture, enterprises identify with different goals and pursue legitimacy to different degrees. This paper holds that LCCP has a more positive impact on the EIE in high-carbon emission industries than low-carbon emission industries. To test this hypothesis, the industries were divided into high-emission industry, medium-emission industry, and low-emission industry, according to the trisectional quantiles of carbon emissions of all industries in China, in reference of the carbon emission data in 2009. The relevant data come from Carbon Emission Accounts & Datasets (CEADs). The regression results are shown in Table 6. It was learned that, compared with that in low-emission industries, LCCP has a significant positive impact on the EIE in high-emission industries. This is in line with the original policy intention of low-carbon city piloting. To improve the robustness of the results, this paper combines the medium-emission group and the low-emission group before starting a new robustness test. The regression results are still consistent.

6. Influence Mechanism Analysis

The impact of LCCP on EIE mainly manifests as three effects, namely, technological innovation effect, financing constraint effect, and resource allocation effect. These effects are tested separately in this paper.

6.1. Technological Innovation Effect. The R&D expenditure reflects the willingness of enterprises to invest in technological innovation. Therefore, this paper selects R&D expenditure as a proxy variable for technological innovation and measures the variables with the ratio of R&D expenditure to operating income. The regression results are shown in column (1) of Table 7. It can be seen that LCCP boosts the R&D expenditure of enterprises, indicating that LCCP enhances EIE through the effect of technological innovation. Hypothesis 3 is therefore verified.

6.2. Financing Constraint Effect. Scholars mainly use KZ, WW, and SA indices to measure the financing constraint of enterprises [34, 35]. Among them, KZ is the most widely

Table 6: Regression results of industrial heterogeneity in carbon emissions.

Variables	(1) High emissions	(2) Median emissions	(3) Low emissions	(4) Medium- and low-emission industries
LCC	-0.009*	-0.000	-0.003	-0.003
	(-1.81)	(-0.11)	(-0.49)	(-1.05)
Constant	0.078*	0.009	0.220***	0.113
	(1.78)	(0.23)	(2.83)	(1.60)
Observations	3,974	3,483	2,910	6,393
R-squared	0.033	0.045	0.048	0.033
Control variables	Yes	Yes	Yes	YES
Time fixed effects	Yes	Yes	Yes	YES
Enterprise fixed effects	Yes	Yes	Yes	YES
Province fixed effects	Yes	Yes	Yes	YES
Industry fixed effects	Yes	Yes	Yes	YES

Note: robust *t*-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

Table 7: Regression results of influence mechanisms.

Variables	(1) Technological innovation effect	(2) Financing constraint effect	(3) Resource allocation effect
LCC∗ROA			-0.043
			(-0.91)
LCC	0.007***	-0.115**	0.009***
	(3.63)	(-2.11)	(3.01)
ROA			0.065**
			(2.34)
Constant	0.039***	-0.966	-0.010
	(3.06)	(-0.87)	(-0.37)
Observations	10,158	15,071	13,198
R-squared	0.182	0.228	0.093
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Enterprise fixed effects	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes

Note: robust *t*-statistics are in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

used measure, owing to the maturity of its theories. Drawing on Kaplan and Zingales' methodologies, this paper constructs the KZ index to measure the financing constraint of enterprises. The regression results are shown in column (2) of Table 7. It can be seen that LCCP can effectively alleviate the financing constraint of enterprises; i.e., LCCP promotes EIE by alleviating enterprise financing constraint. Hypothesis 4 is thereby validated.

6.3. Resource Allocation Effect. This paper uses capital allocation efficiency as a proxy variable of resource allocation efficiency and designs model (4) following the investment-investment opportunity sensitivity model:

$$\begin{aligned} \text{invest}_{i,t} = {} & \partial_0 + \partial_1 \text{LCC}_{i,t} \times \text{ROA}_{i,t} + \partial_2 \text{LCC}_{i,t} + \partial_3 \text{ROA}_{i,t} \\ & + X_{i,t}{}' \gamma + \mu_i + \sum \text{Year} + \sum \text{Industry} \\ & + \sum \text{Province} + \varepsilon_{i,t}, \end{aligned} \tag{4}$$

where invest is the investment level of the enterprise, which is equal to (cash paid for the purchase and construction of fixed assets, intangible assets, and other long – term assets – cash recovered from the disposal of fixed assets, intangible assets, and other long – term assets)/total year – end assets, and ROA is the return on assets used to measure enterprise investment opportunities; the coefficient of the cross-term between LCC and ROA measures the impact of LCCP on the efficiency of enterprise resource allocation; the definitions of other variables are consistent with model (1). The regression results are shown in column (3) of Table 7. It can be seen that LCCP does not significantly improve the resource allocation efficiency of enterprises. Hypothesis 5 is therefore falsified.

7. Conclusions and Policy Implications

This paper measures the EIE with the Richardson enterprise expectation investment model. The research samples are the A-share listed nonfinancial enterprises in Shanghai and Shenzhen stock exchanges of China from 2007 to 2016. On this basis, the impact of LCCP on EIE was estimated by using HTDID, and the heterogeneous effect of urban culture was also investigated.

The main conclusions are as follows:

(1) Overall, LCCP improves EIE, and the research conclusion passes a series of robustness tests. (2) Mechanism analysis reveals that LCCP mainly acts on EIE along two paths: promoting enterprise technological innovation and easing financing constraint. But the LCCP does not have a significant effect on resource allocation. (3) The influence of LCCP over EIE varies with urban cultures. The ecological wisdoms of green urban culture and Confucian culture, such as benevolence to all beings and the harmony between man and nature, help to enhance the promoting effect of LCCP on EIE

The policy implications are as follows:

First, the positive effect of LCCP on EIE was demonstrated through empirical research. The construction of low-carbon cities is an important means for European developed countries to improve residents' well-being and urban competitiveness. In developing countries, the legal system is relatively weak, and the relevant pilot policies may be difficult to implement. The research results prove that LCCP has the same ideal effect in developing countries like China and can be used as an important means to promote high-quality economic development.

Second, strengthening urban cultural governance is of great significance to LCCP promotion. Urban cultural governance focuses on improving the cultural connotation and quality of urban governance. This is particularly true as China witnesses increasing urban scale, rapid construction, the lack of urban culture, and cultural imbalances. Then, it is necessary to highlight the construction of cultural soft power in governance goals and contents. Special attention should be paid to urban cultural governance from the perspective of green development, making cultural governance a powerful guarantee for promoting the progress of urban civilization and green development.

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

The "Booster" of Corporate Eco-Innovation: Government Pressure Perceived by Chinese Private Firms

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This study explores the relationship between perceived government pressure for environmental regulation and corporate eco-innovation. Based on the questionnaire data of Chinese private firms in 2016, this study explores the role of government pressure perceived by private firms in corporate environmental innovation, and the moderating effects of foreign ownership and entrepreneurs' political status. The results show that there is a positive relationship between perceived government environmental regulatory pressure and corporate eco-innovation, and this relationship can be strengthened by foreign ownership and entrepreneurs' political status. These findings provide a new strategic motivation for firms to undertake eco-innovation, i.e., the environmental regulatory pressure released by the government can urge firms to undertake strategies as an external "booster."

1. Introduction

In recent years, environmental issues have received increasing attention from the Chinese government and various business stakeholders. From the government's proposal that "green water and green mountains are the silver mountain of gold" and its strong advocacy of corporate environmental protection and pollution reduction, to the implementation of the "Plastic Restriction Order" and further interpretation of corporate eco-innovation, all reflect China's new requirements for corporate environmental responsibility. Different scholars have given different explanations for the so-called eco-innovation. OECD considers environmental innovation as "any innovative activity that reduces environmental impact" [1], while Europeia considers environmental innovation as a progress of sustainable development [2]. According to Kemp and Pearson [3], eco-innovation refers to the production, development, or absorption of relevant alternatives that can reduce environmental risks, pollution, or other negative impacts [4]. In order to meet the growing economic demands and address the growing environmental problems, China has developed many environmental policies [5]. In this new era, the government requires firms to not only reduce pollution, but also to reduce pollution from another perspective – by proactively reducing emissions through eco-innovation, thereby achieving sustainable development.

Many scholars have studied the motivation of corporate eco-innovation, some of which consider corporate eco-innovation as a strategic behavior of firms [6], while others suggest that government intervention affects the process of eco-innovation [7–9]. In addition, technology is one of the important factors that promote environmental innovation in firms [10, 11]. Firms' own technological capabilities, external market influences, and consumer demands all influence corporate green innovation. However, relatively few studies have examined firms' innovative behavior through entrepreneurs' perceptions of government pressure on environmental regulatory [5]. In order to fill the existing research gap, we should clarify why entrepreneurs engage in corporate eco-innovation when they perceive pressure from government. Institutional theory can be a good solution to this problem. It suggests that entrepreneurs and firms tend to do what the government expects if they want to achieve sustainable development. In China's institutional context, the key resources available to firms are controlled by the government and firms must meet the government's expectations.

Based on these literature reviews and the research gaps described above, the purpose of this study is clear: What impact do entrepreneurs have on the eco-innovation of firms when they feel the pressure of government regulation? Furthermore, what role does the self-perceived political status of the entrepreneur and the foreign ownership of the firm play in this influence process? Based on these research gaps, we used cross-sectional data from 2,244 Chinese private firms in 2015 to address this question by examining the environmental regulatory pressures felt by entrepreneurs and how this affects firms to innovate environmentally. According to previous literature, firms heed the government's calls or "orders" to maintain their political legitimacy in Chinese institutional context. In addition, we argue that entrepreneurs' perceived pressure is positively related to firms' environmental behavior. Furthermore, by considering the moderating role of entrepreneurs' political connections and foreign ownership in the firm, this study provides a more accurate framework for the relationship between the role of government and corporate eco-innovation in the unique Chinese institutional context. Thus, this study provides new evidence on why some firms are willing to engage in eco-innovation and why the political status of entrepreneurs and foreign ownership of firms significantly influence corporate environmental strategies.

In order to answer the above research questions, this study provides several contributions to the current literature on corporate eco-innovation. First, this study uses institutional theory to examine the response of firm behavior to perceived governmental environmental regulatory pressures, combining "perceived pressures" with "corporate eco-innovation". Second, it gives explanations for the factors affecting firm eco-innovation, both internal and external, using the entrepreneurs' own political connections and the firm's foreign ownership as moderating variables. This also brings valuable practical insights and implications for researchers and policy makers.

The remainder of this study is organized as follows. Section 2 provides further details on the theoretical framework of the study and sets out three hypotheses of this study. The third section describes the data and the methodology of analysis. The empirical results are then presented, and next section shows our discussions and limitations. Conclusions are outlined in the final section.

2. Theories and Hypotheses

2.1. Relationship between Government Pressure and Eco-Innovation. Eco-innovation has become an important part of green economy. Among the existing studies, there is no shortage of research on corporate eco-innovation. Most scholars focus on a resource-based perspective with institutional and stakeholder theories as the underlying logic, and their drivers are mostly external non-institutional factors, such as markets and monitoring [4]. Institution is defined as "regulatory, normative, and cognitive structures and activities that provide stability and meaning to social behavior" [12]. In the Chinese context, the policies proposed by the government are considered to be an institutional regulation. Institutional theory suggests that institutionalized activities have an impact on individuals, organizations, and interorganizations [13]. At the individual level, managers consciously or unconsciously follow norms, habits, customs, and traditions [14]. At the organizational level, shared political, social, cultural, and belief systems support traditions of institutionalized activities. At the interorganizational level, pressure from government determines what is socially acceptable and expected organizational behavior [15]. That is, firms make decisions under external pressure. Therefore, we can assume that when firms feel environmental regulatory pressure from the government, they tend to follow the government's instructions. Therefore, we propose the following hypothesis:

Hypothesis 1. The greater the perceived government pressure on environmental regulation, the more firms will engage in corporate eco-innovation.

2.2. Moderation Effect of Political Status. In the process of business operation, many firms have some political linkages with the government, which can influence corporate strategies to some extent, such as charitable donations, green economy. When an entrepreneur perceives that he has a high political status (by comparing with people around him or others), he may participate in some government organizations, such as being a deputy to the National People's Congress or a member of the Chinese People's Political Consultative Conference. These positions influence their business behavior. In other words, they are more willing to be close to the government and more inclined to follow the government's wishes. Therefore, the higher the political status of entrepreneurs, the closer the relationship between firms and the government. Under the such logic, the closer the entrepreneur's relationship with the government, the more willing the firm is to follow the government's instructions or meet its expectations, so it is more willing to engage in eco-innovation. Therefore, we propose the following hypothesis:

In China, the government controls key resources needed by firms to develop. As the provider of resources, local governments provide relevant resources to local firm through government intervention [16–18]. As mentioned above, under institutional pressure, individuals tend to follow norms, while firms under pressure will follow government directives in order to gain "legitimacy" [19, 20]. Thus, when the entrepreneur has a certain status in society, he has more personal contact with the government. When the entrepreneur perceives more pressure, he is more willing to follow the new requirements for environmental protection and to do eco-innovation. For example, firms are more willing to make charitable donations when entrepreneurs have more connections to the government [21]. Therefore, based on this logic, firms with higher political status of entrepreneurs are more likely to be perceived by local governments to engage in eco-innovation. At the same time, this behavior will help firms obtain resources from local governments more easily through corporate environmental strategies. Therefore, we propose Hypothesis 2:

Hypothesis 2. The entrepreneur's perceived political status strengthens the positive relationship between government pressure and corporate eco-innovation.

2.3. Moderation Effect of Foreign Ownership. A high proportion of foreign ownership is becoming more and more common in the operation of modern firms. The higher proportion of foreign ownership means that firms are more international. They are more willing to align themselves with international standards in terms of business practices or top management than to follow government arrangements, which means that they are increasingly operating outside the government. Thus, these firms lack a certain degree of "legitimacy" in their domestic operations. At this point, such firms need to follow the instructions and ideas of the government. For example, when they feel the pressure of government environmental regulation, they should engage in eco-innovation to gain government legitimacy.

When the foreign ownership is high, we can assume that the firm is more international, which means that the firm lacks a certain local background or political connection to the local government during its operations. In the Chinese context, where the government controls the main resources needed for business activities, foreign firms have relatively little legitimacy in their operations due to their lack of association with the government compared with local firms. Entrepreneurs will face more serious pressure from government environmental regulation, and they need to make more pro-government behavior in order to gain resources from the government [22]. Thus, when firms have a higher foreign ownership, they will be more willing to do eco-innovation for the sake of legitimacy in order to gain the government's perception and attention, and thus easier access to government resources. Therefore, we propose Hypothesis 3:

Hypothesis 3. Foreign ownership strengthens the positive relationship between government pressure and corporate eco-innovation.

3. Methodology

3.1. Data and Sample. In order to study the impact of perceived government pressure for environmental regulation on corporate eco-innovation, we used a questionnaire data describing Chinese private firms. The questionnaire comes from the private firm research group consisting of the Chinese Central United Front Work Department, the All-China Federation of Industry and Commerce, the State Administration for Industry and Commerce, and the China Private Economy Research Association. The research group conducts a nationwide sample survey on the status of private firms every two years, and its time span has exceeded over 20 years. From the previous surveys, the data obtained each time can accurately reflect the basic situation of China's private economy and the difficulties and problems encountered in its development. This study uses data from the 12th survey conducted by the research group in 2016, and this source of data has been confirmed in many previous literature [23–25].

The survey respondents are all private entrepreneurs in China. The survey collected data covering more than 8,000 firms. However, due to the lack of some survey data and the limitation of questionnaire completeness, some data were not included in the analysis. We ended up with a final sample of 2,244 observations.

3.2. Variable Measurements. Corporate eco-innovation, our dependent variable in this study, is measured by the probability of innovation, which is a dummy variable, and firms with eco-innovation in 2015 are coded as 1, and otherwise 0 [26].

Government pressure perceived by firms for environmental regulation, the independent variable of this study, is measured by the Likert 5-point scale. The variable values 1 for firms with no perceived government pressure and values 5 for firms with highest degree of perceived government pressure.

Political status presents the entrepreneur's self-perceived status ladder compared with their peers in society. The variable is measured by 10 scales, 1 being the lowest and 10 being the highest. Political status is widely used in corporate strategies literature and is considered an important driver influencing their nonmarket strategies [27].

The variable foreign ownership refers to the proportion of foreign capital including Hong Kong, Macao and Taiwan parts in the net assets of firms in the current operation process. The higher the proportion, the more foreign capital is invested in the firms' operation, while domestic capital is relatively less. Firms with high degree of foreign ownership are more closely connected with foreign investors and has relatively less tied to the stakeholders in China, and firms will encounter more serious legitimacy challenges in operating in China [28].

In this study, we follow the previous literature and control for a number of variables at two levels. First, at the entrepreneurial level, the entrepreneur's gender, age, education level, salary, and political connection are all considered as important influences on corporate strategies. Studies have shown that firms with more female executives are more willing to innovate when faced with environmental problems [29]. Older executives are more conservative when confronted with innovation [30]. The variable gender is measured as 1 for males and 0 for females. The variable age is calculated as the difference between the entrepreneur's year of birth and 2016. The variable salary is calculated as the natural logarithm value of the actual entrepreneurial annual salary. The entrepreneurial education and foreign education experience are controlled in the analysis. The variable education is measured as 1 for junior high school and below, 2 for senior high school, 3 for junior college, 4 for undergraduate degree, 5 for master degree, and 6 for doctorate degree. Foreign education is a dummy variable, coded as 1 for overseas education experience, and 0 otherwise. Political connection is well considered by most previous studies as a key factor that affects corporate nonmarket strategies [31]. In

this study, political connection is a dummy variable coded as 1 if the entrepreneur is a deputy of the National People's Congress or a member of the Chinese people's Political Consultative Conference, and 0 otherwise. In addition, we included the variable charity member, measured as 1 for entrepreneurs participating in charity organizations, and 0 otherwise.

At the firm level, firm size is considered to be one of the most important factors influencing a firm's environmental behavior, since larger firms are more flexible in resource usage in environmental innovation [32]. In this study, firm size is measured as the natural logarithm value of a firm's total employees. Firm age is measured as the number of years a firm has been in existence until the end of 2016. The studies have proved that firms with a longer history have a higher social relevance and they are more active in the face of environmental innovation [33]. Also, corporate performance affects their environmental behavior, and previous studies have proved that firms with good performance are more likely to practice corporate environmental practices [34]. We measure the performance as the value of Return to Assets (ROA). Finally, we include industrial dummies and regional dummies to control for the potential industrial and regional variances.

4. Results

4.1. Descriptive Statistics and Correlations. Table 1 reports sample characteristics, including sample size, mean, and standard deviation of each variable. It can be seen that the sample includes 2,244 private firms, of which 17% have made eco-innovation, and the mean value and standard deviation of each variable are within the acceptable range.

Table 2 summarizes the Pearson correlation analysis results of all variables in this study. It can be seen that the government pressure is positively correlated with eco-innovation (0.18), which is in line with expectations, and the first inertia between any two variables is not higher than 0.5. Therefore, there is little concern about the high correlations between variables. At the same time, the variance inflation factor (VIF) is calculated and can be found that the highest VIF value is 1.95, and the average VIF value is 1.25, which are lower than the critical value of 10 as a general requirement [35]. Therefore, the collinearity interference will not be a significant problem in this analysis.

4.2. Hypotheses Tests. Table 3 reports the probit model regression results of this analysis. Model (1) only adds all control variables. Model (2) adds the independent variable. Model (3) adds the first moderating variable and its interaction item (Political status × Government pressure), and Model (4) adds the second moderating variable and its interaction item (Foreign ownership × Government pressure). Model (5) adds all variables to test the three hypotheses together.

Hypothesis 1 proposes that entrepreneurs' perceived government pressure on environmental regulation promotes corporate eco-innovation. In Model (2), it can be seen that the coefficient of government pressure is 0.154 with p value of less than 0.01, which is positive and significant. Therefore, we can verify the positive impact of government pressure on corporate eco-innovation. Therefore, Hypothesis 1 is supported.

Table 1: Characteristics of the sample.

	N	Mean	S. D.	$P1$	P99
Eco-innovation	2,244	0.17	0.38	0	1
Government pressure	2,244	2.51	1.28	1	5
Gender	2,244	0.82	0.38	0	1
Age	2,244	45.89	9.47	25	67
Education	2,244	2.98	1.13	1	6
Foreign education	2,244	0.13	0.34	0	1
Salary	2,244	3.18	1.43	0	7.67
Political connection	2,244	0.33	0.47	0	1
Charity member	2,244	0.2	0.40	0	1
Firm size	2,244	3.56	1.81	0	7.78
Firm age	2,244	10.5	6.66	1	30
ROA	2,244	7.64	233.76	−1	3.62

Hypothesis 2 proposes that entrepreneurs' self-perception of political status plays a positive moderating role in the main hypothesis. In Model (3), it can be seen that the coefficient of the interaction term between political status and government pressure is 0.026, with p value of less than 0.05, which is positive and significant. It means that the higher the political status of entrepreneurs' self-perception, the positive impact of government pressure on corporate eco-innovation will be enhanced. Therefore, Hypothesis 2 is supported.

Hypothesis 3 proposes the positive moderating effect of foreign ownership. In Model (4), the coefficient of the interaction term between foreign ownership and government pressure is 0.01 with p value of less than 0.05, which is positive and significant. It can be seen that the higher the proportion of foreign ownership, the stronger the positive impact of government pressure on corporate eco-innovation. Therefore, Hypothesis 3 is also supported.

5. Discussions

The purpose of this study is to explore the relationship between government pressure on environmental regulation perceived by entrepreneurs and corporate eco-innovation, as well as the moderating effects of political status and foreign ownership. By empirically testing the data from the 12th national private firms survey in 2016, we find that government pressure has a significant impact on corporate eco-innovation. Specifically, the more perceived pressure of environmental regulation from the government, the more firms are able to promote eco-innovation. This result supports our hypothesis about firms' motivates to undertake eco-innovation. Meanwhile, based on the institutional theory, entrepreneurs will be willing to "listen to the government" when they perceive certain government pressure in order to gain legitimacy for sustainable operations and better performance. Thus, firms with high degree of political status and more foreign ownership have more incentives to engage in eco-innovation to obtain necessary resources and legitimacy controlled by the government.

Table 2: Correlation matrix of variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Eco-innovation	1.00											
(2) Government pressure	0.18	1.00										
(3) Gender	0.07	0.05	1.00									
(4) Age	0.11	0.07	0.12	1.00								
(5) Education	0.16	−0.01	0.04	−0.15	1.00							
(6) Foreign education	0.07	0.01	0.01	−0.04	0.22	1.00						
(7) Salary	0.15	0.08	0.11	0.09	0.17	0.10	1.00					
(8) Political connection	0.19	0.09	0.11	0.29	0.20	0.10	0.23	1.00				
(9) Charity member	0.13	0.02	0.07	0.04	0.14	0.08	0.18	0.17	1.00			
(10) Firm size	0.31	0.16	0.18	0.26	0.35	0.13	0.39	0.49	0.24	1.00		
(11) Firm age	0.16	0.11	0.09	0.40	0.12	0.07	0.22	0.36	0.13	0.48	1.00	
(12) ROA	−0.01	0.01	−0.02	−0.04	−0.02	−0.01	−0.01	−0.02	−0.01	−0.02	−0.03	1.00

Table 3: Regression results.

	(1) Eco-innovation	(2) Eco-innovation	(3) Eco-innovation	(4) Eco-innovation	(5) Eco-innovation
Gender	−0.004	−0.015	−0.026	0.035	0.029
	(0.103)	(0.103)	(0.104)	(0.123)	(0.124)
Age	0.005	0.006	0.005	0.004	0.003
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Education	0.121***	0.131***	0.127***	0.139***	0.140***
	(0.035)	(0.036)	(0.036)	(0.042)	(0.042)
Foreign education	0.113	0.130	0.101	0.135	0.090
	(0.098)	(0.098)	(0.100)	(0.116)	(0.118)
Salary	0.059**	0.052**	0.045*	0.063**	0.054*
	(0.025)	(0.026)	(0.026)	(0.029)	(0.030)
Political connection	0.102	0.092	0.045	−0.019	−0.090
	(0.081)	(0.081)	(0.084)	(0.096)	(0.1)
Charity member	0.246***	0.262***	0.278***	0.320***	0.325***
	(0.082)	(0.083)	(0.084)	(0.097)	(0.098)
Firm size	0.147***	0.137***	0.137***	0.168***	0.166***
	(0.027)	(0.028)	(0.028)	(0.033)	(0.033)
Firm age	−0.001	−0.002	−0.004	0.003	0.001
	(0.006)	(0.006)	(0.006)	(0.007)	(0.008)
ROA	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Government pressure		0.154***	0.015	0.151***	0.020
		(0.028)	(0.071)	(0.034)	(0.083)
Political status			−0.030		−0.013
			(0.039)		(0.047)
Political status × Government pressure			0.026**		0.024
			(0.013)		(0.015)
Foreign ownership				−0.040**	−0.029
				(0.020)	(0.020)
Foreign ownership × Government pressure				0.010**	0.007
				(0.005)	(0.005)
Industrial dummies	Included	Included	Included	Included	Included
Regional dummies	Included	Included	Included	Included	Included
Constant	−2.489***	−2.943***	−2.725***	−3.115***	−3.043***
	(0.377)	(0.392)	(0.435)	(0.458)	(0.514)
Observations	2,244	2,244	2,192	1,738	1,705
Pseudo R^2	0.178	0.193	0.199	0.228	0.235

Note. Standard errors are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.1. Contributions and Implications. This study contributes to the existing literature in several aspects. First, to the best of our knowledge, this study is one of the few empirical studies to examine the relationship between government pressure on environmental regulation perceived by firms and corporate eco-innovation. More precisely, this study is the first to focus on its direct relationship. Considering that the particular factor of institution plays an important role in this relationship, institution theory is proposed in the context of eco-innovation research. Thus, this study broadens the scope of corporate eco-innovation and entrepreneurs' perception of government pressure.

Second, based on previous literature, we find that entrepreneurs' political status plays an important role in corporate environmental practices, and positively moderates the positive relationship between government pressure and corporate eco-innovation. Institutional theory has previously noted the role of the government in shaping corporate nonmarket strategies [36, 37]. In this study, we have expanded the political status of entrepreneurs. Instead of using the previous dummy variables such as deputies to the National People's Congress and members of the Chinese People's Political Consultative Conference, we explore the dual political pressure regulation of self-perceived political status on external pressure from the perspective of entrepreneurs. Therefore, using the Chinese context, our study finds that China can better reveal the influence of institutional environment on corporate environmental behavior.

5.2. Limitations and Future Research Directions. There are some limitations to our study, which provides a direction for future research. First, although we have clearly explained the motives of firms to engage in eco-innovation from the perspective of institutional theory, these motives still depend on political relevance. Some scholars pointed out that there are other motives for corporate eco-innovation, rather than purely political considerations [38, 39]. Future research needs to further test whether political concerns are indeed the main motivation for firms to engage in eco-innovation.

Second, our study measures corporate environmental behavior in terms of whether they engage in eco-innovation, which captures firms' willingness but not the intensity of their eco-innovation. Thus, it cannot well explain the changes in the intensity of corporate eco-innovation. Future research may find a better way to measure the intensity of corporate eco-innovation and thus better explore the dynamics of this variable.

Third, from the perspective of institutional pressure, we test the positive relationship between government pressure and corporate eco-innovation, and assume that firms can gain legitimacy from the government through eco-innovation. Previous studies have demonstrated that firms engaged in corporate eco-innovation are more likely to gain access to government resources, but the performance benefits brought by government legitimacy are not clear. Research on these issues may provide greater insight into the impact of corporate eco-innovation on firm benefits. Therefore, how to gain government legitimacy through corporate environmental innovation, which leads to better benefits, is an important topic for future research.

6. Conclusions

The analysis of the data on the 12th Chinese private firms survey conducted by the private enterprise research group composed of the Central United Front Work Department, the All-China Federation of Industry and Commerce, the State Administration for Industry and Commerce, and the China Private Economy Research Association provides better evidence of the influence of institutional environment on firm behavior, especially when entrepreneurs feel more pressure from the government in terms of environmental regulation, firms will be more willing to engage in eco-innovation. Political status and foreign ownership are important factors. As a complement to "legitimacy", both play the positive moderating effects. We hope that this study will contribute to a better understanding of the factors influencing corporate eco-innovation, especially from the perspectives of institutional aspects.

Data Availability

The second-hand survey data used to support the findings of this study were supplied by the Chinese Academy of Social Sciences under license and so cannot be made freely available. Requests for access to these data should be made to the author Peng Lv, lv-peng@cass.org.cn.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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Research Article

Green Message Framing in Enhancing Sustainable Consumption Behavior of Fashion Based on the Cross-Theoretical Model

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Promoting green consumption is key in meeting ambitious sustainable fashion targets being set around the world. This research examined how framing of green message as positive or negative (i.e., benefit framing) influenced formation of sustainable consumption behaviors of fashion (SCBF) based on the cross-theoretical model and, especially, how self-efficacy, decision balancing, and perceiving threats-mediated green message framing effects. Data were collected from 217 Chinese residents in an online experiment. Our findings show that green message framing has different effects on individuals in different change stages of SCBF and loss framing-based green messages induce more positive responses toward SCBF with greater perceived threats in the pre-intention and intention stages, while gain framing-based green messages might stimulate positive behaviors toward SCBF with greater perceived benefits in the preparation and action and maintenance stages. Results suggest that highlighting green message expression in relating to SCBF may be useful for promoting broader sustainable behaviors. Therefore, this article significantly fills the gaps between green message framing and SCBF. The findings of this article have significant implications for fashion companies who wish to explore the fashion green market potential.

1. Introduction

Growing concerns over climate change and environmental issues are making governments and citizen groups attentive to changing the way people consume on fashion [1]. As early as 1992, the United Nations Conference on Environment and Development had pointed out that consumer behavior was closely related to environmental issues. Anticipating continued increased attention from consumers on sustainability issues, considerable attention has been directed toward sustainable consumption behaviors of fashion (SCBF) intended to reduce negative environmental harm [2]. In this regard, scholars and public policy makers stress the urgency to motivate consumers to engage in SCBF; the relevant enterprises and organizations have taken many publicity measures to convey green messages and promote the sustainable consumption of fashion [3–5]. However, due to the neglect of the important role of expression of green messages and consumer demand in the dissemination of green messages, many education and publicity effects are not ideal, and there is still a gap between consumers' intention and behavior to consume sustainable fashion. What kind of green messages can arouse consumer recognition more? How should green messages be delivered in order to effectively promote the formation of SCBF? These issues deserve our further attention and research.

Furthermore, despite a diverse array of green messages designed to direct at individuals to care about the environment and save resources [6, 7], it is unclear how many customers carefully read and internalize such messages, what type of green messages have the greatest effect upon consumers, and how likely they are to change their SCBF in keeping with those messages. Researchers have verified the effectiveness of green messages on sustainable consumption behavior [8] and have increasingly focused on the expression of green messages, namely, the effect of green message frame

[9]. Previous researches involved the impact of green message framing on individual environmental behavior, energy-saving behavior, water-saving behavior, green travel, greenhouse gas emissions, and the purchase of green products [9–13]. However, few studies have investigated the effects of green message framing in terms of SCBF.

A great deal of research has been devoted to examining how individual perceptions are affected by message framing as a guide to constructing appropriate messages [14]. Message framing can be used to focus on individual's attention on some aspect of the message [9]. In green message framing, the message is framed so as to make an individual feel gain or loss; such green messages would thus relate to consumer decision making [10]. The provision of green message can be seen as an expression to increase the likelihood of intention or behavior of sustainable consumption. With regard to expression of green messages, it is noted that positive or negative expression affects how green messages are perceived and their impact on consumers' intention and behaviors toward sustainable fashion consumption [6]. Appropriate expression of green messages is an essential tool for individuals to change their perception and behaviors. Therefore, this article frames the gain and loss framing of green messages, aims to explore the influencing mechanism of green message framing on SCBF, and provides suggestions for enterprises to carry out more targeted green marketing.

Lastly, it can be seen that consumers' awareness of SCBF is gradually increasing, but the behavior formation is not good. Existing studies in sustainable consumption behavior have examined the influencing attributes based on planned behavior theory, value-belief-norm theory, and interpersonal relationship theory [15, 16], which consider sustainable consumption behavior as a static status and cannot well explain the differences of "intention-behavior." Therefore, aiming at the appeal problem, this article introduces the transtheoretical model into the field of SCBF, combines the framing message with the transtheoretical model, and studies the impact of the gain and loss framing-based green messages on the "intention-behavior" formation process in SCFB of individuals.

Taken together, this research provides policy makers and business strategists with useful insights to cultivate and drive SCBF, design green messages, and accurately present green message to consumers to facilitate the consumer formation of SCBF. This is achieved by analyzing the relationship between the gain and loss framing, self-efficacy, decision balancing, perceived threats, and the change stages of SCBF based on the cross-theoretical model, which explores the influence mechanism of green message framing on SCBF. To this end, research hypotheses are proposed and justified in the following section. Next, the research methods and empirical results are described. The last section draws implications for theory and practice.

2. Hypotheses Development

2.1. Green Information Framing and Sustainable Consumption Behavior of Fashion. Previous research shows that how green message is presented can significantly promote individuals' willingness and action to participate in environmentally friendly behaviors, which means that appropriate message framing can improve the persuasiveness of green message [17]. However, it is still uncertain whether gain framing or loss framing is better in encouraging consumers' sustainable consumption behavior [18]. On the one hand, some scholars believe that, for sustainable consumption behaviors or pro-environmental behaviors, gain message can more arouse positive emotions of individuals than loss message, by conveying the contribution of sustainable consumption to individuals or the environment, so that they are willing to make efforts for social, environmental, and personal interests. Gain message framing is more likely to promote consumer participation in energy-saving behaviors [19], stimulate individual green buying behaviors, attract individual attention to air pollution problems, and promote preventive measures and environmental behaviors than loss message framing. On the other hand, some scholars believe that loss message framing describes the harm caused by bad behavior to personal health and natural environment, which can better attract the attention of individuals and make them feel threatened, so that they are willing to change bad behavior to avoid harm. Loss message framing is more likely to promote consumer participation in hotel linen recycling projects [20], promote citizens' awareness of water conservation and water-saving behaviors in environmental public service advertisements, be conducive to individual choice of sustainable transportation in the study of the impact of transport CO_2 emissions information on individual transportation choices [12], and be conducive to consumer use of eco-friendly biofuels when the negative impact of gasoline is emphasized [14].

According to prospect theory, people usually weigh their gains against losses before making decisions. When the gains in the situation are more obvious, people usually tend to be risk-averse, choosing profitable behaviors in order to maintain or enhance existing gains; when the loss is more obvious, people are often more inclined to identify risk in order to change the status, choosing behaviors that are likely to gain more. In this study, the individuals in the pre-intention stage and intention stage of SCBF are still in the early stages of behavior change, and there is no actual behavior change. Therefore, it is considered that sustainable consumption of fashion is a risk behavior for those consumers. Simultaneously, the loss message can better indicate that they are currently in a state of loss because they may concern personal or environmental harm caused by the unsustainable consumption of fashion. In the preparation and action and maintenance stages, consumers are gradually beginning to change behavior because the regression of the behavior stage is seen as a risk behavior. Meantime, because they are enjoying the benefits of sustainable consumption of fashion to individuals and environment, gain message framing can better strengthen the awareness of the benefits of their own state so as to promote them to avoid risks and continue to maintain or advance the formation of SCBF. Therefore, we propose the following hypotheses:

H1. Loss framing based on a green message promotes consumers' formation of SCBF in the pre-intention and intention phases

H2. Gain framing based on a green message promotes consumers' formation of SCBF in the preparation and action and maintenance phases

2.2. Self-Efficacy. Self-efficacy mediates individual acquisition of knowledge, experience, and behavior [21]. It has been established as one of the most important mediators in gain and loss message framing studies [22]. Self-efficacy refers to the amount of confidence on whether they have sufficient ability to accomplish their target behavior [23]. As the executing agent of behavior, the successful execution of behavior depends to some extent on people's belief that they can achieve the goal [24]. The higher the self-efficacy of the individual, the higher the self-confidence of the individual in behavior change, the more the confidence in overcoming difficulties to complete the behavior change, the greater the possibility of changing behavior [21]. Obviously, individual choices and persistence in behavior are influenced by self-efficacy [23]. The mediating role of self-efficacy in message framing research has been greatly demonstrated in the studies of healthy behaviors. Self-efficacy is established to play a mediating role in message framing and human papillomavirus vaccine [25]. Gain message increases individual self-efficacy in physical activities more than loss message, thereby increasing the user's intention to use the fitness app [26]. Gain framing can promote the improvement of individual self-efficacy and thus promote the formation of individual healthy behaviors than loss framing [27]. In the studies on sustainable consumption behavior, researchers have also found that gain framing improves the public's self-efficacy more than loss framing, and individuals who believe they can promote sustainable consumption through action are more likely to engage in and maintain sustainable consumption behaviors than individuals who question their ability to conduct sustainable consumption [28]. Gain message can improve consumers' self-efficacy and thus promote the formation of sustainable consumption behaviors [29]. Morton noted that gain message can promote an individual's environmentally friendly behavior by stimulating an individual's self-efficacy [22]. Therefore, for SCBF, gain framing based on green message describes the benefits of sustainable consumption of fashion to individuals and the environment, enabling individuals to acquire the knowledge and skills of sustainable consumption of fashion and to believe that they can cope with the difficulties that may exist in sustainable consumption of fashion, so as to implement or adhere to sustainable consumption of fashion. Based on the above studies, the following hypotheses are suggested:

H3a. Gain farming based on a green message positively impacts self-efficacy in the preparation stage

H3b. Gain framing based on a green message positively impacts self-efficacy in the action and maintenance stage

H4a. Self-efficacy is positively associated with consumers' formation of SCBF in the preparation stage

H4b. Self-efficacy is positively associated with consumers' formation of SCBF in the preparation and action and maintenance stages

H5a. Self-efficacy mediates the relationship between gaining framing-based green messages and consumers' formation of SCBF in the preparation stage

H5b. Self-efficacy mediates the relationship between gaining framing-based green messages and consumers' formation of SCBF in the action and maintenance stage

2.3. Decision Balancing. Decision balance is the important variable to explain individual behavior change, including perceived benefit and perceptual barriers. Perceived benefit refers to the individual's perception on the benefits brought by behavior change, while perceptual barriers refer to the individual's perception on the obstacles or costs that may be encountered in the process of changing behavior [30]. Changes in individual behavior are caused through weighing perceived benefits against perceptual impairments, which promote behavioral changes, while perceptual impairment inhibits behavioral changes [31]. People always want to pay the least cost to reap the greatest benefits when making decisions, and people will only make decisions when the benefits obtained are greater than the costs [32]. Similarly, the implementation of sustainable consumption behavior depends on the weighing of the individual's trade-off of the costs to be paid and the benefits that can be obtained, and when people perceive that the benefits of sustainable consumption behavior are much higher than the costs, the bad behavior will be changed for personal gain. For example, people first consider the benefits of green products to the environment and personal health, as well as the difficulties caused by the higher price of green products before buying green products, and they will buy green products when the perception on the benefits of green products is greater than the obstacle to purchasing it [33]. In this study, because there are no obstacles and costs that need to be paid for the sustainable consumption of fashion, consumers' perception on sustainable consumption in fashion has basically not changed during the four changing stages. Therefore, the formation of consumers' SCBF is mainly due to the improvement of perceived benefits rather than the decline of perceptual barriers [32]. Gain message mainly describes the benefits of behavioral change, so perceived benefits are often mediated in the impact on behavioral change in message framing-related research. Gain framing based on advertising messages promotes consumers' perception on health and environmental benefits, making them more willing to buy organic foods [34]. Gain framing message can more effectively influence the perceived benefits of individuals than the loss framing messages, thereby promoting individual willingness of vaccination [35]. Gain framing message can also better promote individual participation in sports with perceived benefits acting as intermediaries [36]. In this study, gain

framing based on green message involves the benefits of SCBF to individuals and the environment, so individuals will be more willing to adopt sustainable consumption behaviors of fashion when the perceived benefits are greater than the costs they need to pay. Based on the above studies, the following hypotheses are suggested:

H6. Perceived barriers are not associated with consumers' formation of SCBF

H7a. Gain framing-based green messages have a favorable impact on perceived benefits in the preparation stage

H7b. Gain framing-based green messages will have a favorable impact on perceived benefits in the action and maintenance stage

H8a. Perceived benefits are positively associated with consumers' formation of SCBF in the pre-intention phase

H8b. Perceived benefits are positively associated with consumers' formation of SCBF in the action and maintenance stage

H9a. Perceived benefits mediate the relationship between the gain framing-based green messages and consumers' formation of SCBF in the preparation stage

H9b. Perceived benefits mediate the relationship between the gain framing-based green messages and consumers' formation of SCBF in the action and maintenance stage

2.4. Perceived Threats. Perceived threats are individual's perception on the degree of harm caused by the external environment to himself, which are aroused by the appeal of fear. Perception on the level of threats will affect the individual's probability of adopting the recommended scenario. Loss message describes the harm of bad behavior, which can produce negative emotions such as fear and threat, and these negative emotions can make individuals tend to avoid bad behavior so that loss framing message can be effective in discouraging bad behavior [37]. The mediating role of perceived threats in message framing has been demonstrated in the research on healthy behaviors. Loss message is found to make individuals in grief more easily develop a sense of threat and behavior in the research on genital herpes message seeking [38]. Loss framing message is more persuasive than gain framing message when the object of message description is considered a threat [37]. Loss message describing that it will cause health problems affects an individual's perceived threat and perceived severity, prompting individuals to support weight loss policies [39]. Loss message describing the threats that smoking behavior poses to human health would make individuals feel frightened, thereby increasing the persuasiveness of the message [40]. When given a message about the negative effects of skin cancer on the appearance of the skin, people are more likely to feel the huge threat posed by skin cancer and are more willing to take skin protective behaviors [41]. In the research of sustainable consumption, when individuals realized the adverse effects of a certain behavior on their health and the ecological environment through loss message, the individual perceived threat will increase, which will cause the likelihood and severity of the perceived harm to continue to increase [42]. Furthermore, when it is felt that environmental problems have seriously affected the health and living environment of the individuals, they will not allow it to continue to develop and they will be motivated to deal with the threat [43]. In this research, loss framing-based green message conveys the damage of unsustainable consumption behavior of fashion to personal health and ecological environment, which is more likely to arouse people's attention to the problem of unsustainable consumption of fashion, enhance the recognition of the serious destruction, and thus seriously reflect on their current behavior. When the perceived threat is increasing, individuals will be more strongly aware of the harm caused by unsustainable consumption of fashion to the physical health of individuals and the bad situation of life, and they will make behavioral changes and adopt sustainable fashion consumption behaviors in order to avoid harm and change the status [33]. Based on the above studies, the following hypotheses are suggested:

H10a. Loss framing-based green messages have a favorable impact on a perceived threat in the pre-intention phase

H10b. Loss framing-based green messages have a favorable impact on a perceived threat in the intention phase

H11a. Perceived threats are positively associated with consumers' formation of SCBF in the pre-intention phase

H11b. Perceived threats are positively associated with consumers' formation of SCBF in the intention phase

H12a. Perceived threats mediate the relationship between the loss framing-based green messages and consumers' formation of SCBF in the pre-intention phase

H12b. Perceived threats mediate the relationship between the gain framing-based green messages and consumers' formation of SCBF in the intention phase

In the following section, green message framing, self-efficacy, decision balancing, perceiving threats, and fashion-sustainable consumption behavior are tested in a unified framework to gauge their respective associations with the formation of SCBF. Please refer to Figure 1.

3. Survey Experiments

3.1. Survey Experiment Design. This study employed survey experimental design, in which the phase of consumers' sustainable fashion consumption was investigated before and after the framing-based green message intervention. The survey experiments are divided into three parts, including pretest, green message intervention after the gain/loss framing, and posttest. The pretest questionnaire was

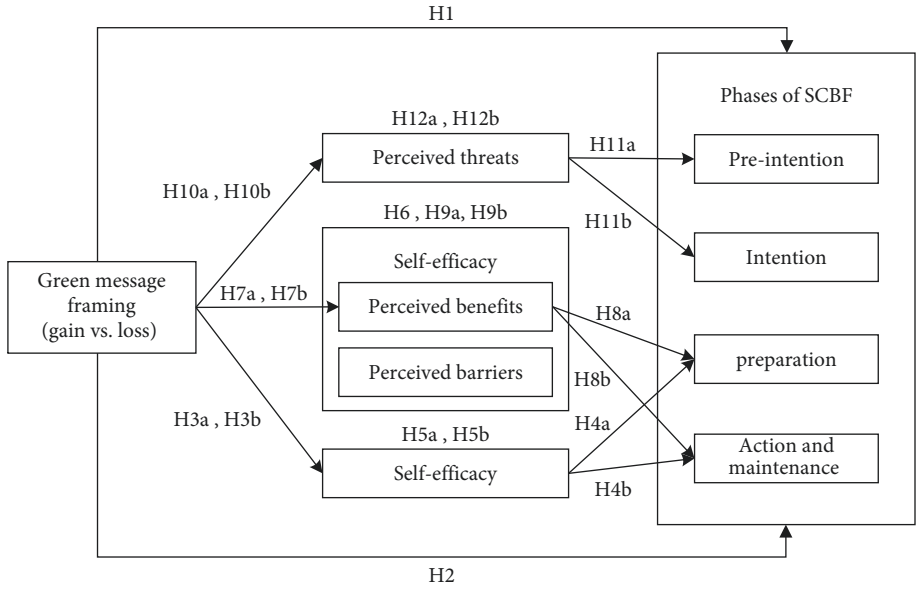

Figure 1: Cross-theoretical model.

designed to survey the phase of sustainable fashion consumption of participants before receiving green messages. Then a green message frame that was either gain or loss was designed as intervention material to conduct group intervention for participants. Furthermore, the posttest survey was used to investigate the phase of sustainable fashion consumption of participants after receiving green messages, which can be compared with the results of pretest so as to explore the different effects of gain/loss framing green messages. The experiments were conducted online, with pretest and posttest questionnaires distributed through "Questionnaire Star" software and intervention messages disseminated to participants through "WeChat" social platform.

Participants were first asked to watch a brief video about what is SCBF. Respondents completed a pretest questionnaire that measured the current status of SCBF. Subsequently, they were divided into four groups including pre-intention, intention, preparation, and action and maintenance according to the stage of SCBF of pretest subjects, and each group was randomly and uniformly divided into three groups to receive gain framing message, loss framing message and blank message intervention for one month (30 days). As the respondents deepened their understanding of sustainable fashion consumption behavior, the message intervention frequency was slowly extended from 2 days at a time, and a total of 9 interventions were conducted, and the specific intervention time is shown in Table 1. Among them, the gain framing group received the positive green messages, the loss framing group received the negative green messages, and the blank control group did not receive messages. Respondents answered a question related to the message materials after each message was distributed to ensure that they carefully read the messages; then they were asked to fill out the posttest questionnaire to measure the SCBF after the message intervention.

Table 1: Green message intervention schedule.

Number of interventions	Day
Intervention 1	1
Intervention 2	3
Intervention 3	5
Intervention 4	7
Intervention 5	10
Intervention 6	14
Intervention 7	18
Intervention 8	24
Intervention 9	30

3.2. Questionnaire and Materials. The questionnaire consisted of three parts which were administered in a particular order. The first part investigated the sociodemographic characteristics. In the second part, the respondents had to read a message and answer questions relating to perceived self-efficacy, decision-making balance, and perceived threats of the messages. The third part investigated the change stage of SCBF in which respondents are. The pretest and posttest questionnaires were identical, except the framing of the green message the respondents had to read. The manipulation test scale is added to the posttest questionnaire to ensure that the experimental materials are clearly framed and the group intervention is successful, and the respondents in both the gain group and the loss group should answer one question.

Experimental stimulus materials are divided into two groups: the gain framing-based green messages and the loss framing-based green messages. The gain framing-based green messages emphasize the benefits of SCBF for individuals and the environment, while the loss framing-based green messages emphasize the harm to individuals and the environment caused by loss framing-based green messages. Two versions of green messages contain the same content. These benefits and hazards involve air quality, natural

environment, living environment, resources, life and health, personal welfare, etc. The experimental materials include a total of 9 pairs and 18 articles, and each time a pair of materials is sent to the gain group and the loss group, the respondents are required to answer a simple reading comprehension question related to the materials.

3.3. Participants. Responses were collected from 217 Chinese residents in the pretest experiment, which were then subjected to a validation process. The time spent by the respondents on the entire survey was over 10 min and the time spent on viewing the manipulation message was over 10 s, which can ensure the validity of the data. Among these 217 respondents, 110 were females, 107 were males. They ranged in age from 18 to 50, with 67.34% clustered between 23 and 35. The majority of respondents have a college degree including bachelor's degree (49.77%) and master's degree and above (43.78%). Most (61.51%) of the respondents had an annual income greater than $5000, including 31.34% that had an annual income greater than $15000. Most (70.05%) of the respondents live in first-tier cities, including 11.98% in second-tier cities and 11.52% in third-tier cities in China. Conducted message intervention for one month, some respondents withdrew, who do not complete the reading of message materials or fill out the post-test questionnaire carefully, and there are 186 respondents who completed validly the whole experiment, which is shown in Table 2.

3.4. Analysis Procedures. All data were analyzed with SPSS 26.0. Descriptive statistical analysis, independent sample *t*-test, Scheffe posttest, and logistic binary regression were conducted to find out the important prediction and explanatory variables for the development of each stage of SCBF, and linear regression analysis to find out the important prediction and explanatory variables of SCBF in the action and maintenance stages, in order to find out the mediating variables of different framing-based green messages that have different effects on individuals at different stages of change.

4. Empirical Results

4.1. Reliability and Validity Analysis. SPSS 26.0 was used for reliability and validity tests in this study. The specific results are shown in Table 3. The interpretation rate of each variable reached the criterion of 70%, and the overall KMO value and Cronbach's α coefficient were 0.842 and 0.889, respectively, greater than 0.7. Meanwhile, the KMO (0.731–0.938) and Cronbach's α values (0.788–0.970) of each variable reached the acceptance standard 0.7. The measurement scale can be considered to be of good reliability and validity based on the above analysis.

4.2. Variables in Different Stages of SCBF

4.2.1. Descriptive Statistical Analysis. Descriptive statistical analysis and variance analysis of the perceived benefits, perceived barriers, self-efficacy, and perceived threats were conducted to explore the changes of those variables in the process of SCBF and find out the important variables that explain the changes in each stage. The data collected through pretest questionnaire before the message intervention were used for analysis, and the results are shown in Table 4. The F value of perceived benefits is 14.703 ($p = 0.000 < 0.05$), the F value of perceived barriers is 4.320 ($p = 0.006 < 0.05$), the F value of self-efficacy is 28.457 ($p = 0.000 < 0.05$), and the F value of perceived threats is 18.069 ($p = 0.000 < 0.05$), which show that the mean values of each variable at different stages of SCFB are significantly different, indicating that there are significant differences in individual perceived interests, perceived barriers, self-efficacy, and perceived threats at different stages of SCBF. For convenience, the changes of SCBF are shown sequentially as phases in Table 4. Phase 1 represents the pre-intent phase, phase 2 the intent phase, phase 3 the preparation phase, and phase 4 the action and maintenance phase.

In order to more intuitively observe the changing trends of perceived benefits, perceived barriers, self-efficacy, and perceived threats at different stages of SCBF, the average values of each variable at different stages of SCBF are plotted, as shown in Figure 2. With the development of the changing stages of SCBF, the perceived benefits increase significantly in phase 1 to phase 2 and phase 3 to phase 4, with less increase in phase 2 to phase 3. In general, individual perceived benefits will keep increasing, perceived barriers will keep decreasing, self-efficacy will continue to increase with a large increase from phase 1 to phase 2 and from phase 3 to phase 4, and a smaller increase from phase 2 to phase 3, and perceived threats will continue to increase with gradually decreasing magnitude.

4.2.2. Post Mortem Results. Scheffe method was used to conduct multiple comparisons for each variable changes in two phases to identify the stages in which the variables vary significantly. The results are shown in Table 5. It can be seen that in the formation of SCBF, adjacent changing stages with significant differences in perceived benefits are from phase 1 to phase 2 and phase 3 to phase 4 and perceived benefits are increased; in self-efficacy, they are from phase 3 to phase 4 and self-efficacy is increased; in perceived threats, they are from phase 1 to phase 2, and perceived threats are increased. There was no significant difference for perceived barriers in any changing stages.

4.2.3. Logistic Regression Analysis. Logistic regression analysis was performed to determine the important prediction and explanatory variables when the adjacent change stage of SCBF is changed. First, the adjacent change stage is used as the dependent variable; the perceptual benefits, perceived barriers, self-efficacy, and perceived threats are selected into the equation for binary logistic regression analysis by the forward Wald method to get the important prediction and explanatory variables of moving forward of each adjacent change stages of SCBF. Then as phase 4 can no longer move forward, the linear regression analysis is used to obtain the important explanatory variables that remain

Table 2: Number of respondents at different stages of change in each experimental group.

	Preintention	Intention	Preparation	Action and maintenance	Total
Gain framing group	15	18	14	17	64
Loss framing group	15	17	14	17	63
Blank group	15	15	14	15	59
Total	45	50	42	49	186

Table 3: Reliability and validity analysis.

Variables		Cronbach's α	KMO	Interpretation rate (%)
Decision balancing	Perceived benefits	0.970	0.822	82.20
	Perceived barriers	0.866		
Self-efficacy		0.917	0.880	75.58
Perceived threats		0.731	0.731	83.61
Dependent variables	Preintention stage	0.788	0.938	78.08
	Intention stage	0.952		
	Preparation	0.927		
	Action and maintenance stage	0.959		

Table 4: Descriptive statistics of variables in different change stages of SCBF.

Variables	Phase 1	Phase 2	Phase 3	Phase 4	F value	P value
Perceived benefits	5.420 ± 1.071	5.952 ± 0.887	6.006 ± 0.829	6.476 ± 0.9690	14.703*	≤0.001
Perceived barriers	4.686 ± 0.884	4.365 ± 0.988	4.205 ± 0.846	4.017 ± 1.202	4.320*	0.006
Self-efficacy	4.068 ± 0.906	4.542 ± 0.786	4.718 ± 0.739	5.457 ± 0.898	28.457*	≤0.001
Perceived threats	4.007 ± 1.338	4.891 ± 0.887	5.311 ± 0.896	5.446 ± 1.179	18.069*	≤0.001

Note: *P is significant below 0.05.

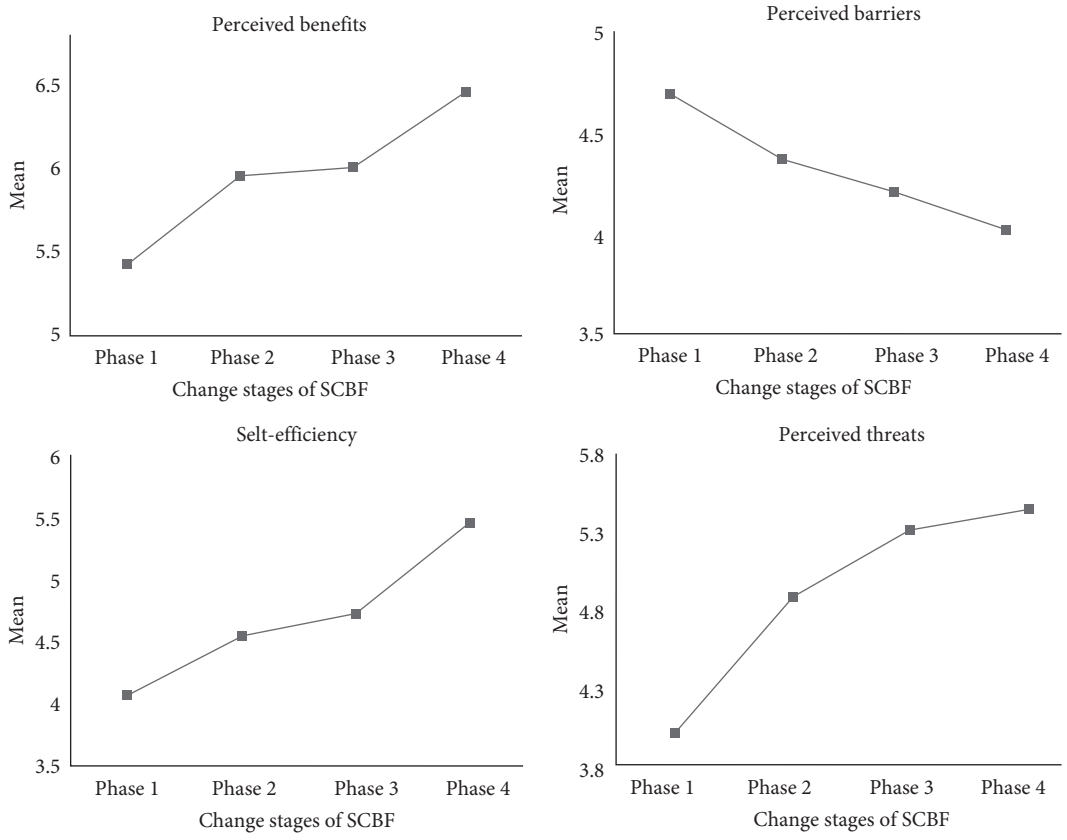

Figure 2: Changes of variables in different stages of SCBF.

Table 5: Comparison of differences of variables in change stages of SCBF.

Variables	(*I*) Change stages	(*J*) Change stages	Mean difference (*I*-*J*)	Stand deviation	*P* value
Perceived benefits	1	2	−0.531*	0.173	0.026
		3	−0.585*	0.180	0.016
		4	−1.032*	0.160	≤0.001
	2	3	−0.054	0.176	0.993
		4	−0.501*	0.155	0.017
	3	4	−0.470*	0.164	0.043
Perceived barriers	1	2	0.321	0.205	0.488
		3	0.482	0.214	0.171
		4	0.669*	0.190	0.007
	2	3	0.161	0.209	0.898
		4	0.348	0.185	0.316
	3	4	0.188	0.194	0.818
Self-efficacy	1	2	−0.474	0.170	0.053
		3	−0.650*	0.177	0.004
		4	−1.389*	0.157	≤0.001
	2	3	−0.176	0.173	0.793
		4	−0.914*	0.153	≤0.001
	3	4	−0.739*	0.161	≤0.001
Perceived threats	1	2	−0.884*	0.222	0.002
		3	−1.304*	0.231	≤0.001
		4	−1.439*	0.205	≤0.001
	2	3	−.0420	0.226	0.329
		4	−0.555	0.199	0.054
	3	4	−0.135	0.210	0.937

Note: *P is significant below 0.05.

unchanged after the behavior is formed. The logistic regression analysis results are shown in Table 6. It can be seen that perceived benefits and perceived threats can predict and explain the shift from phase 1 to phase 2, perceived threats can predict and explain the shift from phase 2 to phase 3, perceived benefits and self-efficacy can predict and explain the shift from phase 3 to phase 4, self-efficacy and perceived threats can predict and explain the maintenance of phase 4, and perceived threats play no role in the formation of SCBF. H6 was thus established.

4.3. Manipulation Check. The test value was set to 4 to ensure the effectiveness of the framing message control, and the single sample t-test was conducted to establish the manipulation test scale. The test results are shown in Table 7. M gain = 6.203 > 4, t = 24.592, p = 0.000 < 0.05, and M loss = 6.333 > 4, t = 23.658, p = 0.000 < 0.05, which demonstrated that the gain group and the loss group on the manipulation scale are significantly higher than 4 points and indicated that manipulation of the gain and loss framing messages is effective, the participants in the gain group and the loss group can distinguish the framing green messages they received, and the framing of experimental materials was obvious.

4.4. The Influence on Variables of the Green Message Framing at Different Stages of SCBF. The difference between the mean of the same score in the post-questionnaire and the pre-questionnaire was used to analyze the difference in the degree of change in the same variables of individuals at different stages of SCBF after receiving gain and loss framing messages. The independent sample t-test and univariate analysis in general linear models were used for comparison, and the results are shown in Table 8.

The difference in perceived threats was found to reach a significant level (p = 0.005 < 0.05) in phase 1, indicating green messages from different framing on the changes in individual perception of threats were significantly different (M gain = 0.200, M loss = 3.267), the increase in perceived threats of individuals receiving loss framing messages was significantly higher than that of gain framing messages, and the effect value in this item was 0.247, which represents that there is a high correlation strength for differences between the framing messages and perceived threat changes. R^2 is 0.220, indicating that the loss framing-based green messages can explain the 22.0% variation of the perceived threats. The results demonstrate that the loss framing-based green messages have a significant positive impact on the perceived threats in phase 1. Moreover, the above proves that the perceived threats are an important prediction and explanatory variable in SCFB from phase 1 to phase 2, so it is believed that loss framing-based green messages to enhance the individual's perceived threats are more conducive to the development of the change stages. H10a, H11a, and H12a were established.

The difference in perceived threats was found to reach a significant level (p = 0.004 < 0.05) in phase1, indicating green messages from different framing on the changes in individual perception of threats were significantly different (M gain = −2.111, M loss = 1.647), the increase in perceived threats of individuals receiving loss framing messages was

Table 6: Regression results of variables between adjacent change stages of SCBF.

Logistic regression equation	P value	
Y (phase 1 – phase 2) = 0.755 ∗ perceived benefits + 0.514 ∗ perceived threats – 6.465	Perceived benefits Perceived threats	0.010 0.032
Y (phase 2 – phase 3) = 0.541 ∗ perceived threats – 2.926	Perceived threats	0.028
Y (phase 3 – phase 4) = 0.641 ∗ perceived benefits + 0.807 ∗ self-efficacy – 7.496	Perceived benefits Self-efficacy	0.026 0.004
Y (phase 4) = 0.685 ∗ self-efficacy + 0.188 ∗ perceived threats	Self-efficacy Perceived threats	≤0.001 0.020

Note: $^*P$ is significant below 0.05.

Table 7: Experimental maneuverability test results.

	Number of cases	t	DF	Sig.	Mean	Standard deviation	95% confidence interval	
							Lower limit	Upper limit
Gain framing group	64	24.592	63	0.000	6.203	0.72	2.0241	2.3821
Loss framing group	63	23.657	62	0.000	6.333	0.78	2.1362	2.5305

Table 8: Comparison of the changes of variables in SCBF for gain group and loss group.

	Group	No. of cases	Mean	SD	p	t	η^2	R^2
Phase 1								
Perceived threats	Gain framing	15	0.200	2.651	0.005	−3.028	0.247	0.220
	Loss framing	15	3.267	2.890				
Phase 2								
Perceived threats	Gain framing	18	−2.111	3.376	0.004	−3.058	0.221	0.197
	Loss framing	17	1.647	3.888				
Phase 3								
Perceived benefits	Gain framing	14	2.000	4.132	0.009	2.811	0.233	0.204
	Loss framing	14	−2.357	4.069				
Self-efficacy	Gain framing	14	2.786	4.371	0.695	0.397		
	Loss framing	14	2.000	5.974				
Phase 4								
Perceived threats	Gain framing	17	2.941	2.968	0.000	−4.303	0.367	0.347
	Loss framing	17	−1.353	2.849				
Self-efficacy	Gain framing	17	3.235	3.898	0.004	−3.145	0.236	0.212
	Loss framing	17	−2.353	6.204				

Note: $\eta^2 \geq 0.14$ indicates that there is high correlation between the grouping variable and the test variable, $0.14 > \eta^2 > 0.06$ indicates moderate correlation, and $\eta^2 \leq 0.06$ indicates low correlation.

significantly higher than that of gain framing messages, and the effect value in this item was 0.221, which represents that there is a high correlation strength for differences between the framing messages and perceived threat changes. R^2 is 0.197, indicating that the loss framing-based green messages can explain the 19.7% variation of the perceived threats. The results demonstrate that the loss framing-based green messages have a significant positive impact on the perceived threats in phase 2. Moreover, the above proves that the perceived threats are an important prediction and explanatory variable in SCFB from phase 2 to phase 3, so it is believed that loss framing-based green messages to enhance the individual's perceived threats are more conducive to the development of the change stages. H10b, H11b, and H12b were established.

The difference in perceived benefits was found to reach a significant level ($p = 0.009 < 0.05$) in phase 3, indicating green messages from different framing on the changes in individual perception of benefits were significantly different (M gain = 2.000, M loss = −2.357, $p = 0.005 < 0.05$), the increase in perceived benefits of individuals receiving gain framing messages was significantly higher than that of loss framing messages, and the effect value in this item was 0.233, which represents that there is a high correlation strength for differences between the framing messages and perceived benefit changes. R^2 is 0.204, indicating that the gain framing-based green message can explain the 20.4% variation of the perceived benefits. The results demonstrate that the gain framing-based green messages have a significant positive impact on the perceived benefits in phase 3. Moreover, the above proves that the perceived benefits are an important prediction and explanatory variable in SCFB from phase 3 to phase 4, so it is believed that gain framing-based green messages to enhance the individual's perceived benefits are more conducive to the development of the change stages. H7a, H8a, and H9a were established.

Table 9: Changes of different stages of the framing group and the blank group.

Group	Changes of different stages of SCBF				Z	P value
	Phase 1	Phase 2	Phase 3	Phase 1		
Phase 1						
Loss framing	2	7	4	2	-3.247^{b}	0.001
Blank	13	2	0	0	-1.414^{b}	0.157
Phase 2						
Loss framing	0	2	4	11	-3.578^{b}	≤0.001
Blank	3	7	1	4	-1.508^{b}	0.132
Phase 3						
Gain framing	0	0	3	11	-3.317^{b}	0.001
Blank	1	3	7	3	-0.632^{c}	0.527
Phase 4						
Gain framing	0	0	0	17	-0.000^{b}	1.000
Blank	1	1	0	13	-1.342^{b}	0.180

Furthermore, the difference in self-efficacy was found not to reach a significant level ($p = 0.695 < 0.05$) in phase 3, indicating there is no significant difference for green messages from different framing on the changes in individual self-efficacy. H3a, H4a, and H5a were not established. This may be because the individuals have not yet carried out SCBF in phase 3, and they need to be surrounded by more tips and guidance related to SCBF, so that the improvement of self-confidence is not enough to promote the development of their behavior.

The differences in perceived benefits ($p = 0.000 < 0.05$) and self-efficacy ($p = 0.004 < 0.05$) were found to reach a significant level in phase 4, indicating green messages from different framing on the changes in individual perceived benefits (M gain = 2.941, M loss = −1.353) and self-efficacy (M gain = 3.235, M loss = −2.353) were significantly different, the increase in perceived benefits and self-efficacy of individuals receiving gain framing messages was significantly higher than that of loss framing messages, and the effect value η^2 in the items was 0.367 and 0.236, which represent that there is a high correlation strength for differences between the framing messages and perceived benefit and self-efficacy changes. R^2 is 0.347 and 0.212, indicating that the gain framing-based green messages can explain the 34.7% variation of the perceived benefits and 21.2% variation of the self-efficacy. The results demonstrate that the gain framing-based green messages have a significant positive impact on the perceived benefits and self-efficacy in phase 4. Moreover, the above proves that self-efficacy is an important prediction and explanatory variable in SCFB from phase 4, while perceived benefits are not, so it is believed that gain framing-based green messages to enhance the individual's self-efficacy are more favorable to stay in phase 4 for them. H3b, H4b, H5b, and H7b were established and H8b and H9b were not established. This may be because consumers in phase 4 have been more familiar with SCBF, and they can perceive benefits conveyed by the gain framing-based green messages, but they have their own judgment on whether these benefits can really come true, so they will not maintain the current behavior based on their perceived benefits.

4.5. The Effects of the Green Message Framing on Individuals at Different Stages of SCBF. The blank group without any green message framing was designed to further demonstrate the effect of green message framing on the formation of SCBF. The differences between the change stages before and after the message framing were compared by the Wilcoxon symbolic rank and test of the paired samples, and the outcome differences between loss group and blank group after message framing intervention were compared as shown in Table 9. Subsequently, the independent sample Mann–Whitney U test was used to further compare the degree of stage changes between loss group and blank group.

Before the loss framing intervention, there are 15 people in loss group and blank group in the pre-intention stage, and 7 people in loss group entered the intention stage, 4 people entered the preparation stage, 2 people entered the action and maintenance stage, and the remaining 2 people did not change, and the change was significant ($p = 0.001 < 0.05$) after loss framing intervention. At the same time, 2 people in blank group entered the intention stage, the remaining 13 people did not change, and there was no significant difference in the change ($p = 0.157 < 0.05$). In addition, the results show a significant difference ($p = 0.000 < 0.05$) for the stage changes between loss group and blank group, which indicates that loss framing effect is significantly better toward the formation of SCBF in phase 1 than that of blank group.

Before the loss framing intervention, there are 17 people in loss group in the intention stage, and 4 people in loss group entered the preparation stage, 11 people entered the action and maintenance stage, and the remaining 2 people did not change, and the change was significant ($p = 0.000 < 0.05$). At the same time, 15 people in blank group were in the intention stage, 1 person in blank group entered the preparation stage, 4 people entered the action and maintenance stage, 3 people retreated to the pre-intention stage, and the remaining 7 people did not change, and there was no significant difference in the change ($p = 0.132 < 0.05$) after loss framing intervention. In addition, the results show a significant difference ($p = 0.004 < 0.05$) for the stage changes between loss group

and blank group, which indicates that loss framing effect is significantly better toward the formation of SCBF in phase 2 than that of blank group.

Before the gain framing intervention, there are 14 people in gain group and blank group in the preparation stage, and 11 people in gain group entered the action and maintenance stage, and the remaining 3 people did not change, and the change was significant ($p = 0.001 < 0.05$). At the same time, 3 people in blank group entered the action and maintenance stage, 3 people retreated to the intention stage, and the remaining 7 people did not change, and there was no significant difference in the change ($p = 0.527 < 0.05$) after gain framing intervention. In addition, the results show a significant difference ($p = 0.002 < 0.05$) for the stage changes between gain group and blank group, which indicates that gain framing effect is significantly better toward the formation of SCBF in phase 3 than that of blank group.

Before the gain framing intervention, there are 17 people in gain group in the action and maintenance stage, and the remaining 17 people did not change, and the change was not significant ($p = 1.000 < 0.05$). At the same time, 15 people in blank group entered the action and maintenance stage, 1 person retreated to the intention stage, 1 person retreated to the pre-intention stage, and the remaining 13 people did not change, and there was no significant difference in the change ($p = 0.180 > 0.05$) after gain framing intervention. In addition, the results show no significant difference ($p = 0.126 > 0.05$) for the stage changes between gain group and blank group, which indicates that gain framing effect has higher behavior stability toward SCBF in phase 4 than that of blank group.

5. Discussion and Conclusion

5.1. Theoretical Implications. The impact of green messages on consumer environmental behavior has been widely confirmed, and the influence of green message framing on individual environmental behavior has been proved. There are many different ways to divide the green message framing, but the benefit and loss framing, as one of the important frameworks for promoting consumer decision making, has not yet been agreed. Therefore, this article frames the benefits and losses of green messages, aims to explore the impact mechanism of green message framing on the SCBF, and provides suggestions for enterprises to carry out more targeted green marketing. Furthermore, the cross-theoretical model can comprehensively explain the behavior change of individuals through four parts including change stage, change process, decision balance, and self-efficacy, which not only pays attention to why behavior changes, but also pays attention to how behavior changes. The application of cross-theoretical models in the field of healthy behaviors has been very mature, and the applicability in the field of sustainable consumer behavior has been proven.

Communicating the need for sustainable consumption and presenting new related policy initiatives require a good understanding of how the public are motivated to be sustainable. This study examined how gain and loss framing-based green messages influenced participants' changing stages in SCBF and perceived outcome benefits, barriers, efficacy, and threats related to SCBF and, more importantly, how individual differences in perceived benefits, perceived barriers, self-efficacy, and perceived threats interacted with these framing manipulations. This study yielded several findings of interest which, we believe, underscore the importance of considering the perceived outcome and predisposition of an individual when framing green messages about the formation of SCBF.

Theoretically, this study contributed to the description of the framing of green messages in the formation of SCBF. We found that effects of framing green messages on the formation of SCBF will vary depending on the change stage that individuals are in. In the pre-intention stage and the intention stage, the SCBF is mainly because the loss framing-based green message promotes the improvement of individual perceived threats. The SCBF in the preparation stage and the action and maintenance stage is mainly due to the fact that the gain framing-based green message promotes the improvement of perceived benefits in individual self-efficacy and decision balancing.

Another contribution is the introduction of trans-theoretical model into the field of sustainable fashion consumption behavior. It constructs and verifies the theoretical model of gain and loss framing of green messages and the four changing stages of SCBF and explains the intrinsic mechanism of "intention-behavior" of SCBF. Results imply that perceived benefits and perceived threats may be a more tangible outcome of SCBF for many people; the perception on green message framing should not be ignored and may be a more significant driver for SCBF. This study provides new ideas for the follow-up studies of SCBF and provides references for enterprises to formulate more effective green messages intervention strategies.

Our study also points to the value of intervention strategies of green messages to reduce the gap of "intention-behavior" in SCBF, because results show that green messages have a framing effect in the formation of SCBF, and individuals at different changing stages react differently after receiving different framing green messages. Loss framing can significantly promote the development of individual behaviors in phase 1 and phase 2, while gain framing can significantly promote the development of individual behavior in phase 3 and maintain the stability of individual behaviors in phase 4. Furthermore, the effects of green message framing are different for each phase. In phase 1 and phase 2, the difference in changes between gain group and loss group reaches a significant level in terms of perceived threats including greater change in loss group, and perceived threat is an important prediction and explanatory variable for SCBF from phase 1 to phase 2 and from phase 2 to phase 3, thus loss framing green messages should be more conductive to the moving forward of changing stage in SCBF. In phase 3, the difference in changes between gain group and loss group reaches a significant level in terms of perceived benefits including greater change in gain group, and perceived benefit is an important prediction and explanatory variable for SCBF from phase 3 to phase 4, thus gain framing green messages are more conducive to the development of individual behavior. In phase 4, the difference in changes

between gain group and loss group reaches a significant level in terms of perceived benefits and self-efficacy including greater change in gain group, and self-efficacy is an important prediction and explanatory variable for SCBF to maintain in phase 4, thus gain framing green messages can enhance self-efficacy to promote the maintenance of SCBF.

5.2. Practical Implications. In an era of increasing concern about environment and resources, insights into consumers' adoption of SCBF will have applications for fashion enterprises to carry out green marketing and promote SCBF. Findings demonstrate that green message framing effects were observed when consumers received positive or negative green messages. The implication is that participants at different changing stages of SCBF are likely to perceive green messages in quite different ways from each other. There is therefore unlikely to be a same message that can effectively engage everyone. The reasons why the differences in "intention-behavior" of sustainable consumption of fashion became salient for some of our participants to a greater extent than others remain unexplained and potential individual perception differences that may explain why expression differences of green messages have affected people differently should be explored further [39]. For example, people who already have sustainable consumption intention may be more likely to be influenced by engaging with loss-framed green messages, and people who already have sustainable consumption behavior may be more likely to be influenced by engaging with gain-framed green messages.

Overall, we find green message framing is useful in engaging people with SCBF and could result in greater levels of SCBF given the outcomes of our perceptions. This finding highlights the importance of considering and accounting for the potential of behavioral changes in the potential impact of expression of green message displays.

Based on the findings in this study, enterprises may need to place more managerial and marketing efforts into consumers' perception on green messages framing. When exposed to effective green messages, consumers may change their intention and behavior toward SCBF so that they can make contribution to promoting green marketing and protecting the environment [44]. In addition, the fashion enterprises also need to identify what changing stages that individuals are in and what motivates individuals to change their intention or behavior of SCBF. The enterprises could promote and enhance green fashion marketing, actively establish a green brand image, and take the initiative to assume the responsibility of protecting the environment because consumer demands for green fashion products and services were realized, which they believed to save resources and protect the environment through SCBF.

Finally, it is worth mentioning that green messages are important means of disseminating green ideas, and contact with more green messages may greatly affect consumers' understanding of environmental issues, correct their misconceptions about fashion consumption, and then stimulate their determination to carry out sustainable consumption as well as take the initiative to understand SCBF, inspire themselves to change SCBF, and ultimately achieve sustainable consumption behavior. In this way, consumers may save resources and reduce waste through SCBF, improving the ecological environment and thus the quality of life. Meanwhile, consumers' demand for green products will increase, thus prompting enterprises to change traditional production methods, actively establish a green brand image, and take the initiative to assume the responsibility of protecting the environment. Obviously, in order to alleviate the pollution problem of the garment industry, it is the key means to promote the formation of SCBF.

5.3. Limitations and Future Research Avenues. Our results are limited by the use of young people aged from 18 to 25 within this study and therefore the generalizability of our results is limited. However, this sample was homogenous across conditions, giving assurance to the reliability of results noted. In addition, given that a young and well-educated sample is already likely to be more environmentally concerned, we should suggest that the observed green message framing effects might be stronger in a broader cross-section of the population. Further, the message intervention experiment and questionnaire survey were conducted online throughout the process, which may not help in understanding the real situation of the respondents, and some respondents didn't finish the whole experiment, resulting in an unstable number of experimental samples. Therefore, future research is recommended to focus on these topics in order to combine online and offline methods to ensure that participants take each experiment seriously and do not quit halfway.

When perceived benefits or perceived threats are salient within either a particular context or social group, then our findings suggest that this might in itself be enough to promote sustainable fashion consumption behaviors. Thus, in the development of an efficient green message intervention strategy, besides the gain and loss framing green messages, individuals' uniqueness and self-efficacy decision making have also to be taken into account to further generalize the conclusions to a wider range of applications. In addition, the psychology and behavior of consumers can also be tested using neural mechanism-related methods, so that the experimental results are more realistic and reliable.

Data Availability

The data can be provided by the corresponding author on request.

Conflicts of Interest

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Research Article

The "Spatial Equilibrium" Evolution of the Tourism Ecosystem and Theoretical Construction from a Multidisciplinary Perspective

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The evolution of the tourism ecosystem is characterized by its complexity, imbalance, and spatial heterogeneity. As a result, it has been the focus of academic attention across a wide range of disciplines, including geography, ecology, economics, management, sociology, and philosophy. Firstly, this article explores the connotations and characteristics of the spatial evolution of tourism ecosystems, subsequently proposing that the spatial evolution of tourism ecosystems is essentially different and "mutually inclusive." To do so, it searches through the relevant research results on "spatial equilibrium" in ecosystems from the perspectives of different disciplines and analyzes their different core concepts, theoretical systems, and research methods. Second, the coupling force acts as a key character and exerts an influence on "spatial equilibrium" in ecosystems as a dynamic mechanism, internal stability mechanism, and dynamic mechanism. Third, nonlinear, dynamic, evolutionary, systematic thinking, and axiomatic theories are combined to construct an internal stable evolution mechanism and abstract tourism ecosystem model to form an explanatory theoretical system. The results of the research show that the construction of the "spatial equilibrium" of the tourism ecosystem model should pertain to the initial state of the comprehensive environmental carrying capacity of the tourism ecosystem as it evolves to form a tourism ecosystem based on the coupling relationship between the internal and external elements of the "spatial equilibrium" state. Finally, the future research approaches in this field are summarized and assessed. The methodology and theoretical exploration discussed in this article will contribute to a better understanding of how to sustainably develop tourism destinations.

1. Introduction

Since the Earth entered the Anthropocene (Paul Jozef Crutzen, the Nobel laureate in chemistry, proposed in 2000, based on human influence on geology and ecology, that the year of 1950 could be considered the starting point of the Anthropocene) [1], the degree and pace of human influence on many aspects of the planet have reached an unprecedented scale. Notably, during this era, its ecosystem structure and function are changing faster than in any other period in human history [2, 3]. The cost of human survival continues to increase, although this is at the expense of the environment (cited from Guang ya·Shigu III).

By the turn of the millennium, most countries and regions in the world had entered or were entering into the era of mass tourism. In 2018, the Oxford English Dictionary selected the word "overtourism" as the word of the year. In the intervening years, "overtourism" has become something of a global focus and has been widely discussed in both industry and academia to examine the essence and coping strategies underpinning the global phenomenon [4].

As a typical social-ecological system (SES) [5–9], the evolution and development of the tourism ecosystem have been explored from the perspective of various academic disciplines, such as geography, ecology, economics, management, sociology, and philosophy due to its complexity,

spatial heterogeneity, and imbalances [10–12]. For example, researchers have attempted to analyze the "spatial imbalance" problem of the tourism ecosystem by means of philosophical reflection as well as science and technology in an effort to redress this imbalance. However, at the beginning of this process, attempts to solve problems through technological solutions proved unsatisfactory. Since then, the issue has been explored using a philosophical lens, based on the Eastern environmental philosophy of "The Unity of Heaven and Man" [2] and Western environmental philosophy [3]. Unfortunately, these attempts were unsuccessful in fundamentally solving the complex problem of "spatial imbalance" in the tourism ecosystem [13]. Furthermore, based on their respective ontology, each discipline has sought to define the concept, explore the methodology, and construct the theoretical framework of the spatial evolution of the tourism ecosystem. However, in terms of practical research, the discussion of the "spatial equilibrium" of the tourism ecosystem and its sustainable development has not yet progressed past the descriptive analysis level, and there is a notable lack of a scientific and operable evaluation system. In its current state, the theoretical research on the "spatial equilibrium" of the tourism ecosystem has yet to progress past the "preparadigm" stage.

On the basis of the above, it is necessary to examine the theoretical system and research methods related to the "spatial equilibrium" of the tourism ecosystem from the perspectives of different academic disciplines. The basic concepts, characteristics, evolutional mechanisms, and theoretical models should be evaluated by adhering to a systematic and scientific thinking mode of "nonlinearity," "dynamic," and "evolution." Then, based on the previously articulated theory of ecological sustainability of "spatial imbalance" and the differences and correlations between the evolution of "balance" and "equilibrium," a new research method pertaining to the "spatial equilibrium" of the tourism ecosystem is constructed. These theoretical and practical methods will enrich our understanding of the sustainable development of tourism destinations.

2. The Connotations of "Spatial Equilibrium" from the Perspectives of Different Disciplines

Equilibrium has different manifestations across different disciplines, such as average, balance, harmony, and unity. Each manifestation is a state that presents a different facet of the object. The average is a mathematical concept describing a statistic of a position in a data set by counting statistical averages; balance is a physical concept that represents the resting state of an object when subjected to the influence of two or more forces; equilibrium is a philosophical concept and also of the states used to describe moving objects, which can also be employed to reflect a state in a mutually causal relationship. Although equilibrium has the meaning of average and balanced, it describes things less precisely than the other concepts [14].

2.1. Harmonious/Balanced Evolution: From Thought to Economy

2.1.1. Philosophy: Harmonious Thought. In ancient Chinese philosophy, the Chinese character "he" means "harmony" [15]. The classic texts of Tao Te Ching say that the Tao gives birth to one, one to two, two to three, and three to all things. At the same time, all things bear yin and embrace yang, and the middle qi is harmonious. That is to say, "harmony" is the optimal state of existence for "all things." Where there is "a moderate mix of yin and yang," the yin and yang come into conflict and intermingle with each other to form a new unity, thus achieving a specific harmonious state. In the Western Zhou Dynasty, Shi Bo argued that the coexistence of different elements is the premise of harmony and can produce new things [4]. Confucianism posits that the world exists in the form of a complex "human-society-nature" ecosystem. The interrelationship between these three elements is the essence of the Confucian worldview, practicing the "Way of the Three Talents," but also the natural law followed by Confucianism to achieve its goals [16].

The famous 19th-century French philosopher Auguste Comte (1798–1857) regarded "order" as a rule of stability and harmony; as such, it is the cornerstone of social existence and development [17]. The idea of "harmony" was first introduced into Western social science by Socrates, who explored the "harmonious society" [5] concept. Heraclitus, one of the founders of Western dialectics, believed that "opposites create harmony." Later, in his "Theory of Harmony," Hegel explained that harmony is produced by the interaction of opposites; the corollary of this argument is that things that are the same cannot produce harmony [6]. Plato's social view that "justice is harmony" proposes that the foundation of social harmony lies in justice. Furthermore, justice is realized when each level of society performs its duties, holds its place, and does not transgress the other levels [18]. From Plato's Republic, Rousseau's social contract theory, and the economic harmony of Adam Smith to the political harmony of Grimm and Rawls' theories of fairness and justice, Western philosophers have engaged in multidimensional, multilevel thinking about social harmony. Their core philosophical logic is that harmony is equal to justice, which falls within the remit of the "essentialist harmony theory" of social existence [19].

2.1.2. Economics: Equilibrium. Economic equilibrium is the maximization of both efficiency and fairness. Equilibrium is both the start and end point of all research questions in economics.

Under the conditions of regional division of labor, location selection, and new economic geography, the application of equilibrium ideas in economics at the spatial level is mainly reflected in the three main research stages of spatial equilibrium [20]. Together, these gradually gave rise to the agricultural location theory (Johan Heinrich von Thunnen, 1783–1850), industrial location theory (Alfred Weber, 1868–1958), and the central Earth theory (Walter

Christaller, 1893–1969). To improve the premise of location theory and explain the formation mechanism of spatial agglomerations and their "spatial equilibrium," Paul Krugman (1991) proposed the "core-edge" (CP) model. Specifically, he successfully incorporated spatial dimensions into the analysis framework, demonstrating how agglomerations form in space and how the spatial distribution of activities of economic agents is balanced [21]. However, the concept of "space" in economics is premised on the assumption that a given geographical space is homogeneous. This model can be deployed to study the maximization of economic profits and the mode of spatial allocation. However, it should be noted that it ignores the differences in natural, social, economic, cultural, and other conditions from place to place, as well as the coordination between development intensity and ecological environment [22, 23]. With the quickening, more intense expansion of regional spatial planning and development, the decline in the carrying capacity of the environment will inevitably become the most significant bottleneck in regional development, thus leading to a slowdown in economic development [24–27].

2.2. The Evolution of Equilibrium in Science and Technology

2.2.1. Physics: Equilibrium. In physics, "equilibrium" (a system in equilibrium must meet three equilibrium conditions: mechanical equilibrium (requiring that there is no unaltermined interaction force within the system and between the system and the outside world); thermal equilibrium (requiring that there is no temperature difference between the parts of the system and between the system and the outside world); and chemical equilibrium (requiring that the parts of the system no longer spontaneously tend to change in the internal structure). The disruption of any one of these equilibriums will cause the disruption of the equilibrium state of the system) refers to the state of a macroscopic system in which its state does not change over time when external conditions remain unchanged [28]. In this context, the simplest manifestation of equilibrium is symmetry. Accordingly, space-time symmetry is a fundamental concept in physics (the law of conservation of energy derives from temporal symmetry, the law of conservation of angular momentum from spatial rotational symmetry, and the law of conservation of momentum from spatial translational symmetry) [29]. At the same time, physics research shows that forces do not exist in isolation; rather, they must interact with other forces. Hence, any action between things does not propagate in a one-way direction. That is to say, if there is a force, there must be an equal reactive force (Wei Lin). In physics, the "equilibrium state" is called "thermodynamic equilibrium" [30]. When the system enters a certain "equilibrium state," the temporary deviation caused by the fluctuation of the system around the "equilibrium state" is expected and always present. This fluctuation phenomenon can be observed and measured without destroying its systemic characteristics.

Second, the "equilibrium" of a system in physics is assumed to be an ideal concept; specifically, it is an abstract description of how the world works under specific conditions. However, there is no situation in which objects can be entirely independent of external influences. To be precise, all things in the world are interconnected and interact with each other, and the nature of the system remains absolutely unchanged. To minimize the complexity of practical research, the actual state of the system is often treated as an "equilibrium state" [31].

2.2.2. Systems Science: Balance. Systems science is the study of the objective world carried out by examining the relationship between parts and wholes, and the hierarchical relationship between them. The system has a specific structure and function composed of interrelated, interacting, and mutually restricting elements (Qian) [32, 33]. Notably, system equilibrium constitutes an important part of "some kind of function" (system optimization and equalization problems can be expressed in a triplet (S, F, P), where S represents a system, F represents a metric that judges the state of the system, F is usually represented as an objective function, and P represents a criterion for comparing the size of the "value" of the objective function, also known as preference. The size of the objective function "value" corresponds to the quality of the system state. For example, if S is a system described by a polynomial inequality, F is a linear or nonlinear function, and P is the preference for natural numerical size, and then, (S, F, P) characterizes a linear or nonlinear programming problem in operations research. If S is a system described by a differential equation and F is a functional objective function, then (S, F, P) characterizes an optimal control problem [34]. In a system, the balance between its elements is the foundation of its order. Contrastingly, imbalance is the source of power for the evolution and development of the system, which underscores the role of "balance" as the dynamic evolution mechanism of everything in the world [35].

Synergetics argues that ecological synergy is always replaced by old symmetrical equilibrium and harmony by a new one, resulting in systematic evolution and adaptation to the external environment. Prigogine, who first articulated the theory of dissipative structures, emphasized the dynamic behavior of open systems that moves away from equilibrium and the nonlinear interrelationships between constituent elements (Nicolis and Prigogine) [36]. His theory broke down the unbalanced state problem into a number of local equilibrium problems so they can be more readily studied and, in doing so, found a bridge between equilibrium and unbalanced posture mechanics (Chen Gong).

2.3. Evolution from Ecological Equilibrium to Geographical Equilibrium

2.3.1. Ecology: Ecological Equilibrium. The term "ecological equilibrium" was first formally proposed by the American scholar Vogt [37]. In his theory, the energy flow of an ecosystem corresponds to its structural equilibrium

(structural equilibrium is that the types and energy of the producers, consumers, and decomposers in the ecosystem can remain relatively stable for a long time), while the material cycle of the ecosystem corresponds to its functional equilibrium (functional equilibrium refers to the fact that the material and energy inputs and outputs of ecosystems are basically equal). In the 1980s, scholars around the world tried to define and theoretically construct ecology in a systematic way. American ecologist Odum (Odum) proposed the system ecology model in 1982 [38]. Around the same time, Chinese scholars Ma et al. proposed the "socio-economic-natural composite ecosystem," which promoted a return of ecology to the holistic theoretical research paradigm. These two approaches were the precursors to the sustainable development of human and natural systems (E.C. Lindeman notes that "ecology is a middle ground left over from physics and biology and beginning to grow in the social sciences." Odum believes that ecology is a systematic science independent of biology and even natural science, linking life, environment, and human society to sustainable development; in their view, ecology is a systematic science that studies the life and death process of organisms, the process of life and death of matter, the rise and fall of things, and the relationship between the environment) [39].

The structure and function of the ecosystem are constantly in the process of dynamic change, such that "ecological equilibrium" constitutes a kind of dynamic equilibrium and follows the law of material recycling and dynamic equilibrium (Ma) [5]. Therefore, the equilibrium evolution of the ecosystem requires the system components to form a comprehensive evolutionary synergy by constituting coupling relationships, which then adaptively regulate the structure and function of the system through the positive- and negative-feedback mechanisms. In this way, chaos is replaced by order, and the system presents an "S" growth curve during its evolutionary process (this is mathematically expressed in the logistics model). The "S-shaped" evolutionary growth of an ecosystem disrupts the existing equilibrium and continuously alternates evolution when forming a new equilibrium, so as to achieve the coordination of the spatiotemporal coupling relationship of the system (Wang) [40].

2.3.2. Geography: Spatial Equilibrium. Geography has always adhered to the perspective of the coordination of human-land relationships in the exploration of geospatial states. Meanwhile, the coordination relationship between the intensity of regional development and the carrying capacity of the environment [41–44] can be regarded as balanced or imbalanced.

Compared with the single spatial target model of spatial economics, which exclusively focuses on economic growth, the geographical research perspective places greater emphasis on the study of the "spatially balanced" development model from the aspects of politics, economy, society, culture, and ecological environment to improve the deep understanding of the "spatial equilibrium" of the system in the practice of rational planning in the land space [45–47]. Jie Fan constructed "spatial equilibrium models" in 2007 and 2012, respectively, both of which had a unique logic. One is a three-dimensional spatial equilibrium model based on "economic single equilibrium," while the other is a comprehensive spatial equilibrium model based on the comprehensive economic-ecological-environmental benefits and the production-distribution-consumption three-dimensional system [48]. These models focus on the evaluation of the carrying capacity of resources and the environment under the influence of the coupling mechanism of the human-earth system (Jie Fan, Kan Zhou, Dong Chen).

The above research results reflect a paradigm shift in geographical research; that is to say, the geographical research on "spatial equilibrium" has evolved from the initial exploration of a single "spatial equilibrium" in traditional economic geography into a regionally comprehensive "spatial equilibrium" based on the harmonious development of the relationship between man and Earth. Through the development and application of research methods such as systems science and big geographic data, the process and driving mechanism of regional "spatial equilibrium" factors will be further studied.

3. Summary

As a typical social-ecological system (SES) [5–9], he evolution and development of the tourism ecosystem has been the focus of academic attention in geography, ecology, economics, management, sociology, philosophy, and other disciplines due to its complexity, spatial heterogeneity, and imbalances [10–12]. From the perspective of evolving research on equilibrium in the above disciplines, the same method of discussing the evolution of balance to construct the development theory of equilibrium is always selected, regardless of whether the investigation is from the perspective of ideology, technology, space, and so on. Thus, from a multidisciplinary perspective, there needs to be a focus on the base of "balance" and "equilibrium" to discuss how to construct the "spatial equilibrium" of the tourism ecosystem and its theoretical construction.

4. The Connotations and Characteristics of the "Spatial Equilibrium" of the Tourism Ecosystem

The "spatial equilibrium" of the tourism ecosystem needs to be defined. First of all, in terms of the research on the development of the "spatial equilibrium" of the tourism ecosystem, different disciplines have tried to define this concept based on their ontology and through the use of various research perspectives. In fact, no matter how the division of perspectives and criteria are selected and determined, the definition and research are premised on two assumptions. First, the tourism ecosystem itself, as a giant open and complex system, covers tourist sources, tourist passages, and tourist destinations, including resource development and protection, the tourism economy, the contradictions between social and ecological benefits, and the contradictions between tourism supply and demand.

Second, these can be condensed into two contradictions: between people and nature and between people and people. These contradictions are universal and absolute, and found in all the evolutionary processes of the tourism ecosystem. The interactions between these contradictions promote the evolution of the tourism ecosystem (As Mao Zedong said: "We Marxists believe that imbalance, contradiction, struggle and development are absolute, while balance and stillness are relative") [49].

The tourism ecosystem—the definition of a tourism ecosystem varies in three angles. From the tourist-centred point of view, the tourism ecosystem is the systemic wholeness of various tourist destinations and external conditions such as natural, social, and cultural conditions that enable tourism activities to exist, proceed, and develop. From the perspective of tourism resources as the centre, the tourism ecosystem refers to the system of natural ecological, cultural, and social factors influencing tourism resources. From the perspective of a tourism destination in time and space as the centre, it is built around tourism activities. The tourism destination system constitutes the elements formed on a basis of the interaction between the coupling of both the specific structure and function and with the external environment to realize the material circulation, energy flow, and information transfer to adapt to the external environment, to achieve internal and external balance system of a complex system. The third definition of the concept of "tourism ecosystem" is adopted in this paper specifically. It is a complex and dynamic evolution system built on tourism activities. Due to the inherent complexity of its characteristics, it cannot be studied in an isolation rather, and it needs to be studied in a systematic manner. However, static ways of thinking and one-dimensional research approaches, such as those of the widely used static mechanical equilibrium models, cannot satisfy the status quo of the tourism ecosystem. As a result, in the study field of tourism ecosystem, a unified theoretical paradigm and common platform has yet to form. On this basis, a beneficial research approach is to construct the theoretical framework and methodology system of the "spatial equilibrium" of the tourism ecosystem based on the paradigm of ecological civilization theory and systematic scientific research. Moreover, the spatial-temporal differentiation characteristics, evolution driving force, dynamic process, and dynamic mechanism of the tourism ecosystem need to be further explored. Finally, the coupling interaction mechanism between the "spatial equilibrium" of the tourism ecosystem and regional ecological-social-economic development warrants further discussion.

4.1. The Connotations of Spatial Balance and Spatial Equilibrium of the Tourism Ecosystem. Many factors of space-time change have less or more contributed to the realization of the "spatial equilibrium" of the tourism ecosystem. These include, but are not limited to, the development of tourism resources, investment in tourism technology, tourism policy support, the upgrading of tourism industry structure, population migration, and capital flow. This is an S-shaped evolutional process of energy transformation from potential energy to kinetic energy, which gradually exhausts to potential energy again. It must be made clear here that the term "spatial equilibrium" of the tourism ecosystem is set for the discussion of whether the system is in a state of balanced or unbalanced in the process of transformation. Hence, the two concepts of "balance" and "equilibrium" are involved here.

The "spatial equilibrium" of the tourism ecosystem means that the system remains in its original state following transformation; that is, it does not change over time. If time is determined by $t\,t'$, then the state $X(t') = \mathrm{X}(\mathrm{t})$. Expressed in algebraic terms, if $\mathrm{T}(X) = X$, then X is the equilibrium state under T.

The "spatial equilibrium" state of the tourism ecosystem is kind of invariance, and all the state components are invariable. In terms of derivatives, if a state has only two components, x and y, the equilibrium is $= 0, = 0$.

This is expressed by a system of differential equations as follows:

Differential equations are given as follows:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = 2x - y^2, \qquad \frac{\mathrm{d}y}{\mathrm{d}t} = xy - \frac{1}{2}. \tag{1}$$

The equations are in equilibrium at the state point of (1/2)1, because $x = 1/2$, when $\mathrm{y} = 1$, $\mathrm{d}x/\mathrm{d}t = \mathrm{d}y/\mathrm{d}t = 0$.

This point in the state space in equilibrium is referred to as the equilibrium point. If the system is not subjected to other interferences, the state of the system should remain at this point (Zexian Yan).

On this premise, we can gain insights into the differences and correlations between the connotations of "balance" and "equilibrium."

First, regarding the ability to balance and the state of equilibrium, the "spatial balance" of the tourism ecosystem describes the system's capabilities. The system balance can be mathematically expressed and measured using the differential equations detailed above. In contrast, the "spatial equilibrium" of the tourism ecosystem describes its specific state at specific point in time. The main difference between the two is that the former emphasizes "ability," while the latter emphasizes "state."

Second, the capability of balance determines the state of equilibrium. For a tourism ecosystem, its "spatial balance" should be a measurable point under its stability. The "spatial balance" and "spatial equilibrium" of the tourism ecosystem stem from the integrity of the structure and function of the system. The system's capacity for self-regulation is the common basis of its system balance and equilibrium, both of which depend on biodiversity, which is the direct link between the two.

Third, the state of equilibrium contains many points of balances. A system balance is a point, while the equilibrium is the line. Just as "wave-particle duality" tells us that particles are the primary form matter exists in, waves are another form matter can take. This way of thinking profoundly reveals the evolutionary essence of the "spatial equilibrium" of tourism ecosystems, namely, that it contains several

balances. The "spatial balance" of the tourism ecosystem is the "particle," while the "spatial equilibrium" of the system is the "wave" (Figure 1). While balance is a certain space-time point of the system, equilibrium is the evolution curve composed of the system's countless balance points. In the process of movement, equilibrium, once formed, is destroyed by development. Similar views have been expounded from the perspective of ecology and philosophy (see above). Although it is always possible to determine the state of the system following the previous measurement, the system is influenced by unpredictable factors. As a result, the sustainable development of the tourist destination itself is a concept that is difficult to measure and evaluate [50]. In socio-ecosystem theory, sustainability is regarded as an evolutionary process, not an end goal [51]. At the same time, the uncertainty principle is an objective limitation of our cognition: the exact trajectory of the balance point of the tourism ecosystem can usually be used to observe the short-term evolution trend of the system, although it is impossible to accurately predict the future long-term evolution direction of system. A single balance point is nothing more than a formal statement of equilibrium probability. The amplitude determines the probability of finding the particle at a certain location.

4.2. The Characteristics of "Spatial Equilibrium" of the Tourism Ecosystem. As an open system, the succession and renewal of functions and structures of the tourism ecosystem are maintained by the continuous flow of material, energy, and information. The system state continuously changes; as a result, the "spatial equilibrium" of the tourism ecosystem forms a dynamic equilibrium. This dynamic "spatial equilibrium" is also reflected in the local and tolerable disturbances to the tourism ecosystem that act on the whole through positive and negative feedback and are regulated and compensated for by the system regulation mechanism.

When the external interference factors exceed the overall regulation limit of the tourism ecosystem, its self-regulation mechanism will fail, meaning that the "spatial equilibrium" of the system will not be restored. From this, we can discern the basic characteristics of "spatial equilibrium" in a tourism ecosystem (Jian Wang):

(1) Equilibrium is relative and dynamic. Compared with balance, equilibrium is a dynamic, nonabsolute value that is fixed in a state of continuous evolution. As a typical "natural-economic-social" composite ecosystem, the tourism ecosystem has a systemic internal stability mechanism stemming from its own positive and negative feedback (Chunyu Yang), which can resist the constant disturbance of the external environment (i.e., extreme climate conditions and natural disasters). External disturbances force the tourism ecosystem to depart from the equilibrium point formed by the internal stability mechanism, which comes from the adaptability of the tourism ecosystem [52] (detailed below). At this point, the internal stability mechanism regulates the system by comparing the input and output differences of the tourism ecosystem to maintain its equilibrium state, or at the very least ensure it remains within the scope of the structural existence permits.

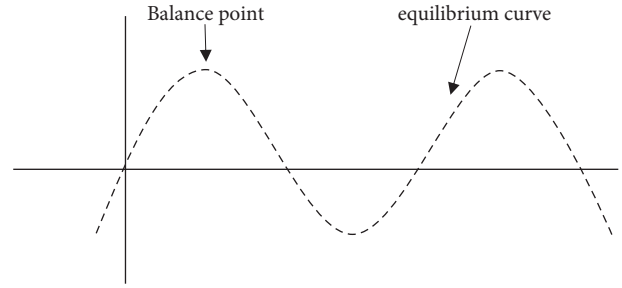

Figure 1: Wave-particle duality of "spatial equilibrium" in the tourism ecosystem.

(2) Equilibrium exhibits the characteristics of oscillation in a short term, although it charts a trend of periodicity in the long run. The adaptive function of the system formed by the stabilization mechanism in the tourism ecosystem ensures that its evolution process remains in a state of dynamic equilibrium. As mentioned above, the dynamic and nonlinearity of the evolutionary process of tourism ecosystems are its intrinsic characteristics. The external characteristics are presented as short-term oscillation and the long-term "periodic" curve of evolution Chunyu Yang. The premise of this evolutionary process is that oscillation and periodicity cannot exceed the systems' limits; otherwise, the dynamic balance of the system will be disrupted, leading to the collapse of the system.

From the perspectives of physics and systems science, based on the tourism ecosystem "oscillation" evolution process, we can find that under the action of inertia (the inertial effect of the tourism ecosystem comes from the cumulative effect and time-delay phenomenon in the process of system evolution), the oscillation evolution of the system not disrupts the original equilibrium, but also cannot immediately reach the new equilibrium point formed by the stabilization mechanism. Rather, it gradually moves away from the new equilibrium position until it is returned back to the balance position by the elastic-like force (If the elastic force disappears, it means that the tourism ecosystem has entered a new equilibrium state or the system has collapsed in evolution. The further the system evolves from its equilibrium point, the greater the corresponding rebound force is, so that the tourism ecosystem beyond the equilibrium point can no longer continue to move forward and return to the equilibrium point, and it is getting faster and faster. When it reaches the equilibrium point due to inertia, the action crosses the equilibrium point again, but in the opposite direction of the first transcendence.) stemming from the system's internal stability mechanism. From this, we can see that the "oscillation" of the tourism ecosystem is an evolutionary process that has undergone many repeated attenuation oscillations and gradually returned a state of

balance to the system. The system sequentially realizes self-succession and renewal through the dissipative evolution process of "equilibrium-to-oscillation-to-new equilibrium" (Figure 2), thereby providing a premise for us to dynamically understand the evolution mechanism through the characteristics and external manifestations of the "spatial equilibrium" evolution of tourism ecosystem.

5. "Spatial Equilibrium" Research Method for the Tourism Ecosystem

5.1. "Spatial Equilibrium" Mechanism of the Tourism Ecosystem. The difference of growth factors [53, 54] including resource endowments' growth factors, transportation locations' growth factors, infrastructure's growth factors, the profit-seeking and decentralized [55] of tourism policy formulation, and the Benefit Game between tourism development entities produces the "spatial disorders." These factors all exert a significant influence on the sustainable development of tourism destinations [56, 57]. Moreover, all of the constituent elements of the tourism ecosystem present in the process of its evolution and development reflect its existence in the form of "individual physical strength" comprehensively forming the "coupling force" [58]. This force then influences the evolutionary trend [18] that the system follows, pointing to the generative theory that "equilibrium" is both a systematic form of motion and a systematic motion mechanism.

First, the coupling force reveals the dynamic mechanism of "spatial balance" in the tourism ecosystem.

Each component of the tourism ecosystem affects the evolution process of the system through its own forces. These elements include differences in natural resource endowments, ecological stability, dynamic changes in environmental carrying capacity, global climate change, exchange rate changes, sudden terrorist incidents, the harmony of political and ecological environment between countries, the advantages and disadvantages of internal and external transportation conditions in tourism areas, the status and importance of tourism industry in regional economic development, the supply of tourism products and tourism demand, and sudden major public health emergencies, such as SARS and COVID-19. However, the constituent forces of tourism ecosystems do not directly impact the process of system evolution and replacement; instead, they indirectly form a comprehensive influence through the interactions between the constituent elements of the system or form a synergy-coupling force [19] to determine how the system evolves (Chunyu Yang). In fact, the positive and passive feedback loops (the nonlinear interaction of the self-organizing process is mainly manifested by the feedback relationship between the components of the system and between the components and the structure of the system, including the positive-feedback loop and the negative-feedback loop. (Zexian Yan. Introduction to System Science-Exploration of Complexity [M]. Beijing: People's Publishing House, 2006, P346)) [59–61] are formed based on the coupling relationships between the constituent elements of the tourism ecosystem. In the tourism ecosystems evolution process, these relationships form a "push-and-pull" interactive force. This leads the tourism ecosystem to "rise and fall" around its spatial evolution balance point, thus providing the requisite development momentum for the evolution of the tourism ecosystem.

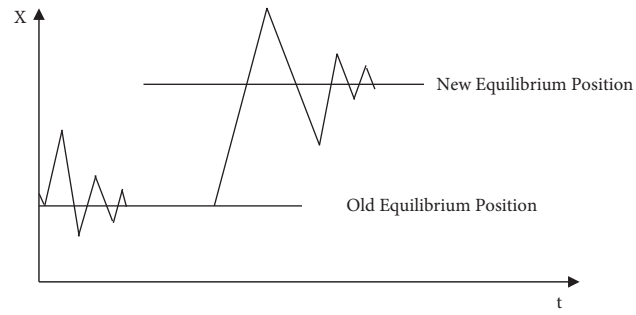

Figure 2: Sketch map of damped oscillation.

Secondly, the coupling force determines the internal stability mechanism of the "spatial balance" of the tourism ecosystem.

By investigating the "spatial equilibrium" of the tourism ecosystem from the perspective of tourism resources, it can be seen that the maximization of tourism resource efficiency is always in the pursuit of certain predefined goals. On the one hand, the tourism economy, driven by the desire for efficiency, will lead to an imbalance occupation of tourism resources. On the other hand, the tourism economy strives for a balance of resource ownership under the constraints of sustainable development concepts and the related systems. The above two modes of action are the result of the evolution of the tourism ecosystem and reaching equilibrium at a certain time. The allocation of tourism resources is carried out through market competition and redistribution. When the above information is reflected in the market, the price of tourism resources promotes the transition of tourism resources in the tourism trade exchange from an unbalanced state to a balanced state. It should be noted that it is not feasible to retrospectively analyze the one-way causal relationship between all the components of the tourism ecosystem in the "spatial equilibrium" evolution process. However, through theoretical analysis, it is possible to comprehensively summarize the logical relationships that exist between the constituent elements of the tourism ecosystem at the macrolevel in the evolution of "spatial equilibrium." For example, when examining the comprehensive carrying capacity of the tourism ecosystem in terms of "spatial equilibrium," the entire system can only be analyzed by determining the reasonable value of the comprehensive carrying capacity of the system environment in advance. Even so, the reasonable value of the comprehensive carrying capacity of the system can be accurately confirmed.

By starting from the coupling relationships that form between the constituent elements of the system, it can be seen that the rise or fall in the number of tourists in the tourism ecosystem at different stages of spatial-temporal evolution has a corresponding impact on the environment's comprehensive carrying capacity. There is a reasonable

corresponding threshold of the comprehensive bearing capacity of the environment related to the positive- and negative-feedback mechanisms of the system. It should be noted here that this threshold is a value in the ideal state of the system; more specifically, it is a reasonable value of the corresponding tourist ecosystem visitor reception through the coupling mechanism. It is this coupling mechanism that determines the existence of "spatial equilibrium points" in different evolutionary periods of tourism ecosystems and maintains the feedback regulation of tourism ecosystems when tourism ecosystems deviate from the balance points. In fact, the coupling relationships between the constituent elements of the tourism ecosystem determine the existence of the balance point. According to Ashby's cybernetic theory and method [62], we can reduce the number of balance points from the interaction model of the coupling relationship of the tourism ecosystem and, in doing so, determine whether the feedback from the stability of the balance point is positive or negative. In this way, the coupling force of tourism ecosystems can effectively explain the origin of the internal stability mechanism, including its purpose itself [21].

Finally, the coupling force indicates the transformation mechanism of the "spatial balance" of the tourism ecosystem.

The "spatial equilibrium" and harmonious development of the tourism ecosystem are both historical category. The state and magnitude of the "spatial equilibrium" of the tourism ecosystem differ across different evolutionary periods, as is the case with its connotations and the external performance of its balanced development (Chen Gong). However, in the "spatial equilibrium" development process of the tourism ecosystem, the contradiction between maximizing the "utilization efficiency" of tourism resources and the "principle of fairness" emphasized in sustainable development is akin to Kant's antinomy, which has long been a key point of contradiction plaguing the development of human society. From a logical point of view, tourism resources can be categorized based on their efficiency and fairness, and then merged to form a combination of the equilibrium of tourism resources, thus forming a logical loop. The evolution of tourism ecosystems constitutes the cycles in this process. Hegel notes this in a profound way, proposing that this is the manner in which things exist.

The internal stability mechanism of the tourism ecosystem maintains equilibrium and balance in the system in the continuous progress of external interference and internal activities of the system. However, due to the multicausal nature of the phased threshold of phylogenetic evolution, emergencies can easily interrupt the steady changes that occur in the tourism ecosystem and turn them into another steady state, namely, the transformation of homeostasis [63]. The succession of tourism ecosystems is also a matter of inabilities and multistability. Therefore, the tourism ecosystem is unpredictable, self-organizing, and nonlinear, and exhibits threshold effects, historical dependence, and multistable mechanisms [64, 65].

5.2. The "Spatial Equilibrium" Model of the Tourism Ecosystem. Based on the above analysis of the logical system of "spatial equilibrium" connotation and characteristics of the tourism ecosystem, this article seeks to explore the rational development and utilization efficiency of tourism resources based on the function and value of the system resource elements, with reference to the logical trajectory of man and nature.

Based on the evolutionary path of man and society, we can explore the intergenerational equity use of tourism resources. More specifically, through the use of multidisciplinary spatial equilibrium theory and systematic scientific dynamic mechanism, it is possible to find the dynamic balance point and equilibrium state of the evolution of the tourism ecosystem and achieve efficiency and fairness. This is the "spatial equilibrium" model of the tourism ecosystem constructed in the paper [22].

The evolution curve in the model diagram is a highly abstract "*S*"-shaped evolution curve pertaining to the "spatial equilibrium" of the tourism ecosystem (Figure 3) [23]. The natural order is seen as a negative-feedback mechanism that functions to limit the overloading of system resources. The system in the evolution process requires a high degree of tourism resource utilization efficiency from the natural system. At the same time, the social system develops equitably and the economic and social systems based on market allocation are taken as a supervisory guarantee system to ensure fair use within and between generations. The two visible and invisible hands mentioned above act together during the evolutionary process of the system, alternately making the tourism ecosystem either over-loaded or insufficient.

From this, it can be concluded that the evolution process of the tourism ecosystem takes the shape of an evolution curve around its "spatial equilibrium." This evolution curve has generated related theories, such as tourism life cycle, tourism environment carrying capacity, tourism ecological footprint, tourism ecological efficiency and compensation, and sustainable tourism development, among others. Just as efficiency is the theoretical basis of Adam Smith's economics, fairness is the theoretical basis of Marx's economics. Analogously, the theory of "spatial equilibrium" is the theoretical basis of the evolution of tourism ecosystems. Tourism resources, which are the material basis for the evolution of tourism ecosystems, have always been derived from two channels. The first channel is to increase the utilization efficiency of natural systems and expand ecological ownership, while the second is to strive to structure a social system that can coordinate the demands of contemporary stakeholders through multiparty games and ensure that there is equitable use between generations.

Based on the meaning of "spatial equilibrium" in the tourism ecosystem, this study proposes the axiomatic definition of $\mathrm{Te} = C\ (\mathrm{Ec})$, which is the "spatial equilibrium" of the tourism ecosystem. This is proposed on the basis of analyzing the characteristics of the "spatial equilibrium" and the graph of evolutionary equilibrium function [24].

Ec represents the tourism ecosystem's capacity, which is the initial value of the system state. It is an independent or endogenous variable.

Te represents the tourism equilibrium of the tourism ecosystem, which is the system state value. It is the dependent or exogenous variable.

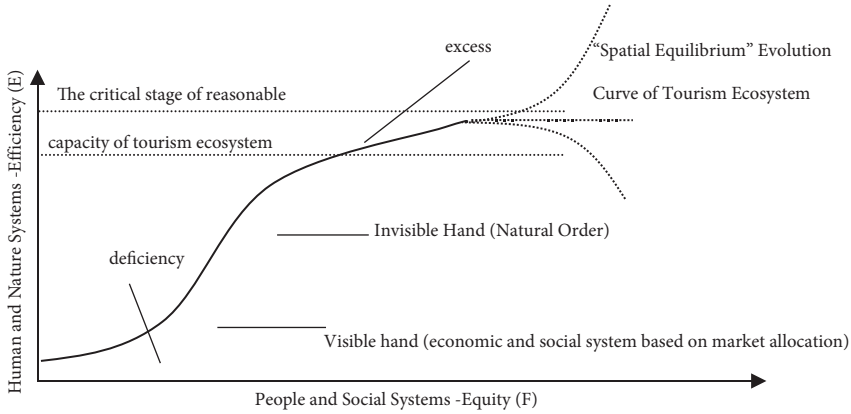

Figure 3: Spatial equilibrium development model of the tourism ecosystem.

C indicates the coupling relationship (Coupling) between the components inside and outside of the tourism ecosystem, and = indicates the "spatial equilibrium" state of the tourism ecosystem:

(1) In the comprehensive environmental carrying capacity (Ec) and coupling relationship (C) of the tourism ecosystem, one is the power source and the other is the driving force.

(2) The comprehensive environmental carrying capacity (Ec) of the tourism ecosystem is the independent variable, while the spatial balance point (Te) of the tourism ecosystem is the dependent variable.

(3) "=" and "Ec" are objects, while "Te" and "C" are subjects.

The object is the existence of the system, which is not influenced by people's desire for it to develop. The comprehensive environmental carrying capacity (Ec) of the tourism ecosystem is the initial value. The initial conditions of the tourism ecosystem are determined prior to it coming into existence, but a new evolutionary development started due to the intervention of human activities. "=" reflects the "evolutionary order" of the "spatial equilibrium" of the tourism ecosystem. Regardless of the similarities and differences in the intensity and direction of the internal and external forces of the system, a comprehensive evolutionary force will eventually be formed the "coupling force" to determine the system's evolutionary state and the future development trend it will follow.

Definition of Te = C (Ec) : The "spatial equilibrium" function model of the tourism ecosystem refers to the initial state (Ec) of the total environmental carrying capacity of the tourism ecosystem, which then evolves to form a tourism ecosystem based on the coupling relationship between internal and external elements' (C) "spatial equilibrium" state (=).

There are three stages in the evolution and development process of the "spatial equilibrium" of the tourism ecosystem:

(1) Equilibrium state Te=C (Ec).

(2) Overload state Te > C (Ec).

(3) Hysteresis state Te < C (Ec).

Among them, (1) Equilibrium state: Te = C (Ec). This is when the evolution and development of the tourism ecosystem meet this condition, which is compatible with its comprehensive environmental carrying capacity. The natural, social, economic, cultural, and institutional settings are aligned with the interests of all participants in the system. The entire tourism ecosystem feeds back to form a virtuous cycle; the energy input and output are balanced, the system's functions and structure are stable, and sustainable development momentum is achieved.

(2) Overload state Te > *C* (Ec). When this state occurs, the evolution and development of the tourism ecosystem deviates from the spatial equilibrium of the system and exceeds the system's total environmental carrying capacity. In the short term, the ecological occupation transgresses the spatial equilibrium point of the tourism ecosystem. In the case of unsustainable development, the ecosystem may collapse where there is a long-term deviation from the "spatial equilibrium" that exceeds the carrying limit of the ecosystem.

(3) Hysteresis state Te < *C* (Ec). When this state occurs, the insufficiency of the evolution of the tourism ecosystem and its development result in a diminished tourism resource utilization rate. This forms an evolutionary cycle in which there is sluggish development of the tourism ecosystem.

The first system stated above offers a positive solution for the evolution and development of the tourism ecosystem. Meanwhile, the second and third pertain to an excessive or lack of development and use of the system, which fails to achieve the "Pareto optimal solution" of spatial equilibrium.

6. Summary and Future Prospects

6.1. Summary. This article draws on multidisciplinary spatial equilibrium theory and the dynamic mechanism of system science to research the efficiency and fairness of the evolution of the development of the tourism ecosystem. In the process, it tries to build the basic idea and framework of the "spatial equilibrium" theory of tourism ecosystems. The results show that the construction of the "spatial equilibrium" of the tourism ecosystem model should be the initial state of the comprehensive environmental carrying capacity

of the tourism ecosystem. This can then evolve to form a tourism ecosystem based on the coupling relationship between internal and external elements' "spatial equilibrium" state. In this state, the left end of the spatial equilibrium model of the tourism ecosystem is the spatial balance point, while the right end is the comprehensive environmental carrying capacity of the tourism ecosystem. These two ends encompass all the connotations and extensions of the natural and social subsystems involved in the tourism ecosystem. Referring to the capacity of carrying all kinds of material and spiritual bodies used in tourism, the comprehensive environmental carrying capacity of the tourism ecosystem is the initial point and development basis of the system evolution. The spatial balance point and its state model are the methods, tools, and structures employed in the theoretical research of the evolution of tourism ecosystems; with their development, the basic idea and framework of the spatial equilibrium theory of the tourism ecosystem have been established.

6.2. Research Limitations and Future Prospects. In the above research, this is the first step is to construct a framework of the spatial equilibrium theory of the tourism ecosystem. Future studies should select corresponding cases to carry out a certain theoretical and empirical analysis. It is expected that they will further this theory in a systemic and in-depth fashion to form a complete theoretical "paradigm."

6.2.1. Exploring the Coupling Theory of the Tourism Ecosystem from the Perspective of Ecological Civilization. Adhering to the systems science and evolutionary generative theories, future studies should seek to observe, understand, explain, and predict the spatial equilibrium development trend, driving mechanism, and coupled evolution process of the tourism ecosystem. Moreover, they should try to construct the theory, method, and model of the coupling effect of the internal and external components of the tourism ecosystem in order to achieve a scientific understanding of the sustainable development status, evolution law, and temporal and spatial differentiation of different types of regions.

6.2.2. Building a Dynamic Threshold Measurement Model for the Spatially Balanced Development of the Tourism Ecosystem. Based on the "multisource data-model fusion" research method, the system science, modern measurement theory, and dynamic threshold model are introduced to construct a dynamic threshold measurement model and index system to pursue the spatially balanced development of tourism ecosystems. This is carried out to scientifically measure the degree and performance of the spatially balanced development of tourism ecosystems. It will provide the basis for scientifically defining the development status and evaluating the degree of the spatially balanced development of the tourism ecosystem.

6.2.3. Comprehensive Evaluation of the Correlation Effect of the Spatially Balanced Development of the Tourism Ecosystem. Through spatial autocorrelation analysis and spatial heterogeneity analysis, the spatial correlation, and the effects of spatial flow, spatial spillover, and agglomeration of the balanced development of tourism ecosystems can be analyzed. Doing so will reveal the characteristics of regional differences in the evolution process and objectively evaluate the status quo, and changes and trends present in the balanced development of tourism ecosystems in space. This will provide the premise and basis for exploring the system regulation mechanism and governance path.

6.2.4. Creating an Adaptive Governance Model for the Spatially Balanced Development of the Tourism Ecosystem. Based on the complexity and uncertainty of the evolution of the tourism ecosystem and the difficulties experienced exerting control due to the conflict of multiple stakeholders' interests, a complex analysis framework involving many human factors and natural factors is created. This framework pays close attention to the nonlinear relationship between adaptive subjects. From this, it expected that an adaptive governance model that optimizes the control mechanism for the spatially balanced development of the tourism ecosystem and negotiates with multiple subjects will be established. This will highlight the downward causal relationship of multiple levels, along with the monitoring and early warning control mechanism.

Data Availability

Our research did not use data to analyze the study. In our research, a nonlinear, dynamic, evolutionary, systematic thinking and axiomatic theories are combined to constructed the internal stable evolution mechanism and abstracted model of tourism ecosystem in order to form a set of explanatory theoretical system. We constructed a new theory from interdisciplinary review. The theories cited in the article can be found in the reference.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Creating Sustainable Cultural Industries: The Perspective of Artificial Intelligence and Global Value Chain

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In the era of artificial intelligence (AI), cultural industries have introduced new development opportunities, and their global value chain (GVC) position is receiving more attention. This study uses panel data from global cross-borders from 56 countries (regions) as the research sample to empirically analyze the impact of AI on improving the GVC position of cultural industries using the double fixed effects regression model and examines the heterogeneity effect. The results confirm that there is a significant positive correlation between AI and the GVC position of cultural industries. The mechanism test shows that AI impacts the division of labor position in the GVC of cultural industries mainly through technological innovation and the industrial structure. Heterogeneity analysis shows that AI has a significant effect on promoting the cultural industry's GVC position in high-income countries (regions) but it has no significant effect on low- and middle-income countries (regions). The results of this study can provide a useful reference for improving the division of labor positions in the GVC and better promoting the development of cultural industries.

1. Introduction

In the era of the digital economy, a new round of scientific and technological revolutions represented by AI is leading to the transformation of social productivity and the reconstruction of the GVC worldwide. At present, the world's major developed countries have begun to strategically deploy AI technology development at the national level, and AI has become a new competitive focus among major countries. With the rise of new technologies such as cloud computing, the Internet of Things, and big data, the development of AI has entered a new stage and is leading the transformation of cultural industries in many fields. The "culture + AI" industry continues to gain momentum. The deep integration of AI technologies such as deep learning, face recognition, intelligent search, and VR with cultural industries has created a new model of content production, dissemination, and consumption. Countries around the world are participating in a new round of global industrial competition with the help of the integrated development of cultural industries and AI technology. Therefore, the value chain of cultural industries is changing. It has become a general trend to introduce AI into content creation, development and production, marketing and promotion, communication and distribution, and consumer services in cultural industries.

Upgrades in AI technology will make it possible for the cultural industries to introduce a new development trend in technology and products, modes, and management. AI technology can promote the content creation of cultural products, improve the quality and efficiency of culture product development and production, transform the production mode of culture products on the production line as a whole, expand marketing channels and patterns, and integrate intelligence and personality. It has greatly enriched the means and content of communication and distribution, produced new experiential and scene-based consumption patterns, and promoted the innovation of cultural products. Furthermore, changes in the structure and organization of cultural industries have increased the size of cultural industries and expanded the layout area, and the integration of

new and old industries has increased in both depth and breadth.

With the development of Internet technology and improvements in national infrastructure, more intermediate products are crossing borders multiple times, the segmentation of product production is being further refined, and the features of GVC are increasingly obvious. Countries specialize in the production of specific products in the value chain due to their resource endowment advantages, thus forming the "smile curve" of the international division of production. The high-quality development of cultural industries is an important aspect of high-quality economic development. In this context, it is of great significance to explore how AI technology affects the GVC division pattern of cultural industries to take advantage of strategic opportunities for AI development and realize high-quality economic development. Thus, this study uses panel data from 56 countries or regions from 2010 to 2018 to empirically analyze the impact of AI on the division position of labor in the GVC of cultural industries. Based on testing the robustness of the empirical results, the influence mechanisms of the impact of AI on improving the division position of labor in the GVC are discussed, and the influence of heterogeneity based on different stages of economic development is analyzed.

2. Literature Review

AI is a core issue in economic and social development. In 1940, Isaac Asimov proposed the "Three Principles of Robots," aiming to protect human beings from the threat of robots [1]. After reviewing the literature, AI can be defined in the following two ways. First, at the technical level, AI is based on fuzzy logic, natural language processing technology, genetic algorithms, convolutional neural networks, adversarial generative networks, and artificial neural networks, and continues to develop [2–4]. Second, at the level of content, AI aims to simulate, extend, and expand human intelligence by using machines, the core of which is the learning of human thinking methods and processes by machines [5].

Research on AI and cultural industries focuses on three main aspects. First, it discusses the relationship between scientific and technological innovation and new forms of cultural industries and the role of science and technology in promoting the reform of cultural industries. This study indicates that the development of culture and technology promotes the repeated and orderly combination and extended use of cultural content to create new forms of products and advance their development to a higher level [6]. Second, the innovative application of AI technology in cultural industries and its impact on industrial development are discussed. Research indicates that the science of machine behavior is booming, using interdisciplinary research on machine behavior and related issues to explore how AI has evolved and what impact it may have on human society [7]. From the perspective of AI empowering cultural industries to improve quality and efficiency, related studies are carried out on the following aspects. At the macro-level, research shows that AI, big data, cloud computing, and Internet technology are highly compatible with the necessary conditions for the development of cultural industries, facilitating the accelerated integration of the cultural industry chain, the technique chain, and the innovation chain, thus realizing intelligent innovation and digital transformation [8, 9]. At the micro-level, with the aid of 5G technology and AI technology, diversified cultural equipment terminals augment the cultural experience of users [10]. Shahzad et al. [11] believed that smart TVs, mobile phones, smartwatches, and other devices as well as AR and VR technologies can better understand user psychology and provide experiential consumption of cultural services. In addition, from the perspective of the integrated development of old and new industries, such as the progress of the digital music industry, AI, machine learning, and big data make the coevolution of streaming music and live music possible [12]. Finally, in terms of AI's impact on economic growth, some scholars use the task-based model to examine the application of AI technology with the theoretical analysis framework of economics. Pioneering exploration has been conducted on how to achieve balanced economic growth under the application of AI technology, how the advancement of AI technology changes income factors of factor, and whether it leads to inequality [13].

Scholars have studied the division of labor in the GVC from different perspectives, including its measurement of the division of labor position in the value chain and influencing factors. Scholars have proposed a variety of indicators for measuring the division of labor in the GVC, such as the degree of upstream and downstream and the complexity of exports [14, 15]. Hummels et al. [16] measured vertical specialization level and growth and defined vertical specialization with import intermediate input as a key factor when producing export products. However, their calculation method controlled strict assumptions. Daudin et al. [17] redistributed the trade flow to the original input-production industries and countries and proposed a new standard for measuring value-added trade in international trade. Koopman et al. [18] assumed that there is no two-way trade of intermediate goods, normalized the calculated indicators in a linear combination, decomposed the export trade of a single decision-making unit into four parts, and proposed the KWW model, which has been widely used by scholars. In terms of the factors influencing the division of labor position in the GVC, the technological level and endowment structure of factors are crucial for a country to participate in the division of labor in the GVC [19]. According to the competitive advantage staged development model, the driving force of position improvement in the GVC is the transformation from simple factor capital to innovative capital. At the same time, the GVC position will also affect the international flow of technological innovation. There is a causal relationship between these variables [20]. Based on an empirical study of China and Mexico, Gallagher and Shafaeddin [21] concluded that technological upgrading and independent innovation are important factors in promoting a country's deep participation in the division of labor in the GVC. In addition, academics have studied the impact of infrastructure on the GVC position. The infrastructure

construction process is often accompanied by the redistribution of many resource factors, such as capital, talent, and technology [22–25]. Infrastructure connectivity can promote trade and investment facilitation and reduce the cost of factor flow [26–28]. Some scholars believe that intellectual property protection is an important factor that affects the innovation capacity of service industries and improving the level of intellectual property protection is conducive to the technological innovation of service industries [29, 30]. By establishing a multicountry and multistage GVC competition model, many studies have proposed that in the division of the labor process in the GVC, improving the technological level and reducing the factor cost are the main ways to promote the upgrading of a country's GVC [31, 32]. There is an inverted *U*-shaped relationship between R&D subsidies and the GVC position, and Internet penetration can weaken the inverted *U*-shaped relationship [33]. Furthermore, the study shows that foreign direct investment (FDI) is an important factor affecting the participation of the division of labor in the GVC of the digital services industry. FDI can improve the technological level of capital inflow to countries through the technology spillover effect, deepen a country's participation in the GVC, and effectively improve a country's division of labor position of a country in the GVC [34, 35].

Based on the statement above, AI technology has great potential for application to cultural industries. Scholars have conducted many studies on how AI can promote the development of cultural industries, but there are at least two deficiencies in existing research: (1) Few studies examine the impact of AI on the development of cultural industries, and only at the technical level; there is a lack of research on GVC position and quantitative analysis of the impact of AI on cultural industries from the trade level. (2) There is a lack of research on how AI technology has a heterogeneous impact on the development of cultural industries in high-income and low- and middle-income countries. Based on the theory of GVC and the panel data of 56 countries and regions from 2010 to 2018, this study empirically analyzes the impact of AI on improving the GVC position of cultural industries in each country. For countries at different levels of economic development, this effect shows heterogeneity. Heterogeneity analysis is also carried out for different stages of economic development. These research results have theoretical value and practical significance for the development of AI and the formulation of relevant policies, the high-quality development of cultural industries, and path selection for promoting the GVC position and provide a reference for upgrading the GVC of cultural industries.

The rest of the article is organized as follows: Section 3 describes the research methods. The double fixed effects regression model is introduced to verify the impact of AI on the GVC position of cultural industries. Based on the benchmark regression analysis, endogeneity, and robustness test, the influence mechanisms of AI on the promotion of the GVC position of cultural industries are examined in Section 4. This step is followed by analyzing the influence of heterogeneity based on different stages of economic development, and the results of models are discussed. The conclusions and some practical suggestions for upgrading the GVC of cultural industries are outlined in Section 6.

3. Research Methods

3.1. Model Setup. Most previous studies have used an ordinary least squares (OLS) model that has only considered the explanatory factors of the division of labor position in the GVC of industries with cross-sectional data but has ignored some variables in the actual development and the disturbance to the GVC position of industries caused by individual and time changes. In practice, many factors affect the GVC position of cultural industries, such as international emergencies. These factors change with time but not with countries and regions. Therefore, the time fixed effect is included in the model to ensure the accuracy of the analysis [36]. At the same time, different countries and regions show differences in unobservable factors that do not change over time, such as geographical location and consumption habits. Therefore, this study adds an individual fixed effect to the model [36]. To verify the impact of AI on the GVC position of cultural industries, this study constructs a double fixed effects regression model, and the econometric model is as follows:

$$\mathrm{GVC}_{it} = \beta_0 + \beta_1 \mathrm{AI}_{it} + \beta Z_{it} + \theta_t + \gamma_i + \varepsilon_{it}, \quad (1)$$

where i is a country or region, t stands for year, GVC_{it} is the explained variable, representing the GVC position of cultural industries in country (region) i in year t, AI_{it} is the explanatory variable, representing the level of AI development of country (region) i in year t, β is the parameter to be estimated, Z_{it} indicates other control variables affecting the cultural industries, ε_{it} is a random disturbance term, θ_t is the time fixed effect, and γ_i is an individual fixed effect.

3.2. Description of Variables

3.2.1. Explained Variable. The explained variable in this study is the GVC position index of cultural industries, which represents the position of a country or region's cultural industries in the GVC. The GVC position can reflect the degree to which cultural industries participate the GVC production activities of a country (region). Koopman et al. [37] proposed a method to calculate the GVC position using value-added trade to measure the position of the producers of the industries in the GVC. Wang et al. [38] calculated the GVC position index based on forward linkage and backward linkage, which is considered highly representative in academia. Following the method used by Wang et al., the production length of GVC based on forward and backward linkages can be expressed as follows:

$$\mathrm{PLv\_GVC} = \mathrm{PLvd\_GVC} + \mathrm{PLvi\_GVC} = \frac{\mathrm{Xv\_GVC}}{\mathrm{V\_GVC}}, \quad (2)$$

$$\mathrm{PLy\_GVC} = \mathrm{PLyd\_GVC} + \mathrm{PLyi\_GVC} = \frac{\mathrm{Xy\_GVC}}{\mathrm{Y\_GVC}}, \quad (3)$$

where PLvd_GVC represents the domestic length of the forward linkage GVC, PLvi_GVC represents the international length of the forward linkage GVC, Xv_GVC represents the total output caused by the export of intermediate goods, V_GVC represents all exports of intermediate goods, PLyd_GVC represents the domestic length of backward linkage GVC, PLyi_GVC represents the international length of backward linkage GVC, Xy_GVC represents the total output caused by initial input, Y_GVC represents the total output of production activities participating in GVC, PLv_GVC indicates the production length of the forward linkage GVC, and PLy_GVC indicates the production length of the backward linkage GVC.

The position of cultural industries in GVC production is expressed by using the ratio of the length of the forward linkage value chain and the length of the backward linkage value chain.

$$\text{GVCPs} = \frac{\text{PLv\_GVC}}{\text{PLy\_GVC}}, \tag{4}$$

where GVCPs represents the GVC position index of a country's or region's cultural industries. The larger the index is, the higher the position of the country's cultural industries in the GVC is.

3.2.2. Explanatory Variable. Currently, in terms of AI measurement, the measurement angle is still relatively singular. AI patent data are often taken as a proxy variable, reflecting the development characteristics and trends of the AI industry [39]. To analyze the influence of AI on cultural industries in countries (regions), this study follows the method of Agrawal et al. [40] and selects the ratio of the number of robots in countries (regions) to the number of jobs in service industries as the proxy variable of the level of AI development. The term "robot" in this study is defined by the International Organization for Standardization (ISO) as an automatic, programmable, multifunctional, and fixed or mobile industrial device consisting of three or more rotating shafts. Given the comparability and availability of data at the international level, the robot stock of countries and regions reported by the International Federation of Robotics (IFR) and the employment number of countries and regions in service industries according to the International Labor Organization are selected to measure the development level of AI.

3.2.3. Control Variables. The development level of AI is one of the complex and diverse factors influencing the position of cultural industries in the GVC, the development level of AI is only one of them. Control variables are designed based on the existing research. The selected control variables include human capital (HC), intellectual property protection (IPP), infrastructure quality (Infra), level of economic development (GDPP), and foreign direct investment (FDI).

(1) Human Capital (HC). As the level and quality of the elements in the GVC division system are important factors determining the position of the division of labor, human capital has a certain influence on the position of cultural industries in the GVC. This study uses the World Bank database of higher education enrolment rates to measure the level of human capital. The indicator calculates the number of university students as a percentage of the total postsecondary school-age population.

(2) Intellectual Property Protection (IPP). The intellectual property protection index of the Global Competitiveness Report of the World Economic Forum is adopted to measure the level of intellectual property protection of a country (region). The index ranges from 1 to 7, with a higher score indicating a higher level of intellectual property protection in an economy.

(3) Quality of Infrastructure (Infra). This study uses the global infrastructure quality index of countries (regions) in the Global Competitiveness Report of the World Economic Forum to measure infrastructure quality. The index ranges from 1 to 7, with a higher score indicating that an economy has a more developed infrastructure.

(4) Economic Development Level (GDPP). The level of economic development is measured by GDP per capita from the World Bank database.

(5) Foreign direct investment (FDI). The proportion of net FDI inflow in GDP from the World Bank database is used to measure the level of FDI utilization in a country or region.

3.3. Sample Selection and Data Sources. The original data on the GVC of cultural industries used in the econometric model in this study come from the OECD TiVA database mainly because it has the same statistical caliber and high authority at the country level. The database links the international input-output tables of 66 economies (countries and regions) and analyzes in detail all transactions between economies and industries in 45 industries from a global perspective. Among them, the statistical scope of cultural industries includes publishing, audiovisual, and broadcasting activities. Therefore, this study uses the UIBE-GVC database to calculate the GVC position index of cultural industries. In terms of the explanatory variable, AI development level data come from the IFR and the International Labor Organization. The stock of robots is one of the more commonly used measures of AI, and the IFR is the world's foremost authority on robot data. This study focuses on the aspects of information dissemination and services of cultural industries, excluding the production, sales, and leasing of telecommunications products. Then, the OECD TiVA database is matched with countries and regions in the IFR database and the World Bank database according to the 4th edition of the United Nations International Standard Industry Classification (ISIC Rev 4.0) and excludes Costa Rica, Luxembourg, the Slovak Republic, Brunei Darussalam, Cambodia, Cyprus, Kazakhstan, the Lao People's Democratic Republic, Myanmar, and Chinese Taipei. These 10 countries or regions do not have subsectors in the database.

In terms of control variables, IPP and Infra are from the World Bank database, while HC, GDPP, and FDI are from the World Economic Forum Global Competitiveness Report. GDPP and FDI are calculated according to the current US$. To reduce heteroscedasticity and multicollinearity among the data, the natural logarithm of HC, IPP, Infra, and GDPP is adopted in the model construction. Based on data availability and consistency, this study selected cultural industry data from the remaining 56 countries or regions in the OECD TiVA database from 2010 to 2018 to construct panel data. The descriptive statistics of the sample data are shown in Table 1 under the condition that consistency of statistical caliber follows and a few missing data are interpolated.

4. Empirical Results and Analysis

4.1. Benchmark Regression Analysis. In this study, considering the possible heteroscedasticity of the model, the Hausman test shows that the sample data have individual fixed effects and time fixed effects. Therefore, the double fixed effects regression model calculated by OLS is used to empirically test model (1). EViews 12 is used for calculating the results of model estimation. The benchmark regression results shown in Table 2 show the impact of AI development on the GVC position of cultural industries. Column (1) is the regression result of individual and time effects considering only the core variable AI; column (2) is the regression result of controlling the individual fixed effects of the model considering all the control variables included in the econometric model; and column (3) is the result of the double fixed effects regression model. The explanatory variable coefficients of columns (1), (2), and (3) in Table 2 are close, indicating that the results of the model estimation are relatively robust. The results of the double fixed effects model show that the regression coefficient between AI and GVCPs is 0.0047, and it is significant at the 1% level, indicating that AI development has a positive effect on the division of labor position of a country (region) in the GVC. In terms of the value of the regression coefficient, AI has a slightly weak positive impact on the GVC position of cultural industries. This situation is caused mainly by the fact that, AI is still in the weak development stage in cultural industries, that is, data intelligence. There is still much scope for developing the technology itself and its application fields, and the promotional role of cultural industries in the GVC has not been fully demonstrated.

4.2. Endogeneity and Robustness Tests

4.2.1. Endogeneity Test. The development of cultural industries in a country (region) has a limited impact on the development of AI in that area. However, to effectively solve the possible endogeneity problem caused by two-way causality in the model, this study uses EViews 12 to replace the original explanatory variable with a lagged explanatory variable with one lag period for the endogenous test and rerun the OLS regression, which can avoid inverse relationships. The regression results of instrumental variables reported in columns (1) to (3) of Table 3 show that AI plays a significant role in improving the GVC position of cultural industries at the 1% significance level, which is consistent with the previous results, indicating the validity of the research results.

4.2.2. Robustness Test. To further ensure the effectiveness of the impact of AI on the GVC position of cultural industries, this study uses EViews 12 to conduct a robustness test by changing the measure of the explanatory variable. At present, few studies conduct a quantitative analysis of AI, and there are limited references for the selection of alternative variables. This study changes the explanatory variable from AI to the citations of the AI academic achievements (AI_C) to measure AI development. AI_C refers to the citations of the AI topic category in the core collection database of Web of Science and the Scimago Journal & Country Rank (SJR) database. In addition, the logarithm of AI_C is taken to repeat the OLS regression. The regression results from columns (4) to (6) in Table 3 are basically consistent with the benchmark regression results in Table 2 in terms of the direction, magnitude, and significance level of the explanatory variable and control variables. These results indicate that the regression results in this study are robust.

4.3. Mechanism Test. The regression analysis has shown that the development of AI can improve the GVC position of cultural industries, but the mechanisms by which this improvement occurs need to be further tested. This study will examine the influence mechanisms of AI on the promotion of the GVC position of cultural industries in terms of technological innovation and the industrial structure.

4.3.1. Technological Innovation Effect. Technological iteration and application popularization will not only directly enhance cultural productivity, stimulate the tertiary industry, and further optimize the economic structure but also promote the innovation behavior of cultural enterprises. With the continuous application of AI, barriers between traditional cultural products and digital technology are continually being eliminated. The combination of the two is conducive to improving cultural consumption, providing favorable conditions for innovating the production mode of cultural products, and achieving the high-quality development of cultural industries. To analyze the influence of AI on the GVC position of cultural industries through the effect of technological innovation, the ratio of R&D expenditure to GDP in the World Bank database is adopted as the index to measure technological innovation (RD). Based on model (1), the mediating effect models (5) and (6) are constructed.

$$\mathrm{RD}_{\mathrm{it}} = \beta_0 + \beta_1 \mathrm{AI}_{\mathrm{it}} + \beta Z_{\mathrm{it}} + \theta_t + \gamma_i + \varepsilon_{\mathrm{it}}, \quad (5)$$

$$\mathrm{GVC}_{\mathrm{it}} = \beta_0 + \beta_1 \mathrm{AI}_{\mathrm{it}} + \beta_2 \mathrm{RD}_{\mathrm{it}} + \beta Z_{\mathrm{it}} + \theta_i + \gamma_i + \varepsilon_{\mathrm{it}}. \quad (6)$$

Table 4 lists the results of the effect of the mediating variable RD on the relationship between AI and the GVC

Table 1: Descriptive statistics of sample data.

Variable category	Variable name	Variable description	N	Mean	Std	Min	Max
Explained variable	GVCPs	GVC position index	504	1.0075	0.1083	0.6983	1.3505
Explanatory variables	AI	Artificial intelligence	504	1.3678	2.0939	0.0003	16.0343
	HC	Human capital	504	4.1032	0.4041	2.6788	4.9618
	IPP	Intellectual property protection	504	1.4986	0.2422	0.8478	1.8841
Control variables	Infra	Quality of infrastructure	504	1.5980	0.1821	1.0722	1.9132
	GDPP	Economic development level	504	9.7817	1.0452	7.0878	11.5416
	FDI	Foreign direct investment	504	4.9016	11.1519	−40.0811	102.3137

Table 2: Regression results of the benchmark.

Variables	GVCPs		
	(1)	(2)	(3)
AI	0.0048*** (2.5838)	0.0037** (2.1206)	0.0047** (2.5067)
HC		0.0364*** (2.8733)	0.0390*** (2.8737)
IPP		0.0291* (1.8274)	0.0243 (1.1345)
Infra		−0.0191 (−0.8994)	0.0143 (0.4831)
GDPP		0.0056 (0.5167)	0.0142 (1.1622)
FDI		0.0001 (0.0846)	−0.0001 (−0.2666)
Constants	1.0010*** (360.3240)	0.7850*** (7.5368)	0.6436*** (5.3180)
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	No	Yes
R-squared	0.9447	0.9553	0.9560
N	504	504	504

Robust t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Endogeneity and robustness tests.

Variables	GVCPs					
	(1)	(2)	(3)	(4)	(5)	(6)
L. AI	0.0056*** (2.4843)	0.0040* (1.9175)	0.0054** (2.4337)			
AI_C				0.0038*** (3.0002)	0.0035*** (2.7348)	0.0036*** (2.7839)
HC		0.0476*** (3.3213)	0.0515*** (3.3483)		0.0409*** (3.3193)	0.0413*** (3.0634)
IPP		0.0370** (2.3013)	0.0366* (1.6759)		0.0254 (1.5833)	0.0136 (0.6339)
Infra		−0.0222 (−1.0783)	0.0141 (0.4773)		−0.0185 (−0.8764)	0.0045 (0.1515)
GDPP		0.0127 (1.1036)	0.0172 (1.3639)		0.0059 (0.5418)	0.0159 (1.3031)
FDI		0.0002 (1.0684)	0.0001 (0.6267)		−0.0001 (−0.0645)	−0.0001 (−0.3152)
Constants	1.0006*** (320.6268)	0.6616*** (5.6632)	0.5425*** (4.1987)	0.9761*** (92.5578)	0.7453*** (7.2430)	0.6263*** (5.1775)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	No	Yes	Yes	No	Yes
R-squared	0.9610	0.9624	0.9630	0.9547	0.9556	0.9562
N	448	448	448	504	504	504

Robust t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

position of cultural industries. Table 4 shows that the AI coefficients of all models are significantly positive based on a comparison of the results of the fixed effects regression model with or without the inclusion of RD, the lagged explanatory variable regression model, and the replacement explanatory variable regression model. Column (1) is listed as the regression result of the benchmark. Column (2) reports the effect of AI on the mediating variable RD. The influence coefficient between AI and RD is 0.0520, which is significant at the 1% level, indicating that the development of

Table 4: Mechanism test (technical innovation).

Variables	GVCPs (1)	RD (2)	GVCPs (3)	GVCPs (4)	GVCPs (5)
AI	0.0047** (2.5067)	0.0520*** (4.4644)	0.0057*** (2.9772)		
L.AI				0.0063*** (2.8060)	
AI_C					0.0035*** (2.7272)
RD			−0.0187** (−2.4443)	−0.0199** (−2.4519)	−0.0132* (−1.7620)
Control variables	Yes	Yes	Yes	Yes	Yes
Constants	0.6436*** (5.3180)	0.4041 (0.5254)	0.6511*** (5.4094)	0.5419*** (4.2217)	0.6319*** (5.2346)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes
R-squared	0.9560	0.9814	0.9566	0.9636	0.9565
N	504	504	504	448	504

Robust *t*-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5: Mechanism test (industrial structure).

Variables	GVCPs (1)	Industry (2)	GVCPs (3)	GVCPs (4)	GVCPs (5)
AI	0.0047** (2.5067)	0.0138* (1.6493)	0.0039** (2.1440)		
L.AI				0.0048** (2.2259)	
AI_C					0.0032*** (2.5934)
Industry			0.0578*** (5.5756)	0.0587*** (5.2658)	0.0582*** (5.6388)
Control variables	Yes	Yes	Yes	Yes	Yes
Constants	0.6436*** (5.3180)	−2.1503*** (−3.9686)	0.7679*** (6.4455)	0.6879*** (5.3789)	0.7532*** (6.3277)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes
R-squared	0.9560	0.9734	0.9590	0.9656	0.9592
N	504	504	504	448	504

Robust *t*-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

AI has effectively promoted the level of technological innovation of a country (region). According to the regression results in column (3), AI has a significantly positive impact on the GVC position of cultural industries, while technological innovation has a smaller impact on the GVC position of cultural industries. Columns (4) and (5) are listed as the results of endogeneity test and robustness test, respectively. Moreover, technological innovation has a partial mediating effect, and the role of AI in improving the GVC position of cultural industries by improving the level of technological innovation needs to be further encouraged. Most cultural enterprises are in the growth stage, and their production mode, management mode, and business form urgently need to adapt to the era of AI to achieve effective transformation. Therefore, AI will play an increasingly important role in stimulating innovation, improving the added value of products, and promoting industrial innovation.

4.3.2. Industrial Structure Effect. AI is a general technology with new infrastructure, and its application prospect is quite different in different industries, which will cause a change in the industrial structure. To analyze the influence of AI on the GVC position of cultural industries through the industrial structure effect, the ratio of the added value of service industries to GDP in the OECD TiVA database is adopted as an indicator to measure industry structure (Industry). Based on model (1), mediating effect models (7) and (8) are constructed.

$$\text{Industry}_{it} = \beta_0 + \beta_1 \text{AI}_{it} + \beta Z_{it} + \theta_t + \gamma_i + \varepsilon_{it}, \quad (7)$$

$$\text{GVC}_{it} = \beta_0 + \beta_1 \text{AI}_{it} + \beta_2 \text{Industry}_{it} + \beta Z_{it} + \theta_t + \gamma_i + \varepsilon_{it}. \quad (8)$$

Table 5 lists the results of the effect of the mediating variable Industry on the relationship between AI and the GVC position of cultural industries. Table 5 shows that the AI coefficients in all models are significantly positive based on a comparison of the results of the fixed effects regression model with or without the inclusion of Industry, the lagged explanatory variable regression model, and the replacement explanatory variable regression model. Column (1) is listed as the regression result of the benchmark. Column (2) reports the effect of AI on the intermediary variable Industry. The impact of AI on the industrial structure is significantly positive, indicating that AI effectively improves the industrial structure of a country (region). Based on the regression results of column (3), the influence coefficient between Industry and GVCPs is 0.0578, which is significant at the 1% level, and the influence of AI on the GVC position of cultural industries is significantly positive. Columns (4) and (5) are listed as the results of endogeneity test and robustness test, respectively. The results show that AI has a mediating effect on improving the division of labor position of cultural industries in the GVC through the industrial structure, that is the development of AI will indeed improve the division of labor position in the GVC of cultural

Table 6: Heterogeneous effect of AI on the GVC position of cultural industries.

Variables	GVCPs					
	High-income countries (regions)			Low- and middle-income countries (regions)		
	(1)	(2)	(3)	(4)	(5)	(6)
AI	0.0056*** (2.92)	0.0050*** (2.5511)		0.0169 (1.3956)	0.0083 (0.5749)	
L. AI			0.0062*** (2.5468)			−0.0211 (−1.4127)
HC		0.0444** (2.1379)	0.0477** (1.9477)		0.0140 (0.6716)	0.0458** (2.1709)
IPP		−0.0073 (−0.1875)	0.0183 (0.4385)		0.0030 (0.0974)	0.0119 (0.4297)
Infra		0.0443 (1.0165)	0.0627 (1.3687)		0.0108 (0.1995)	−0.0278 (−0.5724)
GDPP		0.0120 (0.0789)	0.0143 (0.7867)		0.0218 (1.0326)	0.0356* (1.8302)
FDI		−0.0001 (−0.1269)	0.0001 (0.7793)		0.0001 (0.0316)	0.0022 (0.9120)
Constants	0.9997*** (255.9682)	0.0628*** (3.2828)	0.5136** (2.4173)	0.9968*** (242.8421)	0.7318*** (4.1766)	0.5309*** (3.3079)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.9350	0.9365	0.9431	0.9738	0.9743	0.9827
N	333	333	296	171	171	152

Robust *t*-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

industries by promoting the upgrades of the industrial structure.

5. Further Analysis Based on the Stages of Economic Development

According to the analysis above, the discussion of AI and the GVC position of cultural industries is conducted on a global scale. However, the international environment is very complex, and the income level of a country (region) affects the situation of the GVC position of cultural industries in the country (region). Additionally, Agrawal et al. found that AI has heterogeneous impacts on the labor forces in countries with different income levels, industries, and genders. To analyze the potential heterogeneity effect, 56 countries (regions) in the sample are divided into two subsamples, namely high-income countries (regions) and low- and middle-income countries (regions). According to the classification standard of the World Bank, the former corresponds to "high-income countries (regions)," while the latter includes three categories: "upper middle-income countries (regions)," "lower middle-income countries (regions)," and "low income countries (regions)."

The regression results based on the above sample classification are shown in Table 6. After the addition of control variables, in the sample of high-income countries (regions), AI has a significant positive role in improving the GVC position of cultural industries. For low- and middle-income countries (regions), this effect is not significant. This difference may be due to two reasons: (1) High-income countries (regions) are the main drivers of the development and application of AI. In the process of adjusting the GVC, high-income countries (regions) accumulate technological advantages to gain control over creative design, high-end research and development, and branding and marketing of high-technology and high value-added products in the global culture industry chain. To maintain a dominant position in the value chain of the global cultural industry, high-income countries (regions) have set up links with high barriers to entry. Then, as high-income countries invest their higher incomes in technological innovation, creative research, and the development of cultural products, their high value-added competitive advantages become more obvious, and the gap between them and low- and middle-income countries in the GVC widens. (2) In contrast, due to the constraints of policies, talent, resources, technology, and the market environment in some low- and middle-income countries (regions), there is a large gap in the research and development of emerging technologies in cultural industries with high-income countries (regions), and there are great differences in the technological level and the endowment conditions of the factors. These differences suggest that different countries (regions) will also have different attitudes towards AI technology. In some countries, the application of AI technology in cultural industries is weak due to the incompatibility of AI technology with the factor endowment structure, an incomplete cultural industry system, factor mismatches, structural contradictions, and imperfect governance mechanisms, which are not conducive to improving the GVC position of cultural industries in these countries (regions).

6. Conclusions

With the rapid development of AI technology, the upgrading of cultural industries has ushered in a new digital era, creating many new forms of industries. The transformation of cultural industries by AI has entered a

new stage and is constantly promoting the reconstruction of the GVC. First, this study uses cross-border panel data to measure the level of AI development with respect to robot stock and constructs a double fixed effects regression model to empirically analyze the impact of AI on improving the GVC position of cultural industries. Second, to overcome the possible endogeneity problem of the model, the endogeneity test of the benchmark regression results is carried out using a lagged explanatory variable with one lag period as the instrumental variable, and the robustness test is carried out by changing the measure of the explanatory variable using the replacement explanatory variable method. In addition, the study examines the influence mechanisms of AI on the promotion of the GVC position of cultural industries in terms of technological innovation and industrial structure. Finally, the heterogeneous effect of AI on the GVC position of cultural industries in different stages of economic development is further analyzed. The results show that (1) AI has a significant impact on improving the GVC position of cultural industries. (2) The mechanism test confirmed that AI has a mediating effect on improving the division of labor position in the GVC of cultural industries through the industrial structure. The role of AI in improving the GVC position of cultural industries by improving the level of technological innovation needs to be further encouraged. (3) The level of AI development has a heterogeneous impact on cultural industries in countries or regions with different income levels. AI has a significant positive role in improving the GVC position of cultural industries in high-income countries (regions), while it has no significant impact on low- and middle-income countries (regions). Although this article examines the influence mechanisms of AI on the promotion of the GVC position of cultural industries in terms of technological innovation and the industrial structure, it does not carry out in-depth discussion on how its impact mechanisms work. Future researchers can conduct more in-depth analyses of the aspect.

From the perspective of the development of the world's cultural industries, large-scale and artificial intelligence represent inevitable trends in future technologically based development, and the deep integration of cultural industries and AI is of great significance. Therefore, this study provides the following recommendations:

(1) Vigorously develop AI technology related to cultural industries. Technological innovation, as an endogenous driving force, is the core element in enhancing the technological innovation ability of cultural industries. Therefore, in the era of AI, scientific and technological innovation should be accelerated, the production productivity of cultural products should be improved, cultural formats and product forms should be innovated, the internal restructuring of cultural industries should be promoted, and a cultural production system with international competitiveness should be constructed.

(2) As an important way to improve the international competitiveness of cultural industries, the application of AI technology should be vigorously promoted. It is necessary to fully recognize the importance of the deep integration strategy of AI and cultural industries and to take advantage of the opportunities that AI offers the cultural industries. More importantly, AI provides a new advantage in the international competition of cultural industries to promote industrial transformation, innovation upgrading, and applications of AI in the field of cultural industries.

(3) From the perspective of resource allocation, in the process of iteration and integration of new and old cultural industries, it is necessary to make a rational use of resources from the policy environment, production factor resources, and market factor resources, to better drive the upgrading of cultural industries by optimizing resource allocation.

(4) A high-quality institutional environment is the key to the efficient and orderly operation of cultural industries. Optimizing the policy environment of cultural industries and further refining the industrial system can guarantee the position of cultural industries in the global cultural market competition and help realize the high-quality development of cultural industries. In addition, it is necessary to focus on cultivating the talents of high-quality cultural industries, encourage all types of cultural enterprises to fully exploit their strengths, deeply participate in the division of labor and cooperation among international cultural industries, and comprehensively improve their GVC position.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Design an Effective Blood Distribution Network with Minimal Impacts on the Environment and Blood Supply Assurance

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As the world's population grows, resulting in the aggravating trend of aging population, it brings with it an increase in the demand for blood. Nowadays, in most cities, the blood distribution network is based on a single distribution centre pattern, with the blood centre acting as distribution centre for one-to-one distribution. However, despite its convenience, this pattern has a high frequency of delivery, increased risk of blood shortage, and generates high carbon emissions. This paper aims to understand the real-life problems of the current blood distribution network and to design a more rational blood distribution network by taking the characteristics of the blood supply chain into account. Two blood distribution network patterns are considered, the current single distribution centre pattern and the proposed multiple distribution centre pattern. In order to minimise environmental impacts, we introduce open vehicle routing problem for blood delivery routes planning, using mixed integer programming for modelling, to compare the carbon emissions between the two blood distribution network patterns. Numerical experimental results demonstrate that applying the proposed BDN can reduce carbon emissions by an average of 25.84% and up to 29.59%, and the delivery time in emergency situations is significantly reduced by an average of 33.15%. Such studies are essential for both reducing carbon emissions and safeguarding patients' lives.

1. Introduction

Blood is a valuable resource, one of the most important but perishable materials in nature. As many operations in hospitals need blood, it is essential in the treatment of patients and is closely associated with human life. Up to now, there is no other product that can completely replace blood and its derivatives. With the reform of the health system and the expansion of hospitals, the amount of clinical blood consumption is increasing year by year. Due to its irreplaceable role in clinical treatment, the provision of blood to the healthcare industry and the public is crucial, and the management of blood and its products is a major issue of concern to humanity [1].

The perishable nature of blood results in a relatively contradictory situation. On the one hand, blood is wasted when it is beyond its expiry date. According to statistics, the annual blood waste rate has reached more than 10% in recent years; on the other hand, during the peak periods of blood consumption in hospitals, blood shortage occurs, resulting in healthcare delays [2]. Thus, the management of blood is different from that of ordinary items, with conflicting objectives leading to more complexities; a trade-off needs to be made between the cost of shortages and expiry of blood products.

Activities in the blood supply chain can be briefly divided into the donation and collection phase, the inventory phase (including testing, preparation, and storage processes), and distribution and clinical use phase [3, 4], as shown in Figure 1. The key to blood supply chain management is to guarantee supply and reduce waste, thereby improving the performance of the supply chain system [5]. The structure of the blood supply chain network has a significant impact on its performance, with an emphasis on the implications for the environment and the security of blood supply.

At present, blood is tested centrally by the blood centre, which is then responsible for distributing blood to hospitals

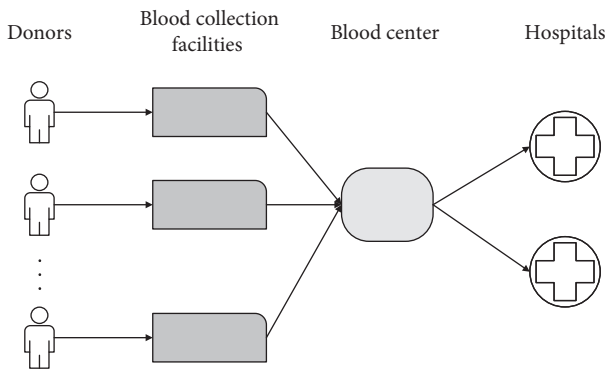

Figure 1: Blood supply chain network.

in most cities. Blood has high requirements for storage and transport conditions and is a perishable item, with different shelf lives for different blood products. Blood distribution is a very important issue that evolves with the growth of urban populations in developing countries. An effective blood distribution system is required to get blood to patients in time. Hence, the blood distribution network (BDN) is critical for blood assurance. From the perspective of supply chain network design, this paper addresses the issue of blood resource allocation and dispatching to achieve optimisation of the BDN, thereby achieving a rapid and effective response to blood demand and ensuring timely treatment of patients.

The difficulty of designing blood supply chain networks is routing planning. Delivery routes are closely linked to carbon emissions, with the more distance a blood delivery vehicle travels and the heavier its load, the more carbon emissions it contributes. The transportation routes of blood products consists of two parts, the first is from the blood collection facilities to the blood centre and the second is from the blood centre to the hospitals. The BDN we study is only the second part. As far as we know, fewer studies have been conducted only on blood distribution routing. This problem is similar to the cold chain logistics problem, so we can draw on relevant research methods and experiences. The transportation problem of blood should be considered separately from that of general materials, considering damage and refrigeration impacts during transportation [6]. A mathematical model of cold chain logistics vehicle routing problem is established and an adaptive genetic algorithm is developed to solve the model [7]. There are also many intelligent algorithms for solving cold chain logistics routing problems, such as ant colony algorithm [8], particle swarm algorithm [9], and so on.

The BDN studied in this paper consists of one blood centre and multiple hospitals. Currently, each hospital orders blood directly from the blood centre, which carries out blood distribution and is responsible for satisfying the demand of all hospitals. It is assumed that the blood centre has sufficient capacity and that the hospitals' demand for blood is random and follows a normal distribution with known means and variances. This BDN pattern is well defined on authority and responsibility, is easy to organise and handle, and performs relatively well in practice. However, as the population grows and with the aggravating trend of aging, demand for blood in hospitals continues to increase, and the problems of this pattern are exposed. This one-to-one distribution pattern between the blood centre and hospitals increases the distance travelled by blood delivery vehicles. When the frequency of distribution increases as the demand for blood increases, it generates significant carbon emissions that can be harmful to the environment.

As a scarce and an important healthcare resource, there is still a need for further research on how to implement reasonable dispatch of blood and ensure its supply, which affects both the safety of patients' lives and has a significant impact on the environment. Optimising the BDN structure is an effective way to improve its performance. Nagurney et al. [10] develop a generalised network optimisation model for the blood supply chain. Sahinyazan et al. [11] design a mobile blood collection system, and they propose a mathematical model to determine the tours of the bloodmobiles, as an extension of the selective vehicle routing problem. Kaya and Ozkok [12] design an effective network for a blood distribution system, with the objective of minimising location, inventory, and routing costs. Motivated by these literatures, we try to design the BDN structure to reduce the environmental impact and enhance the ability to safeguard the blood supply of the BDN.

We attempt to apply a new strategy for centralising hospitals' inventory and build a mathematical model for this pattern. Then, we design a more reasonable BDN by combining the characteristics of the blood supply chain to address the practical problems arising from the current BDN pattern. And, we conduct numerical experiments by using realistic data to verify the strategy effectiveness. The results prove that the proposed BDN pattern can reduce carbon emissions by an average of 25.84% and up to 29.59%, preventing further environmental damage. Meanwhile, it can safeguard the supply of blood, with an average reduction of 33.15% of delivery times in emergency situations. The objectives of this research are to (i) highlight the importance of BDN for environmental and blood supply assurance, (ii) describe the need for better management practice, and (iii) develop a better performing solution.

2. Implications of BDN and Existing Pattern

2.1. Environmental Implications of BDN. Nowadays, all communities are increasingly concerned about environmental issues. Society in general is becoming increasingly aware of and concerned about the environmental impact of human activities and the indiscriminate use of natural resources [13]. There is a growing interest in reducing the environmental impact of various products and services. The BDN's environmental impact is mainly reflected in the transportation process of blood.

The control of environmental impact is a great challenge for modern transport, especially with the current trend of increasing CO_2 emissions. The environmental impact of transportation is due to the large amount of fuel it uses, as well as the greenhouse effect caused by fuel consumption and pollution. Green transportation has therefore emerged at all levels of supply chain management and are of

increasing value to researchers and organisations, due to the fact that current logistics are centered on economic costs without considering the negative impact on the environment and are not sustainable in the long period [14].

The environmental impact of transportation is reflected in the amount of fuel consumed, which depends mainly on distance and load if other factors such as speed and road conditions are held constant [15]. So in this paper the carbon emissions we consider are determined by both the distance travelled and the weight carried. It can be assumed that carbon emissions are proportional to the distance travelled and the weight carried by the vehicle. The BDN model of direct transport between the blood centre and hospitals increases the distance travelled by blood delivery vehicles. If the vehicle routing problem model is used to plan touring blood delivery routes, the distance travelled can be effectively reduced, thereby reducing carbon emissions.

2.2. Blood Supply Assurance Implications of BDN. Blood supply chains play an important role in the healthcare systems. Inventory management and distribution of blood are seen as major components of the cost for blood [16]. The BDN configuration will influence hospitals' inventory management strategies, inventory levels, and transport arrangements. The hospitals' blood demands, distance to the blood centre, and the perishable nature of blood are all factors that need to be considered. Life comes first at all times, and there have been real-life incidents where a patient's life was saved because blood was delivered in time at a hospital near the blood centre. Hence, a well-designed BDN is essential for the effective safeguarding of blood supply.

As the demand for blood products in cities grows gradually, the shortage and surplus of blood is becoming more and more serious. Unlike other alternative resources, blood is an exceptional resource with an irreplaceable and important significance. In BDN, both shortage and surplus of the product should be regulated. Blood shortages indicate that demand of blood is not met, which may lead to untimely treatment and even damage to patients' lives. According to the American Red Cross (ARC), approximately 28.9% of hospitals reported the postponement of surgery in the United States for one or more days due to blood shortages in 2007, which approximately affected 412 patients [17]. On the other hand, blood products have a specific expiry date, which can be costly due to the complexity of the handling process.

An acceptable inventory strategy seeks to maximise demand satisfaction and minimise the amount of units that expire. However, the two goals are conflicting because a larger amount of stored product can better meet the changes in demand but would result in an increased storage time for the products, thus increasing losses due to shelf life [18]. Availability of the needed blood products in the right place on time is critical for clinical treatment. Therefore, hospitals must maintain reasonable inventory levels, and the BDN further determines the hospital's ability to respond to requests for blood supplies.

Furthermore, when there is a sudden increased demand for blood and the hospital's existing inventory levels cannot meet the demand, the blood centre is required to arrange emergency blood deliveries. When hospital inventory levels are low and the distance between the hospital and the blood centre is long, this can lead to serious situations that affect treatment and even endanger patients' lives. The frequency and distance of emergency blood deliveries determines the ability to safeguard the blood supply. The BDN needs to be well designed to ensure that not only the usual blood demands are met but also to provide blood supply assurance in emergency situations.

2.3. Single Distribution Centre Pattern. The current BDN structure involves two layers, the blood centre and hospitals. The BDN pattern in most cities is that each hospital sends its order request directly to the blood centre, which responds to the request and dispatches a blood delivery vehicle to transport the blood product to the demand point, as shown in Figure 2. The blood centre is the equivalent of a supplier and hospitals are the equivalent of retailers. So, it can be seen that the blood centre is faced with a set of customers with different consumption rates and needs to ensure that shortages and damages are minimised and carbon emissions are reduced.

In this pattern, each hospital needs to manage its blood inventory. The objective of blood inventory management is to minimize inventory costs while safeguarding service levels, rather than minimizing inventory costs. With regard to blood inventory strategies, different scholars have chosen different strategies, such as the (Q, s) inventory strategy [19]; the (R, S) inventory strategy [20]; the (S^{-1}, S) inventory strategy [21], which means that as soon as one unit is used, the inventory is immediately replenished to S; and the NIS replenishment strategy [22], i.e., S young units are assumed to enter the system at the beginning of each period. In addition, there are many studies that use a periodic replenishment strategy [23, 24]. Different inventory strategies have corresponding advantages and disadvantages, which need to be combined with the objectives and characteristics of their models to choose the most appropriate strategy; there is no absolute optimal strategy. As for the replenishment lead time, hospitals typically assess their inventory and send requests when the reorder point are reached, with a short delivery time. Therefore, the lead time equal to zero or a fixed nonzero number are reasonable assumptions [25]. In the management practices studied in this paper, we assume that lead time is zero, and hospitals use (T, S) periodic replenishment strategy, i.e., hospitals replenish their inventory levels to S after a certain period T.

There is a huge variation in the amount of blood used by different hospitals, and once blood is distributed to hospitals, inventory levels vary greatly from place to place at different times. On the one hand, because shortages could result in loss of life, large hospitals prefer high inventory levels and order far more blood products than they use, even though this results in higher inventory costs and expiry rates of blood products. And, with their long ordering intervals, the inventory levels in hospital blood banks fluctuate very much during the cycle. It is often the case that hospital blood banks

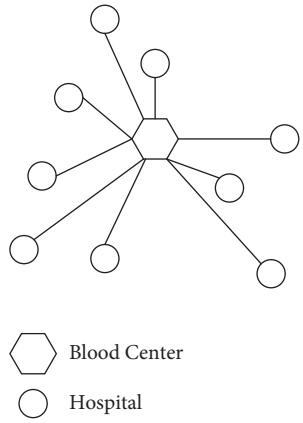

Figure 2: Current blood distribution network.

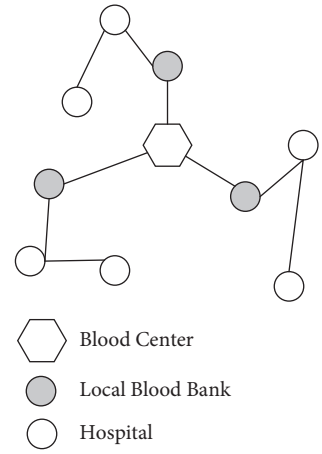

Figure 3: Proposed blood distribution network.

have high inventory levels in the early stages, sometimes even having to purchase additional stock resources to satisfy storage needs, and very low inventory levels in the later stages, requiring an increased number of emergency deliveries and waiting times for patients. On the other hand, some other hospitals with low blood consumption only order almost all the blood products they need on a regular or emergency situation, and the blood centre has to apply emergency delivery. These measures are extremely wasteful of storage resources and expensive blood products, as well as adding additional carbon emissions.

The current BDN pattern suffers from shortages and breakdowns, risking patients' lives. Moreover, point-to-point transportation mode and too frequent emergency transportation generate significant carbon emissions. Hence, there is much room for improvement in BDN management practice.

3. Innovative Pattern Utilised at BDN

Many scholars have proposed new design solutions for BDN [10–12, 26], and optimisation of the BDN structure can contribute to an effective improvement in its performance. To address problems created by the current BDN pattern, we consider a new configuration strategy in which some hospitals are selected as local blood banks (LBBs) to store blood and are responsible for meeting the demands of other nearby hospitals, as shown in Figure 3. Therefore, in the proposed BDN, inventory is managed in a centralised way, hospitals no longer keep inventory and each LBB is only responsible for the blood demands within the region.

Decisions in the blood supply chain can be classified into strategic-, tactical-, and operational-level decisions [27]. Traditionally, these different dimensions of decisions are considered separately, but this may lead to some problems due to the interactions between different dimensional decisions [12]. This problem consists of three decisions: the location decision, i.e., which hospitals are selected as LBBs and responsible for satisfying the demands of other hospitals allocated to it, the inventory decision, i.e., how to manage inventory for LBBs and hospitals, and the routing decision, i.e., how to arrange distribution routes from the blood centre to LBBs and from LBBs to hospitals.

A focus of the study is to explore the potential value of switching from the current single blood centre managed inventory system to a multi-centre managed inventory system, reallocating resources and responsibilities between the blood centre and LBBs to more effectively safeguard patients' lives. For BDN, inventory centralisation has significant implications. After inventory centralisation, the structure of BDN changes from two layers to three layers, including the blood centre, LBBs, and hospitals. Where the blood centre is equivalent to the supplier, selected LBBs are equivalent to distribution centres, and other hospitals are equivalent to retailers. The inventory strategy is classified into LBBs and hospitals. We assume that hospitals adopt the (T, S) replenishment strategy, i.e., replenish inventory to S every period T, and the LBBs use the (r, Q) replenishment strategy, i.e., replenish inventory when it falls to r, with a replenishment quantity of Q. The order cycle T for hospitals without inventory is the same as the cycle for hospitals under the current pattern. Although blood demand is stochastic, the demand of LBBs is relatively stable, so the order cycle for LBBs can be simplified to be t times of the hospital order cycle; this is realistic with reasonable parameters r and Q.

Some literature exists on the centralized management of blood inventory. Based on a study of blood banks in the Chicago area, a modified BDN is proposed, where selected hospitals would retain inventory and other hospitals do not hold inventory [28]. Researchers use the median method to select LBBs that retain inventory, and employ the (r, Q) inventory strategy to construct an academic model, in which there is only direct transportation between nodes and no consideration of vehicle routing problems. What is more, a new BDN structure is proposed where a number of hospitals maintain centralized inventory to meet their and other neighbouring hospitals' demand; the results show that centralization of inventory is a key factor and can improve the sustainability and flexibility of BDN. The numerical experiments find that reducing the number of hospitals holding inventory from 7 to 3 resulted in a 21% and 40% reduction in expiration and shortage in the blood supply

chain, respectively [21]. Hence, we can find that centralising inventory helps to free up pressure on resource utilisation and safeguard the blood supply.

In addition to inventory management, we also have to consider the planning of transport routes. After reviewing the relevant literature, direct transport between points increases the distance travelled, and we believe it is necessary to consider the vehicle routing problem in the BDN. The current one-to-one delivery pattern is created on the basis that blood demand is not fixed and each hospital orders at different times depending on their inventory levels. However, centralised inventory management reduces the effects of stochasticity and therefore continuous delivery routes within a region become feasible. Inspired by the idea of resource sharing, many scholars have introduced the open vehicle routing problem model in their research on green logistics [29, 30], where vehicles do not need to return to the start point after completing all tasks. In this paper, two levels of open vehicle routing problem need to be considered, i.e., from the blood centre to LBBs, and from LBBs to hospitals. We develop a mixed integer programming mathematical model to verify that the proposed solution is effective in reducing carbon emissions of BDN.

3.1. Distribution Model. Combining the characteristics of the BDN we study, we develop a mathematical model of the open vehicle routing (OVRP) problem for finding delivery routes of blood delivery vehicles. The definition of sets, parameters, and variables used in the model are shown in Table 1. We now present our mixed integer programming model as follows:

(i) The objective function is to minimise carbon emissions generated by blood delivery vehicles. The first term indicates the carbon emissions generated by the routes between the blood centre and LBBs, and the second term is the carbon emissions generated by the routes between each LBB and the hospitals it serves.

$$\min \sum_{i\in I} \frac{z_i d_{oi} qc}{t} + \sum_{i,j\in N} \sum_{v\in V} R_{ijv} d_{ij} u_j c. \tag{1}$$

The following constraints are satisfied.

(ii) z_i denotes the number of vehicles from o to LBB i.

$$z_i \geq \sum_{j\in N} \frac{y_{ij} u_j t}{q}, \quad \forall i \in I. \tag{2}$$

(iii) A hospital can be served by just one LBB.

$$\sum_{i\in I} y_{ij} = 1, \quad \forall j \in N. \tag{3}$$

(iv) At most b LBB can be selected.

$$\sum_{i\in I} x_i \leq b. \tag{4}$$

(v) If hospital i is selected as LBB, it serves itself.

$$y_{ii} \geq x_i, \quad \forall i \in I. \tag{5}$$

(vi) Hospitals can be allocated to a LBB only if the LBB is opened.

$$y_{ij} \leq x_i, \quad \forall i \in I, \forall j \in N. \tag{6}$$

(vii) Hospital i can be the start node of vehicle v only if it is selected as LBB.

$$s_{iv} \leq x_i, \quad \forall i \in I, \forall v \in V. \tag{7}$$

(viii) Each route has only one start node and one end node.

$$\begin{aligned} \sum_{i\in I} s_{iv} &= 1, \quad \forall v \in V, \\ \sum_{j\in N} h_{jv} &= 1, \quad \forall v \in V. \end{aligned} \tag{8}$$

(ix) The variable a_{iv} indicates that hospital i is served by vehicle v. The relationship between a_{iv} and the variable R_{ijv} is shown as constraints (9), (10).

$$a_{iv} \geq h_{iv}, \quad \forall i \in N, \forall v \in V, \tag{9}$$

$$a_{iv} \geq R_{ijv} + R_{jiv}, \quad \forall i, j \in N, \forall v \in V. \tag{10}$$

(x) One hospital can be involved in only one route.

$$\begin{aligned} \sum_{v\in V} \sum_{i\in N} R_{ijv} &= 1 - x_j, \quad \forall j \in N, \\ \sum_{v\in V} a_{iv} &= 1, \quad \forall i \in N. \end{aligned} \tag{11}$$

(xi) Except for the start node and the end node, if the vehicle passes through one hospital, it must enter and leave from the hospital.

$$\sum_{j\in N} R_{ijv} - \sum_{j\in N} R_{jiv} = s_{iv} - h_{iv}, \forall i \in N, \forall v \tag{12}$$

(xii) The hospital is allocated to the LBB if the route involves this LBB and this hospital.

$$a_{iv} + a_{jv} - y_{ij} + x_i - 1 \leq 1, \forall i, j \in N, \forall v \in V. \tag{13}$$

(xiii) Recursive constraint. If vehicle v drives from hospital i to hospital j, then the value of f_{jv} is equal to the value of f_{iv} plus the distance from i to j.

$$f_{jv} \geq \sum_{l\in N} \left(f_{lv} + d_{lj}\right) R_{ljv}, \forall j \in N, \forall v \in V. \tag{14}$$

(xiv) Vehicle capacity constraints.

Table 1: Notations used in the model.

Sets:	
N	Set of hospitals, $n \in N$;
I	Set of hospitals that can be selected as LBB, $i \in I$, $I \subseteq N$;
V	Set of vehicles, $v \in V$;
Parameters:	
M	a large number;
o	City blood center;
b	Maximum number of LBBs;
u_j	Mean daily demand of hospitals j;
t	Delivery cycle of LBBs;
d_{ij}	Distance between i and j;
c	Carbon emissions per unit distance per unit weight carried generated by blood delivery vehicles;
q	Maximum vehicle capacity;
Decision variables:	
x_i	Binary variable. If hospital i is selected as LBB, it is equal to 1; otherwise equal to 0;
y_{ij}	Binary variable. If hospital j is serviced by LBB i, it is equal to 1; otherwise equal to 0;
h_{jv}	Binary variable. If hospital j is the end node of vehicle v, it is equal to 1; otherwise equal to 0;
s_{iv}	Binary variable. If hospital i is the start node of vehicle v, it is equal to 1; otherwise equal to 0;
a_{iv}	Binary variable. If hospital i is visited by vehicle v, it is equal to 1; otherwise equal to 0;
R_{ijv}	Binary variable. If vehicle v drives from hospital i To hospital j, it is equal to 1; otherwise equal to 0;
f_{jv}	Distance of the route of vehicle v from the start Node to hospital j;
z_i	Integer variable. Number of vehicles from o to i;

$$\sum_{i \in N} a_{iv} u_i \leq q, \quad \forall v \in V. \tag{15}$$

(xv) Enforce the integrality restrictions on the binary variables and enforce the nonnegativity restrictions on the other decision variables.

$$x_i, y_{ij}, s_{iv}, h_{jv}, a_{iv}, R_{ijv} \in \{0, 1\}, \forall i, j \in N, \forall v \in V,$$
$$f_{jv} \in \mathbb{Z}^+, \forall j \in N, \forall v \in V. \tag{16}$$

3.2. Numerical Experiments. Before conducting numerical experiments, it is necessary to deal with the nonlinear terms. Linearise the constraint (14) by the following equation, using L_{ljv} instead of $f_{lv} R_{ljv}$.

$$f_{jv} \geq \sum_{l \in N} \left(L_{ljv} + d_{lj} R_{ljv} \right), \forall j \in N, \forall v \in V,$$
$$L_{ljv} + M\left(1 - R_{ljv}\right) \geq f_{lv}, \forall l, j \in N, \forall v \in V. \tag{17}$$

This paper considers a BDN to create different instances by varying the number of LBBs and available vehicles and its capacity parameters as the case study. In this BDN, there are 1 blood centre and 60 hospitals; we assume that only large general hospitals are candidate locations for the LBB for experimental fluency, 32 hospitals in total can be selected as LBBs. This is because there are many benefits in choosing these hospitals as LBBs, as they have more storage resources and high blood consumption and are generally in more convenient locations.

The experimental data used in this paper are coordinates of the blood centre and hospitals, which are accessible through Gaode Open Platform; in addition, the hospital demands are generated stochastically according to hospital class. Based on the distances from the blood centre to the hospitals, we get the carbon emissions of the current BDN as 7508.86. By using the commercial Off-the-shelf software ILOG CPLEX with a maximum runtime of 3600 s, the proposed model can be solved efficiently. The comparison results between carbon emissions of current and proposed BDN are shown in Table 2, and the column "Reduced (%)" is obtained from the following equation:

$$\text{Reduced}\,(\%) = \frac{CE_{\text{current}} - CE_{\text{proposed}}}{CE_{\text{current}}}, \tag{18}$$

where CE_{current} and CE_{proposed} are carbon emissions of the current and proposed BDN, respectively.

As results indicate, significant carbon emission reductions compared to current BDN can be achieved by using the proposed BDN. Sensitivity analysis of the different parameters shows the following conclusions. The number of available vehicles, the number of available LBBs, and the vehicle load capacity are all positively proportional to the carbon emission reduction. Applying the proposed BDN results in carbon emissions being reduced by an average of 25.84% and up to 29.59%.

We then further explore the benefits of the proposed BDN for blood supply assurance in emergency situations. The blood supply assurance is mainly determined by the blood delivery time, which is a function of the distance between the hospital and the blood centre. The configuration and allocation of each hospital and its blood delivery facility under the two BDN patterns are shown in Figures 4 and 5, respectively. From the two figures, it can be seen that the

Table 2: Comparison of carbon emissions between current and proposed BDN.

n	v	b	q	Obj	Reduced (%)
60	10	5	500	5733.97	23.64
60	10	5	1000	5287.03	29.59
60	10	2	500	5989.48	20.23
60	10	2	1000	5386.81	28.26
60	5	2	1000	5443.80	27.50
		Average			25.84

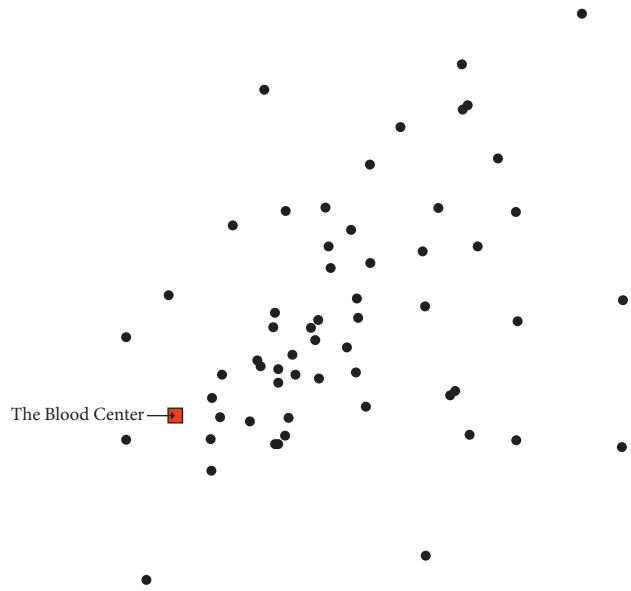

Figure 4: Configuration and allocation of current BDN.

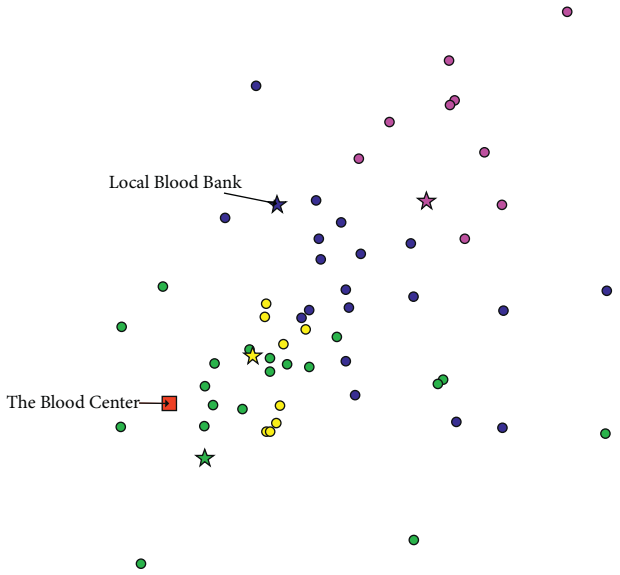

Figure 5: Configuration and allocation of proposed BDN.

blood centre'ss service areas under the current BDN cover all hospitals, and in the proposed BDN, each selected LBB only needs to provide service within a certain region. The smaller service radius would contribute to reducing the distance travelled by blood delivery vehicles. Using the distance between the blood centre and hospitals, we calculate that the average response delivery time for the current BDN is 44.53 min. The response delivery time results for the proposed BDN are shown in Table 3, with an average response time of 29.77 min, representing an improvement of 33.15% in response capability.

Table 3: Comparison of emergency response time between current and proposed BDN.

n	v	b	q	Response time	Reduced (%)
60	10	5	500	34.38	22.79
60	10	5	1000	27.26	38.78
60	10	2	1000	28.34	36.36
60	5	2	1000	31.01	30.36
60	5	5	1000	27.84	37.48
	Average			29.77	33.15

4. Conclusion

In this study, we analyse real-world problems arising from the current BDN, and design a new BDN structure in which OVRP is taken into account to minimise environmental impact and improve blood supply assurance capacity. Our focus is to integrate the blood inventory of selected hospitals, in order to help manage blood inventory effectively, reduce shortage and waste of blood products, and ease the pressure on resource allocation. We select some hospitals as LBBs to

manage the inventory while other hospitals have no inventory, and then optimise blood delivery routing decisions on this basis. The BDN is converted from a two-level structure to a three-level structure. These measures can safeguard patients' blood supply, improve treatment effectiveness, and reduce life-saving risks to a certain extent.

For the proposed BDN, we develop a mathematical model and convert the nonlinear terms to linear, developing a mixed integer linear programming model. Then, we use the CPLEX commercial solver to solve this model to find the location of a given number of LBBs, the allocation of hospitals to open LBBs, and the distribution routes of blood delivery vehicles. The results of the numerical experiments demonstrate that applying the proposed BDN can effectively reduce carbon emissions by up to 29.59%, and can improve response capacity by an average of 33.15% in emergency blood delivery situations. And parameters such as the number of LBBs, the number of vehicles available, and their capacity all have a relatively significant effect on the results. The next step in the research can be to standardise the scales for carbon emissions, location costs, and blood inventory management indicators to develop integrated models, or consider not just the BDN but also analyse other stages of the blood supply chain such as collection stages in more detail. In addition, real-time dynamic BDN models can also be constructed in order to respond to potential blood supply emergencies in advance, and this is also worth further research.

Data Availability

Coordinate data for the blood centre and hospitals are accessible through Gaode Open Platform.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Research on the Relationship between Urban Agricultural Nonpoint Source Pollution and Rural Residents' Income Growth

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Researching the relationship between urban agricultural nonpoint source pollution (*UANSP*) and increases in rural residents' income levels has significant practical implications for effectively controlling *UANSP* and improving the quality of life of urban residents, and it is conducive to achieving a win-win situation between economic and environmental benefits. This study chooses agricultural statistical data from Shanghai from 1998 to 2019, implements the *EKC* and the *VAR* model to dynamically analyze internal interaction between them, and thoroughly examines impact effect and explanatory contribution degree of each variable. The results show the following: (1) There was an inverted "*N*" curve between plastic film application intensity and rural residents' per capita disposable income; there was a linear decreasing relationship between the intensity of fertilizer and pesticide application and rural residents' per capita disposable income. (2) Nonpoint source pollution emissions will decrease as rural residents' income levels rise. Reduction of nonpoint source pollution can promote the short-term improvement of rural residents' income levels, but it has a negative effect on the long-term improvement of rural residents' income levels. (3) Fertilizer and pesticide application intensity had a low driving effect on rural residents' income growth, whereas plastic film application intensity had a strong driving effect. Therefore, the *ANSP* of Shanghai should be treated from both long-term and short-term perspectives on the basis of decreasing stage. In the long term, the government should increase farmers' sense of ownership in agricultural nonpoint source pollution control, prioritize the development of ecological circular agriculture, and gradually improve nonpoint source remote sensing monitoring and service management capabilities. In the short term, the government should reduce farmers' nonpoint source pollution through subsidies and technical assistance. To keep costs down, the government established an administrative reward and punishment system to control *ANSP* at the source.

1. Introduction

Urban agriculture is the "pioneer" of modern agricultural development. Urban agriculture is different from ordinary agricultural areas in a number of respects. On the one hand, the urban area's limited agricultural resources necessitate the provision of a huge supply of agricultural products to its citizens. On the other hand, agricultural nonpoint source pollution (*ANSP*) caused by excessive agricultural resource usage endangers the urban living environment [1–4]. Fertilizer; pesticide residues; agricultural films widely used throughout agriculture; and agrarian or rural wastes such as crop residues, animal urine, manure, domestic sewage, and garbage are really the major causes of *ANSP*. It exhibits inconsistencies in its emission properties, making it difficult to identify and monitor [5–7]. *ANSP* not only jeopardizes local agricultural and drinking water, but also contaminates soil and surface water [8, 9]. In China, the intensive input of production elements is critical to China's agricultural development. Agriculture under the concentrated management model is characterized by high yield, low efficiency, and high input [6, 10]. While such an extensive production strategy helps agricultural economic growth, it also threatens to undermine the agroecological ecosystem [11, 12]. In agricultural production, the *ANSP* generated by agricultural chemicals like fertilizer, pesticide, and plastic films, in particular, has become a detrimental factor that endangers the water and soil environment [13, 14]. The shortage of agricultural resources has become more and more evident in cities, and agriculture will become indispensable to cities and

their citizens. It has progressed from maintaining the supply of agricultural products to performing a variety of complex functions, and from auxiliary duties to core functions. Prevention and control of *ANSP* are linked to the investment environment, urban construction, urban image, quality of life, ecological balance, tourism, culture, and other factors and will ultimately affect the city's overall competitiveness [15, 16]. As a result, efficient control of urban agricultural nonpoint source pollution (*UANSP*) is a critical component of ecological environmental protection and the key to fostering the long-term development of urban agriculture, which is conducive to achieving a win-win situation in terms of economic and environmental benefits [17–20].

According to the Environmental Kuznets Curve (*EKC*) hypothesis, the relationship between environmental pollution and economic growth is an inverted "*U*" shape, which implies that environmental quality begins to deteriorate with economic growth and gradually improves after a certain level of economic growth is attained [21–24]. People have long been concerned about the conflict between agricultural economic development and environmental protection. At present, there is no consensus on whether the *EKC* hypothesis exists in *ANSP* in different countries and regions [25]. In terms of China studies, Hui used the *EKC* to investigate the link between *ANSP* and income in 30 provinces and cities in China. According to his research, the relationship between the two is shaped like an inverted "*U*," which is consistent with the *EKC* hypothesis [26]. In terms of American studies, through the *EKC* hypothesis, Managi empirically analyzed the relationship between economic growth and mitigation of environmental degradation using agricultural data from 48 states in the United States. The findings indicate that lowering pesticide contamination promotes agricultural economic growth [27]. In relation to specific pollutant indicators, the agricultural economy and environmental pollution continue to exhibit "*N*" type, inverted "*N*" type, or linear change characteristics [28]. Liu et al. used the *EKC* to examine chemical fertilizer applications in China from 1978 to 2017, with Hubei Province as a case study. The findings revealed that the growth of farmers' income and the use of chemical fertilizer followed an "*N*" shaped pattern [29]. It can be found that there are variances in the relationship between *ANSP* and agricultural economic growth that do not fully conform to the *EKC* hypothesis. Furthermore, on the one hand, the *EKC* hypothesis ignores the two-way influence mechanism and dynamic correlation effect between *ANSP* and agricultural economic growth, raising the possibility of variable endogeneity bias [30]. On the other hand, most existing research focuses on conventional agricultural areas, and there is still a scarcity of studies on the relationship between *ANSP* and agricultural economic growth from an urban perspective. For this reason, researching the relationship between *UANSP* and agricultural economic growth has substantial practical significance for effectively reducing environmental pollution and increasing the quality of life for urban residents.

Shanghai, as an international metropolis, has evident regional specificity and significant advantages in terms of location, technology, talent, market, and money, despite the scarcity of agricultural and environmental resources. Shanghai's agriculture not only plays a vital role in utilizing nearby villages to adjust the climate, purify the air, mitigate the urban "heat island effect," and improve the ecological environment of megacities, but also provides strategic space for the city's core functions and undertakes more diverse and high-level energy levels of economic development functions. Therefore, this study uses Shanghai as the research object for *UANSP* and develops an *EKC* model between the application intensity of fertilizers, pesticides, and plastic film and rural residents' per capita discretionary income, as well as describing the morphological relationship and trend characteristics of each variable. Based on the research on the evolution characteristics of *ANSP* and economic growth in Shanghai, the dynamic impact effect and interaction mechanism between *ANSP* and per capita disposable income of rural residents were investigated using the impulse response function and variance decomposition method from a time series perspective. This study is expected to serve as an example for the development of *UANSP* prevention and control policies in Shanghai and other cities.

2. Material and Methods

2.1. Data Sources. We take Shanghai as an example; the scale of planting in Shanghai's agricultural production is large, the scale of breeding is small, and the agricultural resources consumed are primarily fertilizer, pesticide, and plastic films. Three indicators of fertilizer application intensity (*NPK*, kg/hm^2), pesticide application intensity (*Pestic*, kg/hm^2), and plastic film application intensity (*PF*, kg/hm^2) were chosen as the Shanghai's *ANSP* index based on agricultural production characteristics. Based on 1998 data, this research chooses rural residents' per capita disposable income as an indicator of agricultural economic progress. The following indicators are derived from the amount of fertilizers applied, the amount of pesticide applied, the effective irrigation area, the amount of plastic film applied, and the area covered by plastic film. The following is the computation method:

Fertilizer application intensity (kg/hm^2) = amount of fertilizers applied/effective irrigation area.

Pesticide application intensity (kg/hm^2) = amount of pesticide applied/effective irrigation area.

Plastic film application intensity (kg/hm^2) = amount of plastic film applied/plastic film coverage area.

Data from 1998 to 2019 were obtained from "China Environmental Statistical Yearbook," "China Agricultural Yearbook," "China Agricultural Statistics," "Shanghai National Economic and Social Development Historical Statistics," and "Shanghai Statistical Yearbook."

2.2. Model Method

2.2.1. EKC Analysis

$$Y_i = \beta_0 + \beta_1 M + \beta_2 M^2 + \beta_3 M^3 + \varepsilon, \quad (1)$$

where Y_i is indeed the *ANSP* index (i = *NPK*, *Pestic*, *PF*); M is rural residents' per capita disposable income; n (n = 0, 1, 2, 3)

is the regression coefficient, whose coefficient symbol determines the shape of the *EKC*; and ε is the random disturbance term. The various values of model coefficients β_0, β_1, β_2, and β_3 reflect the various relationships between *ANSP* and per capita disposable income of rural residents (as shown in Table 1).

2.2.2. VAR Model. The *VAR* (vector autoregression) model is a widely known econometric model for analyzing time series as it can describe the linear relationship between variables in the same sample period as their past values. The formula is as follows:

$$Y_i = A_1 Y_{i-1} + A_2 Y_{i-2} + \dots A_p Y_{i-p} + \delta_i; t = 1, 2, \dots, T, \quad (2)$$

where Y_t represents time series vector, A_p represents time series coefficient matrix, P represents order of autoregressive lag, and δ_t represents error vector.

2.2.3. Impulse Response Function and Variance Decomposition. Because a single regression coefficient has a large impact on results, the *VAR* model uses impulse response function and variance decomposition to analyze the dynamic impact effect between variables as well as the explanatory contribution degree on the whole. Impulse response function is used to analyze response change and response direction of a random error term in a model after it has been impacted by one standard deviation. The formula is as follows:

$$y_i = \alpha + \varphi_0 \varepsilon_i + \varphi_1 \varepsilon_{i-1} + \varphi_2 \varepsilon_{i-2} + \cdots = \alpha + \sum_{j=0}^{\infty} \varphi_j \varepsilon_{i-j},$$
$$\frac{\partial y_{i+s}}{\partial \varepsilon_i} = \varphi_s. \quad (3)$$

Variance decomposition is another method to measure the *VAR* model, which depicts the contribution rate of each endogenous variable in model to system variable in order to assess relative importance of impulse disturbance term to the model variable. The formula is as follows:

$$y_{i+h} - \widehat{y}_{i+h} = \varphi_0 \varepsilon_{i+h-1} + \cdots + \varphi_{h-1} \varepsilon_{i+1} = \sum_{i=0}^{h-1} \varphi_i \varepsilon_{i+h-i},$$
$$y_{i+h} - \widehat{y}_{i+h} = \sum_{i=0}^{h-1} \varphi_i \varepsilon_{i+h-i} = \sum_{i=0}^{h-1} \varphi_i P P^{-1} \varepsilon_{i+h-i} = \sum_{i=0}^{h-1} \omega_i \nu_{i+h-i}, \quad (4)$$

where ν_{i+h-i} represents the orthogonalization shock. The contribution of the first variable's dynamic action to $y_{j,i+h}$ prediction error is calculated further as follows:

$$\frac{\omega_{0,j1}^2 + \cdots + \omega_{h-1,j1}^2}{\sum_{k=1}^{n} \omega_{0,jk}^2 + \cdots + \omega_{h-1,jk}^2}. \quad (5)$$

Formula (5) calculates the contribution ratio as a function of the prediction period h, and the sum of the contribution ratios of all variables to the prediction error is 1.

Table 1: Relationship between *ANSP* and per capita disposable income of rural residents.

Value of coefficients	Variable relationship
$\beta_1 > 0, \beta_2 = 0, \beta_3 = 0$	A simple increasing linear relationship
$\beta_1 < 0, \beta_2 = 0, \beta_3 = 0$	A simple decreasing linear relationship
$\beta_1 < 0, \beta_2 > 0, \beta_3 = 0$	A positive "*U*" curve relationship
$\beta_1 > 0, \beta_2 < 0, \beta_3 = 0$	An inverted "*U*" curve relationship
$\beta_1 > 0, \beta_2 < 0, \beta_3 > 0$	A positive "*N*" curve relationship
$\beta_1 < 0, \beta_2 > 0, \beta_3 < 0$	An inverted "*N*" curve relationship
$\beta_1 = 0, \beta_2 = 0, \beta_3 = 0$	No linear relationship

3. Evolutionary Characteristics of Economic Growth of *ANSP*

EKC tests were conducted on plastic film, chemical fertilizer, pesticide, and per capita disposable income of rural residents, according to the *EKC*. When the curve fitting results of the quadratic and cubic equations were compared, it was discovered that the cubic equation had the best curve fitting effect, so the cubic equation's curve fitting results were chosen, as shown in Table 2 and Figure 1.

Based on the *EKC* results of plastic film application intensity and per capita disposable income of rural residents, the fitting curve's Sig value was $0.001 < 0.01$, and $R^2 = 0.575$. As can be seen, the cubic curve fits well and can be investigated further. According to the research results, the relationship between plastic film application intensity and rural residents' per capita disposable income appears to follow an inverted "*N*" curve. It demonstrates that as rural residents' disposable income increases, plastic film application intensity in agriculture undergoes a "decline⟶rise⟶decline" change process, with two inflection points in the inverted "*N*" curve. According to the derivation of the unary cubic equation function, the application intensity of plastic film corresponding to the inflection point of the *EKC* principle is 217.89 kg/hm^2 and 273.63 kg/hm^2 for the per capita disposable income of rural residents. According to data, the per capita disposable income of Shanghai's rural residents crossed the first turning point in 2011. In 2017, rural residents' per capita incomes did pass the second turning point. By 2019, the per capita disposable income of rural residents in Shanghai had been to the right of the second inflection point, and plastic film application intensity had been decreasing. This demonstrates that as rural residents' income levels rise in Shanghai, so does their quality of life, which does have a positive impact on the reduction of agricultural plastic film pollution.

Based on the *EKC* results of fertilizer application intensity and per capita disposable income of rural residents, the fitting curve's Sig value was $0.001 < 0.01$, and $R^2 = 0.778$. As can be seen, the cubic curve fits well and can be investigated further. According to the research results, there was a decreasing linear relationship between fertilizer application intensity and rural residents' per capita disposable income. In terms of rural residents' levels of income, fertilizer application intensity has been shrinking since 1998, as per capita disposable income has increased, and the downward trend has gradually accelerated.

Table 2: Comparison of curve fitting effects.

Variables	Goodness of fit (R^2)	
	Quadratic equation fitting	Cubic equation fitting
PF	0.393	0.575
NPK	0.778	0.778
Pestic	0.740	0.741

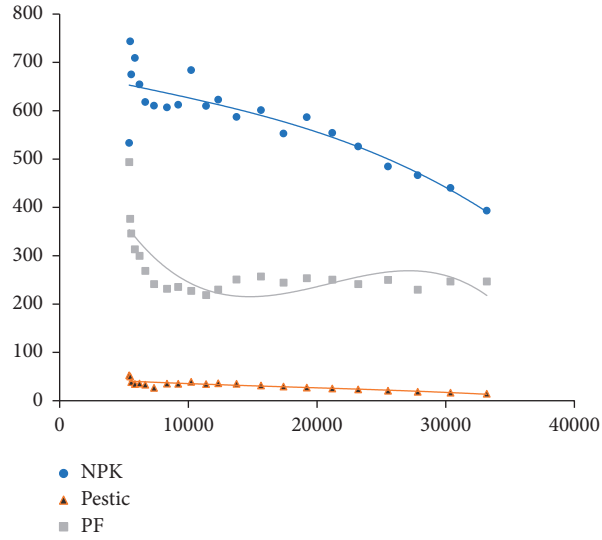

Figure 1: Fitting curve of the *ANSP* index and rural residents' per capita disposable income.

Based on the *EKC* results of pesticide application intensity and per capita disposable income of rural residents, the fitting curve's Sig value was $0.001 < 0.01$, and $R^2 = 0.741$. As can be seen, the cubic curve fits well and can be investigated further. According to the research results, there was a decreasing linear relationship between pesticide application intensity and rural residents' per capita disposable income. It demonstrates that, since 1998, with the dramatic rise in rural residents' levels of income, the pesticide application intensity in Shanghai has shown a downward trend. According to the fitting curve, the rate of decrease in pesticide application intensity in Shanghai slowed from 2008 to 2012, but after 2013, the pesticide application intensity has shown a rapid downward trend, which is likely to be related to China's establishment of a fully grown *ANSP* prevention and control policy system [31].

Finally, the relationship between plastic film application intensity and rural residents' per capita disposable income in Shanghai is shaped like an inverted "*N*," and the *EKC* theory inflection point was crossed in 2011 and 2017. Prior to 2010, Shanghai's cultivated land area decreased year after year, resulting in a decrease in mulching film application intensity and the first inflection point. The mulching film application intensity in Shanghai has been fluctuating at 246 kg/hm^2 since 2010, and the second inflection point appeared as the Shanghai government increased its efforts to manage the human settlement environment. Fertilizer application intensity, plastic film application intensity, and rural resident per capita disposable income decreased. The reason for this is that the arable land area in Shanghai has been decreasing year by year, and the upgrading of agricultural product consumption demand has resulted in a significant decrease in the use of fertilizer and pesticide in agricultural production by rural residents. As a result, it is necessary to master the current situation of the use of chemical fertilizers, pesticides, and mulching film in Shanghai and determine whether their application effects hinder farmers' economic income and lead to agricultural nonpoint source pollution, which needs to be discussed further from other perspectives.

4. Economic Driving Characteristics of *ANSP*

The *EKC* can explicitly explore form and trend characteristics between *ANSP* in Shanghai and rural residents' income levels and can determine whether there is an inflection point in *ANSP* when rural residents' income level increases, but the curve fails to provide in-depth proof of the inherent logical relationship and dynamic influence between the two, and the *VAR* model can compensate for the *EKC* model's limitations. The model can analyze the dynamic effects of random disturbances on endogenous variables by using *ANSP* and per capita disposable income of rural residents as system endogenous variables. As a result, this paper employs the *VAR* model to conduct an empirical analysis of *ANSP* and rural resident income level in Shanghai, dynamically analyzes the internal interaction between the two, deeply discusses the impact effect, and explains the contribution of each variable.

4.1. Stability Check

(1) *ADF* test. During the process of developing the *VAR* model, to avoid the pseudo-regression phenomenon during the time series analysis process, the data should really be tested for stationarity. *ADF* unit root test is used in this paper to perform the stationarity test. When the *ADF* test value of each variable is less than the 5% horizontal critical value, it means that the variable belongs to a stationary series; otherwise, it belongs to a nonstationary series. Concurrently, to eliminate potential influence of heteroscedasticity in data, logarithms within each variable were used to ensure model's stability. The findings of unit root test of *LnNPK*, *LnPestic*, *LnPF*, and *LnFarm* (as shown in Table 3) show that only *LnFarm* is a nonstationary sequence in the original variables, but after the first-order difference, *ADF* values of all variables are less than 5% significant, which meets *VAR* modeling requirements.

(2) Lag order determination and *VAR* model results. To ensure the model's validity, the lag period should be evaluated when constructing a *VAR* model. The lag order of the *VAR* model constructed by agricultural nonpoint source pollution and rural residents' income level is 1 based on AIC and SC information values in Table 4. Each variable is applied to first-order lag vector autoregression as a consequence. After regression, the goodness of fit is greater than

Table 3: Influencing factor index stationarity test.

Sequences	(C, T, K)	ADF statistics	0.05 critical value	Conclusion
LnNPK	(C, T, 0)	−4.1602	−3.6450	Stationary
LnPestic	(0, 0, 0)	−2.4708	−1.9581	Stationary
LnPF	(C, 0, 0)	−6.3853	−3.0124	Stationary
LnFarm	(C, T, 0)	−3.6233	−3.6584	Nonstationary
DLnNPK	(C, T, 0)	−10.392	−3.6584	Stationary
DLnPestic	(C, 0, 0)	−4.6850	−3.0207	Stationary
DLnPF	(0, 0, 0)	−4.6566	−1.9591	Stationary
DLnFarm	(C, 0, 1)	−3.6091	−3.0299	Stationary

Note. In (C, T, K), C means intercept, T means trend, K means lag, and 0 means no intercept or trend.

Table 4: Model lag order.

Lag	AIC	SC
0	−3.8491	−3.6502
1	−13.0959*	−12.1011*

Note: *Represents the optimal lag order.

0.9, indicating that the model is reasonable and can accurately reflect the dynamic relationship between variables.

4.2. Johansen Co-Integration Test. The Johansen co-integration test method is used in this paper to test *LnNPK*, *LnPestic*, *LnPF*, and *LnFarm* variables to ascertain whether there is any long-term stable co-integration relationship between many variables (as shown in Table 5). The findings demonstrate that *VAR* model rejects null hypothesis of "no co-integration relationship" at a 5% level of significance, and there are two co-integration relationships in the model, implying a long-term stable co-integration relationship between the variables. As a result, impulse response function and variance decomposition method can be used for additional analysis to scrutinize dynamic relationship and synergistic mechanism between growth of rural residents' per capita disposable income and plastic film, fertilizers, and pesticide.

4.3. Impulse Response Analysis. To research dynamic effects of plastic film, fertilizer, pesticide application intensity, and rural residents' per capita discretionary income, an impulse response function model was developed to explain the degree of impact between various endogenous variables, and an impulse response graph was created [32]. The horizontal axis represents the lag period, while the vertical axis represents the response degree.

Figure 2(a) demonstrates that per capita disposable income of rural residents adds one standard error shock disruption to plastic film application intensity. The impulse response value of the first to fifteenth period varies within the range of [−0.0185, 0], and the average driving effect of the first to fifteenth period is −0.0148. The negative inhibitory effect of rural residents' per capita disposable income on plastic film application intensity gradually increased from the first to fifth period, and the overall inhibitory effect from the sixth to fifteenth period showed a gentle trend. It has been shown that the negative impact of rural residents' per capita disposable income on plastic film application intensity has a rising trend and then shrinks. This illustrates that as time passes, the per capita disposable income of rural residents has an inhibitory effect on the application strength of plastic films, and this inhibitory effect tends to increase initially before stabilizing. Figure 2(b) demonstrates that plastic film application intensity adds one standard error shock disruption to rural residents' per capita disposable income, and impulse response value from the first to fifteenth period fluctuates within the range of [−0.0122, 0.0028]. From the first to the third period, plastic film application intensity has a significant inhibitory effect on rural residents' per capita disposable income, with an average driving effect of −0.0064. It exhibited a positive promotion effect after the fourth to eleventh periods, while the impulse response amplitude of the twelfth to fifteenth periods decreased noticeably and showed an inhibitory effect, eventually approaching −0.0009 smoothly. This illustrates that, in the short term, the effect of plastic film application intensity on per capita disposable income of rural residents exhibits an "inhibition⟶promotion⟶inhibition" trend. In the long term, the overall impulse response is found to have a negative inhibitory effect, but the effect is quite tiny.

Figure 2(c) demonstrates that per capita disposable income of rural residents adds one standard error shock disruption to fertilizer application intensity. The impulse response value of the first to fifteenth period varies within the range of [−0.0099, 0], and the average driving effect of the first to fifteenth period is −0.0075. The negative inhibitory effect of rural residents' per capita disposable income on fertilizer application intensity gradually increased from the first to sixth period, and the overall inhibitory effect from the seventh to fifteenth period showed a gentle trend. On the whole, the effect of rural residents' per capita disposable income on the fertilizer application intensity reveals that the inhibitory effect rises and then stabilizes over time. Figure 2(d) demonstrates that fertilizer application intensity adds one standard error shock disruption to rural residents' per capita disposable income, and impulse response value from the first to fifteenth period fluctuates within the range of [−0.0065, 0.0107]. From the first to the fourth period, fertilizer application intensity has a significant positive effect on rural residents' per capita disposable income, with an average driving effect of 0.0058. The average driving effect is −0.0052, and the overall income has a negative inhibitory effect. It has been shown that overall impact of fertilizer application intensity on rural residents' per capita disposable income is a promotion effect in initial stages and an inhibitory effect in the subsequent stages, which means the income rises first and then gradually stabilizes.

Figure 2(e) demonstrates that rural residents' per capita disposable income adds one standard error shock disturbance to pesticide application intensity, impulse response value of the first period is 0, and impulse response value of the second to fifteenth periods is in the range of [−0.0113, 0.0006]. Among them, rural residents' per capita disposable income in the second period has a significant positive promotion effect on the intensity of pesticide application,

Table 5: Johansen co-integration test.

Hypothesized No. of CE(s)	Eigenvalue	Trace test		Maximum eigenvalue	
		Trace statistic	0.05 critical value	Max-eigen statistic	0.05 critical value
None*	0.9168	84.2646	47.8561	52.2053	27.5843
At most 1*	0.6714	32.0593	29.7971	23.3685	21.1316
At most 2	0.3365	8.6909	15.4947	8.6148	14.2646
At most 3	0.0036	0.0761	3.8415	0.0761	3.8415

Note. *denotes rejection of the hypothesis at the 0.05 level.

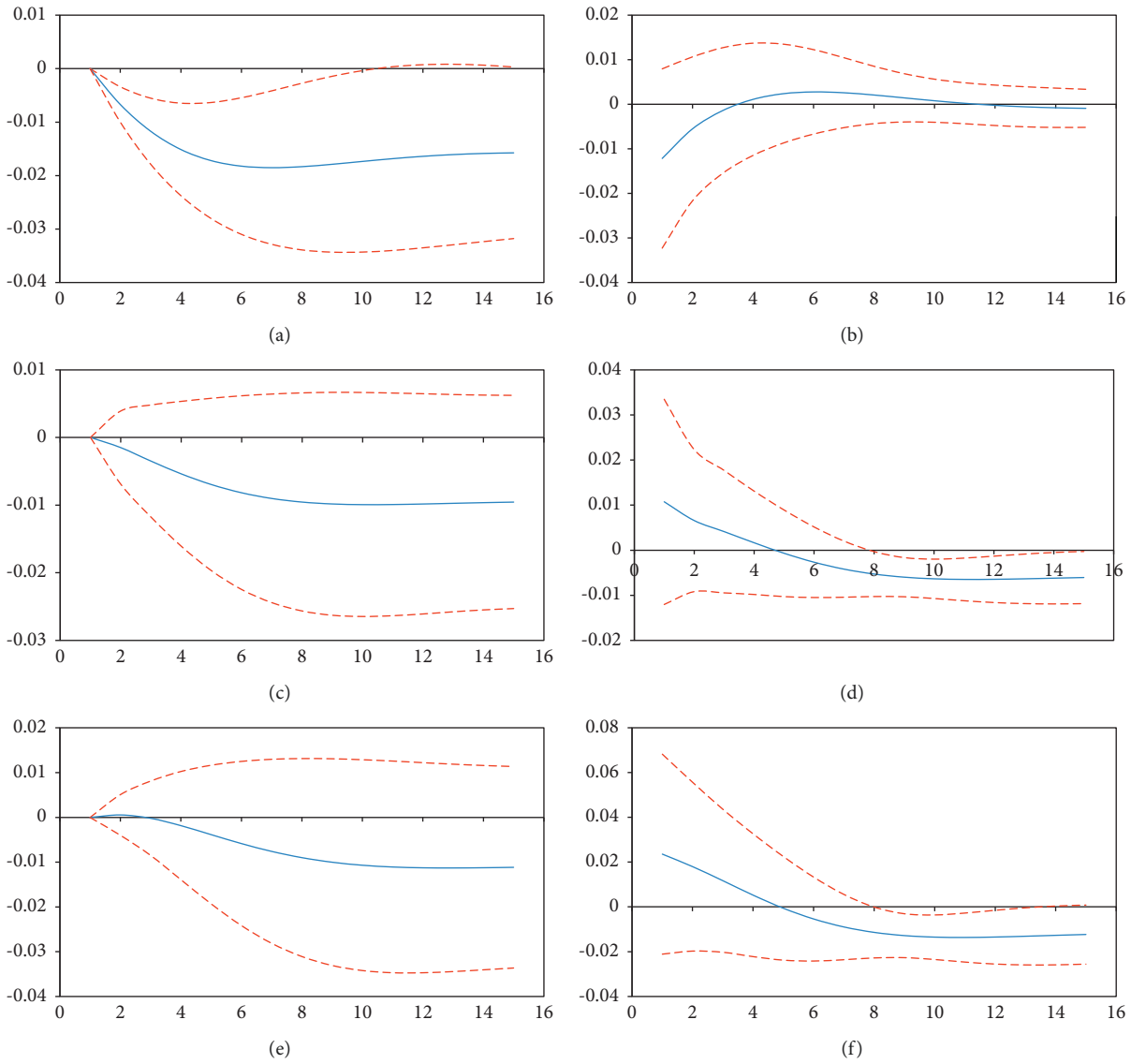

Figure 2: Impulse response graph between the application intensity of *NPK*, pesticides, and plastic film and economic growth. (a) Response of *LnFarm* to *LnPF*. (b) Response of *LnPF* to *LnFarm*. (c) Response of *LnFarm* to *LnNPK*. (d) Response of *LnNPK* to *LnFarm*. (e) Response of *LnFarm* to *LnPestic*. (f) Response of *LnPestic* to *LnFarm*.

with an impulse response value of 0.0006. From the third to fifteenth period, rural residents' per capita disposable income had a negative inhibitory effect on pesticide application intensity, with an average driving effect of −0.0081. From the third to eighth periods, rural residents' per capita disposable income had a significant negative inhibition effect on pesticide application intensity, and impact intensity increased gradually. As a whole, inhibition effect indicates a smooth trend from the ninth to fifteenth periods, eventually stabilizing at −0.0112. Overall, effect of rural residents' per capita disposable income on pesticide application intensity is generally a facilitation effect in the beginning period and an

inhibitory effect that increases first and then gradually stabilizes in the later phase. Figure 2(f) demonstrates that pesticide application intensity adds one standard error shock disruption to rural residents' per capita disposable income, and impulse response value from the first to fifteenth period fluctuates within the range of [−0.0137, 0.0236]. From the first to the fourth period, pesticide application intensity has a significant positive effect on rural residents' per capita disposable income, with an average driving effect of 0.0146. The average driving effect is −0.0108, and overall income has a negative inhibitory effect. It has been shown that overall impact of pesticide application intensity on rural residents' per capita disposable income is a decreasing promotion effect in initial stages and an inhibitory effect in the subsequent period, which raises first and then gradually stabilizes.

To summarize, the impact of *LnFarm* on *LnPF*, *LnNPK*, and *LnPestic* can be seen in the above three groups of impulse response functions as an inhibitory effect that increases initially and then gradually stabilizes. The effect of *LnNPK* and *LnPestic* on *LnFarm* revealed that first to fourth periods had a decreasing promotion effect and fifth to fifteenth periods had an inhibitory effect that increased initially and then gradually stabilized. The influence of *LnPF* on *LnFarm* revealed a fluctuating inhibitory effect. As a whole, the amount of *ANSP* in Shanghai will decrease as rural residents' income levels rise. Nonpoint source pollution reduction can improve rural residents' income in the short term, but it is not conducive to rural residents' income growth in the long run. The reason for this could be that, as shown in Figure 1, the application intensity of the *ANSP* index is relatively stable in the short term, and the input of plastic film, fertilizer, and pesticide can increase rural residents' income and promote agricultural economic growth to a degree. That is, in the threshold range, a short-term increase in agricultural inputs is beneficial to increasing the income of rural residents. Long-term films and the use of fertilizers and pesticides accumulate for farmers and unreasonable fertilization on farmland. In this instance, the long-term accumulation of agricultural pollution is challenging to address in a timely manner, impacting the output of agricultural products, and it is demonstrated as the inhibiting effect of ANSP on the rise in the income level of rural inhabitants. That is, the long-term use of agricultural inputs is detrimental to the income of rural residents. To achieve stable income growth for rural residents, it is necessary to comprehensively measure long-term and short-term benefits, to continuously reduce *ANSP* emissions on the one hand and to reduce the negative effects of *ANSP* on the agricultural environment on the other hand.

4.4. Variance Decomposition. Variance decomposition can decompose variance of a variable in a *VAR* model system into various disturbance terms and assess degree of influence of their interaction. This paper employs the variance decomposition method to investigate the interpretive significance and importance of each index of *ANSP* in Shanghai to the growth of rural residents' per capita disposable income, in addition to analyzing the contribution of each systemic shock to the change of endogenous variables. According to Table 6, in the decomposition of rural residents' disposable income, the average contribution of mulching film application intensity, fertilizer application intensity, and pesticide application intensity changes to the growth of rural residents' income level is 28.44 percent, 5.82 percent, and 4.34 percent, respectively. The results also showed that fertilizer and pesticide application intensity had a minor impact on the increase in rural residents' income, whereas plastic film application intensity had a significant impact. Simultaneously, average self-contribution degree of rural residents' income growth is 61.40 percent, which is average self-contribution rate after excluding plastic film, fertilizer, and pesticide emissions, and primarily includes agricultural mechanization level, production and operation mode, number of agricultural employees, and agricultural technology application and comprehensive development.

Table 6: Variance decomposition table of disposable income of rural residents.

Period	SE	*LnFarm*	*LnPF*	*LnNPK*	*LnPestic*
1	0.0171	100	0	0	0
2	0.0261	93.0320	6.5933	0.3303	0.0445
3	0.0345	83.5210	15.2402	1.2103	0.0284
4	0.0425	74.7705	22.6352	2.3908	0.2036
5	0.0501	67.5611	28.0596	3.6460	0.7333
6	0.0572	61.8488	31.7078	4.8387	1.6047
7	0.0637	57.3920	33.9962	5.8997	2.7122
8	0.0697	53.9389	35.3268	6.8043	3.9301
9	0.0752	51.2735	36.0216	7.5540	5.1510
10	0.0802	49.2208	36.3162	8.1636	6.2995
11	0.0848	47.6412	36.3734	8.6536	7.3318
12	0.0892	46.4243	36.3004	9.0455	8.2298
13	0.0932	45.4828	36.1652	9.3588	8.9932
14	0.0971	44.7482	36.0089	9.6104	9.6325
15	0.1008	44.1671	35.8547	9.8145	10.1637
Mean	0.0654	61.4015	28.4400	5.8214	4.3372

5. Conclusion and Suggestions

5.1. Conclusion. Academic researchers have long focused on the interaction between agricultural nonpoint source pollution and agricultural economy. This paper employs time series data to investigate dynamic relationship between *ANSP* and income level of rural inhabitants in Shanghai. According to the results of the *EKC* analysis, its intensity of mulching film application in Shanghai does have an inverted "*N*" curve relationship to rural residents' per capita disposable income. There was a diminishing linear association between the intensity of fertilizer and pesticide application and rural residents' per capita disposable income. Shanghai is currently on the right side of the *EKC*, and the intensity of plastic film, fertilizer, and pesticide applications will continue to decline and stabilize. A *VAR* model was used to examine the dynamic relationship and mechanism between *ANSP* and the income level of rural residents in Shanghai. The application intensity of plastic film, fertilizer and pesticide, and the per capita disposable income of rural residents showed inhibitory effect on each other. According to

variance decomposition results, application intensity of fertilizer and pesticides had a little driving impact on the growth in rural residents' income, but application intensity of plastic film had a more noticeable driving effect. This reveals that agricultural contamination induced by the use of fertilizers and pesticides is not immediately apparent. In comparison to fertilizers and pesticides, rural residents' desire for plastic film increases as their economic level rises. Plastic film overuse is a significant *ANSP* concern in Shanghai. Although *ANSP* is reducing in Shanghai, the long-term unreasonable and excessive use of chemical inputs such as plastic film, fertilizer, and pesticide continues to have negative effects on the agricultural environment, and the problem of *ANSP* cannot be solved naturally in the short term.

5.2. Suggestions. According to the findings of the preceding studies, economic development will result in the generation of agricultural nonpoint source pollution, as many scholars have concluded [33–35]. This paper demonstrates, through empirical research, that *ANSP* in Shanghai has entered a period of decline, and an improvement trend in Shanghai's agricultural environment is forming. To maintain this trend, not only should environmental governance policies and measures be strictly implemented, but more active ecological protection actions should be taken as well. On this basis, the best strategy for reducing *ANSP* while maintaining long-term economic growth for rural residents can be a composite of long-term and short-term considerations.

In the long term, the government encourages farmers to actively respond to the call, recognize the importance of *ANSP* control, establish farmland protection and nonpoint source pollution control subject consciousness, and improve their awareness of environmental protection and social responsibility sharing. On the other hand, the government should promote agricultural input reduction, clean production, waste recycling, and an ecological industry model, and the priority should be given to the development of an ecological circular agriculture mode for producers to provide green technology, increase capital and technology for nonpoint source remote sensing monitoring, and gradually improve the level of nonpoint source remote sensing monitoring and service management capabilities.

In the short term, the government should, on the one hand, gain a better understanding of farmers' willingness to participate in *ANSP* control and the factors that affect it, reduce farmers' nonpoint source pollution control costs through subsidies and technical assistance, and relieve farmers' financial stress. On the other hand, the government should use managerial means to establish reward and punishment mechanisms, orderly guide farmers to improve plastic film recovery rates and motivate the use of degradable plastic film and other new materials, strengthen the promotion of green fertilizer and organic fertilizer, establish a centralized pesticide distribution system, and control *ANSP* at the source.

Shanghai is used as an example in this paper, and the selection of indicators is based on the current situation of the region, which may lead to the limitations of the research results. In view of the limited academic ability of this paper, there may be differences in the selection of research objects, and the thinking on the problem is not mature enough. It is expected that relevant scholars can supplement and improve the study on urban agricultural nonpoint source pollution in follow-up research, so as to promote the sustainable development of urban agriculture.

Data Availability

Data from 1998 to 2019 were obtained from "China Environmental Statistical Yearbook," "China Agricultural Yearbook," "China Agricultural Statistics," "Shanghai National Economic and Social Development Historical Statistics," and "Shanghai Statistical Yearbook." All data included in this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Wetland Ecotourism Development Using Deep Learning and Grey Clustering Algorithm from the Perspective of Sustainable Development

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The purpose is to promote the sustainable development of wetland ecotourism in China and plan the passenger flow in different tourism periods. This work selects Zhangye Heihe wetland ecotourism spot as the research object. Firstly, the two single wetland ecotourism Demand Prediction Models (DPMs) are proposed based on the time series of the optimized Fuzzy Clustering Algorithm (FCA), grey theory, and the Markov Chain Method. The proposed wetland ecotourism DPM simulates and predicts the ecotourism passenger flow of wetland-scenic spots and verifies the maximum passenger flow. Then, a hybrid model combining the above two single models is proposed, namely, the wetland ecotourism DPM based on an optimized fuzzy grey clustering algorithm. Further, the proposed three models predict the passenger flow in wetland ecotourism spots from 2015 to 2019. A wetland Water Quality Evaluation (WQE) model based on Deep Learning Backpropagation Neural Network (Deep Learning (DL) BPNN) is proposed to evaluate the water quality in different water periods. The results show that the hybrid model's Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) are 1.25% and 0.2532. By comparison, for two single models, the MAPE is 11.67% and 1.45%, respectively, and the RMSE is 0.2526 and 0.1652, respectively. Therefore, the mixed hybrid has the highest accuracy and stability. The water quality of the scenic spot in the wet season is obviously better than that in the dry season and flat season. It is suggested that the natural environmental factors, such as water quality and passenger flow in different periods, should be considered when formulating ecotourism development strategies.

1. Introduction

Wetland is probably the best place for leisure tourism and an ecosystem with various resources for human existence. Thus, wetlands are considered to be the most effective and diversified ecological system in nature, upon which human survival and development depend. Wetlands are also the foundation for hydraulic engineering and water civilization [1, 2]. With the expansion of the global population, particularly the overwhelming number of tourists, and reckless exploitation, the ecological systems, such as wetlands, are being damaged and quickly disappearing. It only serves short-term and unsustainable social development. Meanwhile, the general population does not clearly know the wetland ecosystem, resulting in unreasonable use, large-scale destruction, and intentional waste of wetland resources [3]. The diminishing wetlands and their ecological functions threaten the fragile wetland biological systems, thereby affecting the human species' socioeconomic advancement [4]. Therefore, in response to the central government's sustainable development policies in China [5], it is urgent to efficiently plan the development of wetland ecotourism.

The tourism market is driven by tourism demand which is the critical profitability factor. Under inaccurate estimation of tourism demand, tourism supply may exceed demand, resulting in waste of resources. Hence, tourism investment and development policies should be formulated based on an accurate estimation of tourism demand [6]. Bose and Mali found an alternative solution for seasonal tourism demand estimation through the analysis of the

multisequence structure time series method based on new data restorage technology [7]. Jahani et al. analyzed the tourism impact evaluation model and accurately estimated the tourism pressure through the change in vegetation density [8]. Currently, the tourism DPM is inaccurate and unstable. To sum up, scholars have studied tourism demand from many aspects, which is paramount for predicting and mining tourism demand. However, the prediction of passenger flow from the aspect of wetland WQE in ecological scenic spots is not involved in the above research. Thus, there are also some deficiencies in the above research methods. In the development of information technology, Deep Learning (DL) and Grey Clustering Algorithms (GCAs) gather some observation indexes or observation objects into several definable categories according to the grey incidence matrix or the whitening weight function grey number. According to different clustering objects, it can be divided into grey correlation clustering and grey-whitening weight function clustering. The grey model can be combined with wetland WQE and existing mathematical and statistical methods for modeling and simulation. Thus, the grey model is more prevalent in tourism development and pedestrian flow prediction.

This work puts forward the wetland ecotourism DPM based on grey theory, cluster analysis, and Markov Chain Method (MCM). The proposed wetland ecotourism DPM can estimate the passenger flow of scenic wetland spots in different years. The main innovation is to monitor the water quality of wetland ecotourism using the Deep Learning Backpropagation Neural Network (DL BPNN). It simulates and predicts the tourism demand based on the time series of optimized GCA and the water quality rating of wetland ecotourism spots. The finding provides a practical basis for China's efficient and rapid development of wetland ecotourism spots.

2. Methodology

2.1. Tourism DPM Using Time Series Based on Optimized FCA. Model construction: The existing fuzzy time series generally includes four aspects. The first is the definition and domain division. The second is to fuzzify historical data. The third is to establish fuzzy logic relations and get the fuzzy relation group. The fourth is to calculate the fuzzy relation and produce the corresponding results [9, 10]. Here, based on the analysis of the existing algorithms, the K-means clustering algorithm can optimize the domain division and establish the fuzzy logic relation for estimation using the automatic clustering algorithm [11]. The specific algorithm steps are as follows.

Step 1. Data sorting: The sample data sequence is rearranged. The processed wetland ecotourism's demand data sequence M can be expressed as follows:

$$M = m_1, m_2, \ldots, m_i, \ldots m_n. \tag{1}$$

Step 2. The domain of the observed value is defined, and the interval is divided. The maximum m_n and minimum m_1 in the sequence are found in equation (1). Suppose that the domain is H, then H can be defined as follows:

$$H = [m_1 - P_1, m_n - P_2]. \tag{2}$$

In equation (2), P_1 and P_2 represent the required random positive numbers. Based on the characteristic values of the data sequence, the integral parts of the number are generally selected. Firstly, SPSS26.0 can call the K-means algorithm to cluster the M sequence to obtain k cluster centers. Then, the medians of two adjacent K centers are calculated successively to obtain $K-1$ values and introduced into the domain H to obtain K initial intervals (H_1, H_2, K, and H_k). The absolute value of the difference between two adjacent data in sequence M and the mean of the absolute value is calculated. Then half of the mean is regarded as the maximum allowable distance of the interval. These values are introduced into K initial intervals. The initial interval is divided twice. The length of each interval is different because the distribution of the data in the domain is not uniform, and the clustering results can divide the subintervals. Compared with the equal domain division, the distribution of the data structure can be better reflected, improving the estimation accuracy. Finally, the historical data are introduced into the corresponding interval. Each set of historical data corresponds to an interval.

Step 3. The data is fuzzified, and the logical relation is established. The fuzzy set Q_i is defined according to the interval obtained in step 2. The historical data is fuzzified according to the following:

$$\begin{cases} Q_1 = \dfrac{f_{11}}{H_1} + \dfrac{f_{12}}{H_2} + \cdots + \dfrac{f_{1n}}{H_n} \\ Q_2 = \dfrac{f_{21}}{H_1} + \dfrac{f_{22}}{H_2} + \cdots + \dfrac{f_{2n}}{H_n} \\ \cdots \\ Q_n = \dfrac{f_{n1}}{H_1} + \dfrac{f_{n2}}{H_2} + \cdots + \dfrac{f_{nn}}{H_n} \end{cases} \Rightarrow \begin{cases} Q_1 = \dfrac{1}{H_1} + \dfrac{0.5}{H_2} + \dfrac{0}{H_3} + \cdots + \dfrac{0}{H_n}, \\ Q_2 = \dfrac{0.5}{H_1} + \dfrac{1}{H_2} + \dfrac{0.5}{H_3} + \cdots + \dfrac{0}{H_n}, \\ \cdots, \\ Q_n = \dfrac{0}{H_1} + \dfrac{0}{H_2} + \cdots + \dfrac{0}{H_{n-1}} + \dfrac{1}{H_n}. \end{cases} \tag{3}$$

After fuzzification, the fuzzy logic relation can be obtained, namely $Q_i \longrightarrow Q_j$ (if the m^{th} year corresponds to Q_i, then the $m+1^{\text{th}}$ year belongs to Q_j).

Step 4. Defuzzification and estimation. Here, the wetland ecotourism demand is estimated, and the mathematical expression can be expressed as follows:

$$U_j = \frac{\left(w + E\left[Q_j^*\right]\right)}{(R+1)}, \tag{4}$$

$$\begin{cases} R_i = \left|\left|O_i - O_{i-1}\right| - \left|O_{i-1} - O_{i-2}\right|\right|, \\ X_i = O_i + \dfrac{R_i}{2}, \\ XX_i = O_i - \dfrac{R_i}{2}, \\ Y_i = O_i + R_i, \\ YY_i = O_i - R_i, \end{cases} \tag{5}$$

In equations (4) and (5), $[Q_j^*]$ denotes the interval H_j with a membership degree of 1 in fuzzy set Q_j, O_i represents the actual data of the m^{th} year, and U_j stands for the estimated value of the $m+1^{\text{th}}$ year. If the third-order model is adopted, the data of the $m+1^{\text{th}}$ year are estimated through the data of the $(m-2)$th, $(m-1)$th, and mth years, and then each index is calculated through equation (5). Similarly, if the fourth-order model is adopted, it is so deduced.

Step 5. Model accuracy evaluation. Here, the model accuracy is estimated based on the MAPE and RMSE. The calculation process is shown as follows:

$$\text{MAPE} = \frac{\sum_{i=1}^{m} \left| \hat{y}_i - y_i \right| / y_i}{m}, \tag{6}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i-1}^{m} \left(\hat{y}_i - y_i \right)^2}{m}}. \tag{7}$$

In equations (6) and (7), $\hat{y}_i$ represents the estimated value, y_i denotes the actual value, and m stands for the number of test data. The smaller the MAPE and RMSE are, the higher the estimation accuracy of the model is.

2.2. Tourism DPM Based on Fuzzy Grey Markov Chain. Data of the tourism system are uncertain, incomplete, dynamic, and limited, much in line with the characteristics of a grey system, so the grey system theory can estimate the tourism demand [12]. The deepening research of grey estimation theory suggests that the grey system estimation method shows less accuracy and precision due to the disorder of initial data [13]. Therefore, a new tourism DPM is proposed based on fuzzy grey theory and the MCM [14].

First, the grey theory is discussed. The subjects of grey system theory [15] are uncertain systems with partial information. Information generation and extraction can obtain valuable information to accurately describe and effectively control system operation behavior and evolution rules. Grey system theory is composed of a grey estimation model, grey clustering analysis, grey correlation analysis, grey decision-making method, and grey sequence operator, and the main technical contents include data processing and analysis, model construction, major problem decision, and development trend estimation. Estimation is to speculate and understand the future through past exploration. Grey estimation [16] processes the original data through grey system theory, establishes an estimation model, studies and discovers the system's development law, and scientifically and quantitatively estimates the future state and trend of the system.

The wetland ecotourism demand is a comprehensive random event of fuzziness and contingency. It is estimable with grey theory. Thus, the grey GM (1,1) model [17] is chosen for estimation, the basic grey system theory model. The basic idea is to establish an estimation model by transforming the original irregular sample data sequence to obtain a new and uniform data sequence. The modeling of the grey GM (1,1) model is as follows.

2.2.1. Data are Preprocessed. Original data are mostly irregular and random and cannot construct the model directly, so the original data sequence should be preprocessed. If the original data sequence is D_0, then the following equation can be obtained:

$$D_0 = \{D_0(1), D_0(2), \ldots, D_0(m)\}. \tag{8}$$

Then, the original data are judged for modeling applicability as follows:

$$\alpha(k) = \frac{D_0(k-1)}{D_0(k)}, \quad k = 2, 3, \ldots, M. \tag{9}$$

In equation (9), if $\alpha(k)$ is covered, the original data sequence can be used for the estimation model. Otherwise, the original data sequence should be corrected to the allowable coverage. Then the corrected data sequence is used for modeling and estimation. Generally, the translation variation method is adopted.

$$Y_0(k) = D_0(k) + z, \quad k = 1, 2, \ldots M. \tag{10}$$

In equation (10), (Y_0) represents the estimated value of modeling, and z is a constant. The new data sequences can be obtained through continuous cumulation based on the above operations.

2.2.2. Matrix and Vector are Constructed. The new data sequence obtained through equation (11) improves the regularity of the original data sequence and reduces the randomness. With the increase of the cumulative number, the randomness weakens more. The cumulative matrix G and constant term vector l are constructed through equations (12) and (13) as follows:

$$G = \begin{bmatrix} -\dfrac{(D_1(2) + D_1(1))}{2} & 1 \\ -\dfrac{(D_1(3) + D_1(2))}{2} & 1 \\ \cdots & \\ -\dfrac{D_1(n) + D_1(n-1)}{2} & 1 \end{bmatrix}, \tag{11}$$

$$Y_m = \left(D_0(2), D_0(3), \ldots, D_0(m)\right)^T. \tag{12}$$

In equation (13), T represents the time set.

Afterward, the basic form of the GM (1,1) model is constructed. Assume that the development coefficient is h, and the grey action is f, then equation (13) can be obtained through the LSM (Least Squares Method) as follows:

$$\begin{aligned} f &= \frac{dD_1}{\mathrm{d}t} + hD_1, \\ \hat{h} &= \begin{bmatrix} h \\ f \end{bmatrix} = \left(F^T F\right)^{-1} F^T Y_m. \end{aligned} \tag{13}$$

The estimation model can be obtained through the introduction of h and f into the time function, as follows:

$$\hat{D}_1\ (m+1) = \left(D_0(1) - \frac{f}{h}\right)e^{-hk} + \frac{f}{h}, \quad k = 1, 2, \ldots m. \tag{14}$$

Equation (15) can be obtained through the derivation of $\hat{D}_1$ in equation (14) as follows:

$$\hat{D}_0\ (m) = \hat{D}_1\ (m+1) - \hat{D}_1\ (m). \tag{15}$$

In equation (15), $\hat{D}_0\ (m)$ represents the estimated value.

2.2.3. The MCM is Explained. The Markov estimation method can estimate the probability of events. According to the current situation, the developmental change in each future period can be estimated.

Let $T = \{0,1,2,...\}$ be a random process. Let R be a state space, $R = \{1,2,3,...\}$, random positive integers i_1, i_2, and i_3, nonnegative integers o_1, o_2, and o_3, $o1 > L > o2 > o3$, and the correspondent state are $E_{i_2+i_3}, E_{i_2}, E_{o_1}, L, E_{o_2}, E_{o_3}$, then equation (16) can be obtained as follows:

$$S\{E(i_2 + i_3)\} = P\{E(i_2 + i_3)\} = E_{i_2+i_3} | E(i_2) = E_{i_2}. \tag{16}$$

Specifically, $\{X(t), t \in T\}$ is the Markov chain. Usually, $S_{Ei}(i_2)$ is related to states E, i, and i_2. Only when $S_{Ei}(i_2)$ is not related to i_2, the Markov chain will contain stationary transition probability.

Finally, the tourism DPM based on a fuzzy grey MCM is constructed. Since the traditional grey estimation model is suitable for objects with less data, less time, and less fluctuation, it can estimate the changing trend of the whole system [18]. The Markov chain can estimate a random local change and generate different-state estimated values, leading to large deviation and thereby affecting the final estimation accuracy [19].

The fuzzy grey MCM is based on the traditional GM (1,1) method, which combines the advantages of the MCM with fuzzy classification theory. The fuzzy classification method is used at the end of the estimation period; any sample data may belong to different categories with different adherences. When the sample is disturbed, the estimated value changes. The adherence of the corresponding state class will change, and this method can improve its anti-interference ability [20]. The modeling steps of the fuzzy grey Markov chain estimation model are as follows.

Step 6. Data processing. According to the principle of grey estimation, GM (1,1) is established to achieve a fitting estimation according to the method in Section 2. Then the traditional grey parameters h and f are solved based on the original data sequence to establish a grey estimation model.

Step 7. After the accuracy is tested out according to the method in Section 2.1, the state division and fuzzy classification are carried out. The relative residuals between the original data sequence and the estimated value of the grey model are used as the division standard, and the system state is divided to obtain the membership function of the fuzzy set, obtaining the fuzzy state vector.

Step 8. Model accuracy test. Here, the residual test method [21] can evaluate the accuracy of the constructed model. The residual sequence is obtained from the original sequence and estimation sequence of the model: $\mu 0 = \{\mu 0(1), \mu 0(2), L, \mu 0(m)\}$. Then, the relative error ψi and the average relative error can be expressed in the following equations, respectively:

$$\psi_i = \frac{u_0(i)}{D_0(i)} * 100\%, \tag{17}$$

$$\overline{\psi} = \frac{1}{m}\sum_{i=1}^{m} |\psi(i)| * 100\%. \tag{18}$$

In equations (17) and (18), D_0 represents the initial value of the original sequence, and m denotes the number of test values. When the mean relative error is less than a given value, in general, if $\overline{\psi} < 0.2$, the model passes the residual test, indicating that the model has high accuracy.

2.3. Wetland Ecotourism DPM Based on Optimized Fuzzy GCA. Currently, the domestic tourism DPM is singular, while many internal and external factors may affect the tourism demand. A singular DPM can only capture some main factors and is incomplete and not fully effective, resulting in low accuracy and low stability in the estimation results [22, 23]. The hybrid estimation method can improve the accuracy and stability of the estimation result by utilizing effective information from every single model. Here, the fuzzy grey MCM is combined with the time series model based on fuzzy clustering to form a hybrid wetland ecotourism DPM.

Consequently, two single models of sections 2.1, 2.2 are combined. Assume that the weighted vector in the hybrid DPM is the estimation accuracy a-λ of m estimation methods at time t arranged in order from large to small. a–λ is the subscribe of the nth largest estimation accuracy; then equation (19) can be obtained as follows:

$$f_w(\langle a_{1t}, D_{1t}\rangle, \ldots, \langle a_{mt}, D_{mt}\rangle) = \sum_{i=1}^{m} w_i D_{a-\lambda}. \tag{19}$$

In equation (19), f_w denotes the hybrid estimation value, indicating that the hybrid DPM is only related to the estimation accuracy of the single estimation methods at a given time point. Then, the hybrid DPM based on the minimum sum of squares of errors is expressed as follows:

$$\min R(w) = \sum_{i=1}^{m}\sum_{j=1}^{m} w_i w_j \left(\sum_{t=1}^{n} e_{a-i\lambda} e_{a-j\lambda}\right). \tag{20}$$

In equation (20), $\sum_{i=1}^{m} w_i = 1$, $w_i \geq 0$, $i = 1, 2, \ldots m$, and R represents the sum of squares of the total error. Let $\overline{g_1}(T) = 1/T\sum_{t=1}^{T-1} g_i(n-t)$, $T = 1, 2, \ldots, n$, and $\overline{g_1}(T)$ denotes the mean estimation accuracy from time T to m. The

larger the value is, the higher the accuracy of the hybrid model is.

2.4. WQE of Wetland Based on BPNN. Backpropagation Neural Network (BPNN) is a multilayer feedforward Deep Learning Neural Network (DLNN) trained by the error Backpropagation (BP) algorithm. It has wide applications [24]. BPNN has the ability of arbitrary complex pattern classification and excellent multidimensional function mapping. Thus, it can solve problems that simple sensors cannot solve, such as the XOR problem [25]. BPNN comprises the input, hidden, and output layers. Specifically, the input layer represents the input of data elements. The hidden layer transmits signals between the input layer and the output layer. The output layer is responsible for the transfer and output of signal elements, as shown in Figure 1.

Essentially, the BP algorithm calculates the minimum object function (network error square) through the gradient descent method [26]. Assume that the input layer sample set U contains m training samples (vectors), and the index number of each sample is n. Assume that the training input is I, the output result is Y, the target result is D, and the weight is p. Then, the input of the i^{th} neuron in the first hidden layer is the weight product between the input layer and the first layer, as calculated through the following:

$$H_1^i = \sum_{n=1}^{n} p_n U_{Xn}. \tag{21}$$

In equation (21), U_{xn} represents the X^{th} sample input vector.

The product of the output of the last hidden layer and the weight of the next hidden layer is the input of the next hidden layer. The results are transmitted in the network through the transfer function. The input of the output layer is output through the transfer function as the output of the H^{th} neuron [27], as expressed as follows:

$$Y_D^D = f\left(\sum_{b=1}^{B} p_{bp} Y_b^B\right). \tag{22}$$

In equation (22), Y represents the output marker, B denotes the number of neurons in the final hidden layer, and b stands for the b^{th} neuron.

2.5. Model Parameters' Design

(1) Here, the tourism number in Zhangye Heihe wetland from 2015 to 2019 are taken as the sample [from CSY (China Statistical Yearbook)]. The statistics are shown in Table 1.

(2) Matrix Laboratory (MATLAB) can calculate the optimal weight coefficient of wetland ecotourism DPM based on optimized fuzzy GCA: $w_1 = 1$, $w_2 = 0$.

(3) According to the standard water quality rating in the Environmental Quality Standard for Surface Water, the wetland WQE BPNN is trained. The output values of standard class I, II, III, III, IV, and V water quality are 0.1, 0.3, 0.5, 0.7, and 0.9, respectively. Here, ten water samples are randomly selected from Zhangye Heihe's wetland-scenic spot as BPNN's learning samples.

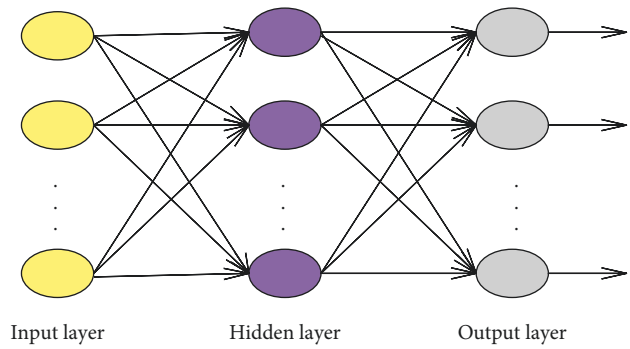

Figure 1: structure of BPNN.

Table 1: Tourism Number of Zhangye Heihe wetland in 2015–2019.

Year	The actual number of tourists (ten thousand)
2015	1,600
2016	2,010
2017	2599
2018	3,000
2019	3,612

Table 2: Fuzzy relation table.

Year	The actual number of tourists (ten thousand)	The fuzzified number of people
2015	1,600	Q_1
2016	2,010	Q_2
2017	2,599	Q_3
2018	3,000	Q_4
2019	3,612	Q_5

3. Results and Discussion

3.1. Results of the Tourism Demand Estimation Using Time Series Based on Optimized FCA. The fuzzy logical relation is obtained through the model calculation for the original data sequence of the number of tourists in the scenic area of Zhangye Heihe wetland from 2015 to 2019, as shown in Table 2.

Then, the number of wetland ecotourism in 2015–2019 is estimated, and the fitting estimation graph is shown in Figure 2.

Figure 2 illustrates that the actual tourism population from 2015 to 2019 is 16 million, 20.10 million, 25.99 million, 30 million, and 36.12 million, respectively. In contrast, the estimated number are 15.6 million, 19.95 million, 25.75 million, 29.68 million, and 35.96 million, respectively. The estimation errors are 400,000, 150,000, 240,000, 320,000, and 160,000, respectively. Thus, the estimability of the improved fuzzy time series model is good, and the error is small, indicating that the estimated value of the model is consistent with the actual situation.

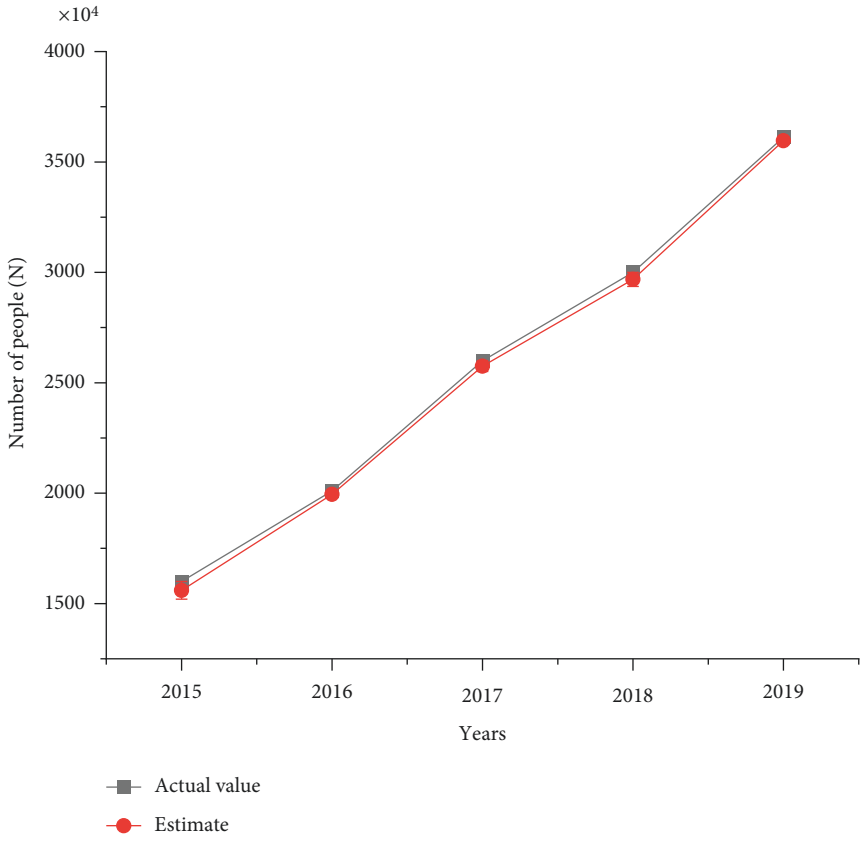

Figure 2: Comparison of estimated and actual tourism population in Zhangye Heihe wetland from 2015 to 2019.

Then, the improved fuzzy time series model is compared with relevant models in the field regarding their accuracy, as shown in Figure 3.

Figure 3 demonstrates that the MAPE of the optimized fuzzy time series model is small, only 1.45%, and the RMSE is 0.2532. Compared with model M_2, the estimation accuracy has been greatly improved. Compared with model M_1, their estimation accuracy is basically the same. However, the research model has strong estimation accuracy while simplifying the calculation process.

3.2. Wetland Ecotourism Demand Estimation Based on Fuzzy Grey MCM. According to the number of tourists in the scenic area of Zhang Ye Heihe wetland from 2015 to 2019, the GM (1,1) model simulation data are tested. The results are shown in Figure 4.

Figure 4 displays that the relative error between the actual value and the estimated value of the model is less than 8%, and the mean relative error is less than 0.2. The estimation accuracy of the model is 95.8%, indicating that the model has passed the residual test. The posterior variance of the model is less than 0.35, and the minimum error probability is greater than 0.95, indicating that the model has high accuracy. However, the relative error between the estimated value and the actual value of the model is greater than 5%, so the accuracy of the model estimation results needs to be further improved.

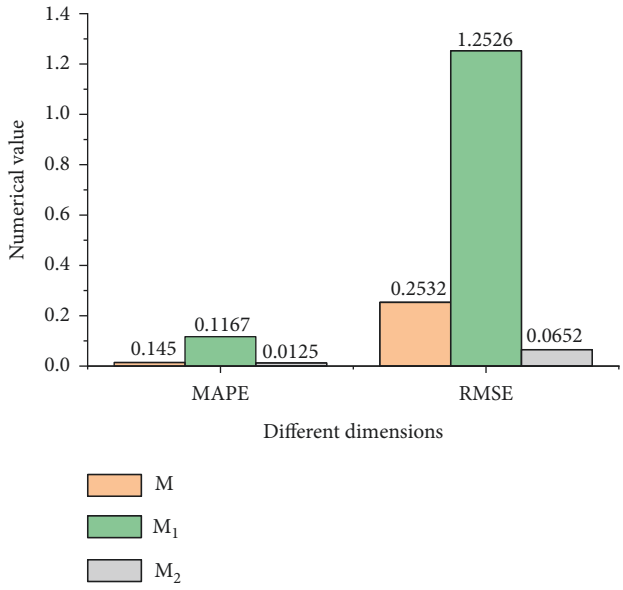

Figure 3: Errors of different models (M) the proposed optimization model M_1: Model 1 in the field M_2: Model 2 in this field).

The estimated value of the model corrected through the MCM is shown in Figure 5.

Figure 5 implies that the relative error of the corrected fuzzy grey Markov chain estimation model is much smaller

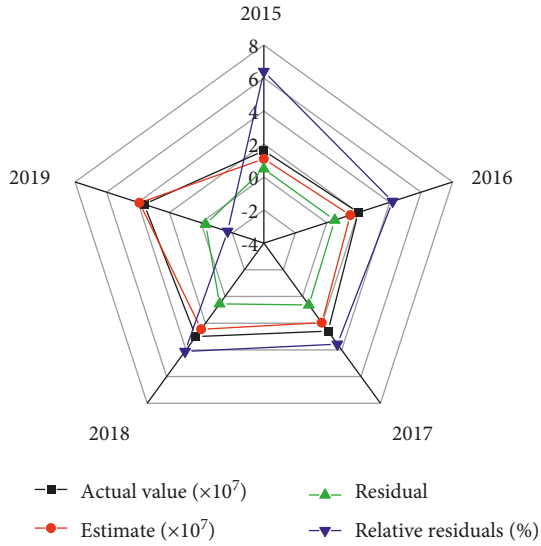

Figure 4: GM (1,1) model simulation results.

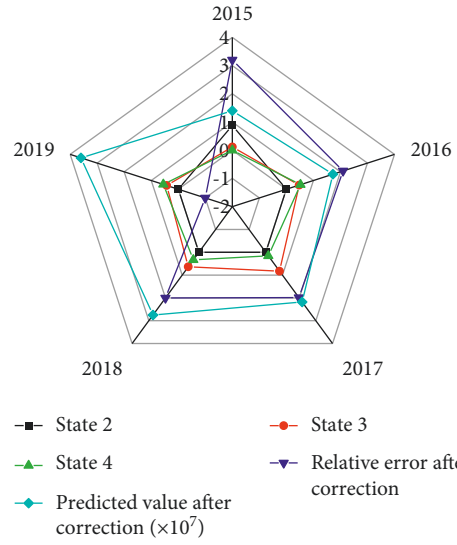

Figure 5: Estimation results after model correction.

than that of the original grey theory model. The mean (1,1) relative error of the original grey GM model is 3.5%, and the mean relative error of the fuzzy Markov chain estimation model is 2.01%. Meanwhile, the maximum relative error of the corrected estimation results is less than 3.8%, which is about 2.9% lower than the maximum relative error of the original model. The estimation results of the corrected model are closer to the actual value, the fluctuation is small, and the overall accuracy of the estimation is greatly improved.

3.3. Estimation Results of Wetland Ecotourism Demand Based on Optimized Fuzzy GCA. A comparison of the estimated results of the three models is shown in Figure 6.

Figure 6 shows that the wetland ecotourism DPM based on the optimized fuzzy GCA (the hybrid model) has obtained more stable results, less estimation error, and higher accuracy. The MAPE of the overall estimation is 1.19%, while the corresponding values estimated by the two separate models are 1.45% and 2.01%, respectively. Besides, the RMSE of the hybrid DPM is the smallest of the three models. Thus, the hybrid DPM has better estimate ability, overcomes the estimation defects of a single model, and improves the accuracy and stability of estimation.

3.4. WQE Results of Zhangye Heihe Wetland Based on DL BPNN. BPNN WQE model for Zhangye Heihe wetland in dry season WQE results is shown in Figure 7.

Figure 7 suggests that the water quality of the wetland-scenic spot in the dry season is mostly maintained at level II. Only two monitoring points are at level III, and two monitoring points are at level IV. The output value of BPNN

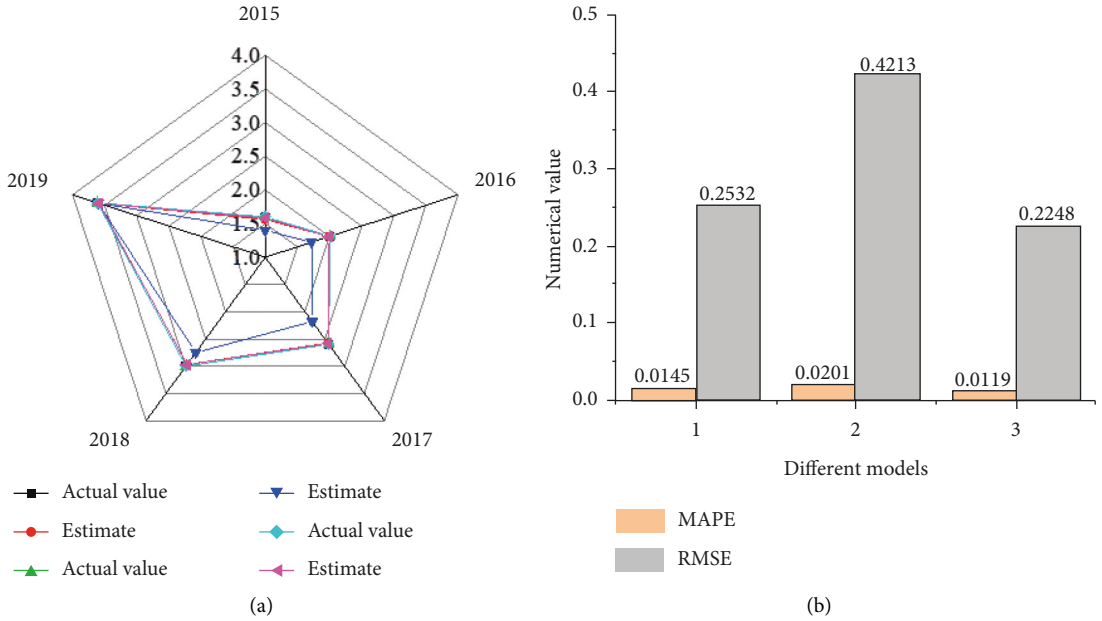

Figure 6: Comparison of estimation results of wetland ecotourism number of different models (a) comparison of the estimated number and the actual number of three models (b) MAPE and RMSE index values estimated by three models 1: Wetland ecotourism DPM of time series based on optimized FCA 2: Wetland ecotourism DPM based on fuzzy grey MCM 3: DPM for wetland ecotourism based on optimized fuzzy GCA).

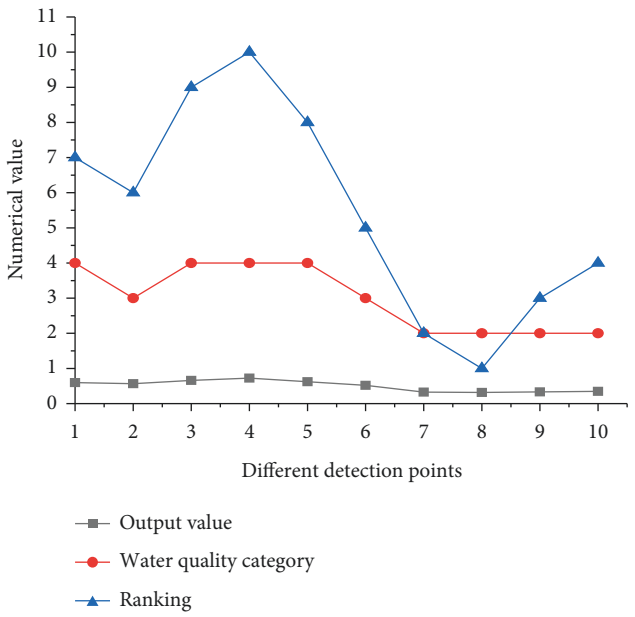

Figure 7: Evaluation results of water quality of Heihe wetland in Zhangye in the dry season.

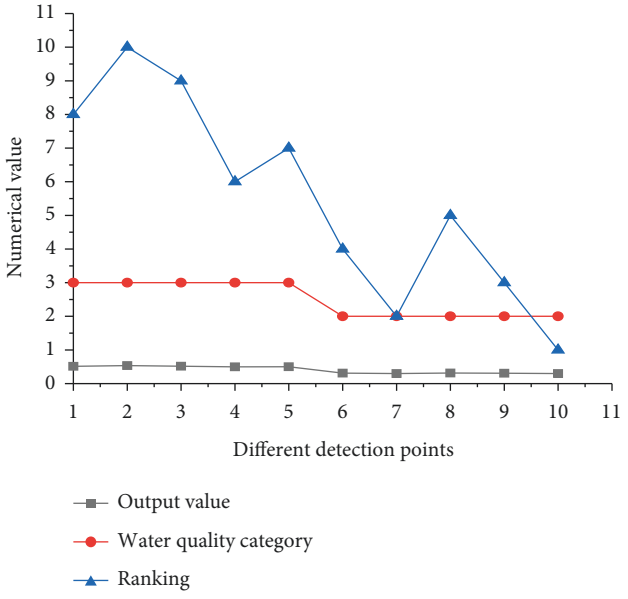

Figure 8: WQE results of Heihe wetland in Zhangye during the level season.

is between 0.3 and 0.8, and the lower the output value is, the better the water quality of the monitoring point is.

The WQE results of Zhangye Heihe wetland in level season based on the BPNN model are shown in Figure 8.

Figure 8 suggests that the water quality of half of the wetland-scenic spots is maintained at level II, and the other half is maintained at level III during the level season. The output value of BPNN is between 0.2 and 0.55. The lower the output value is, the better the water quality of the monitoring point is. In the level season, the quantity of water increases, and the water quality improves significantly.

The WQE results of Zhangye Heihe wetland in the wet season based on the BPNN model are shown in Figure 9.

Figure 9 illustrates that the water quality of six monitoring points in the wetland-scenic spot is maintained at level II in the wet season. Two points are at level III, and another two points are at Level I. The output value of BPNN

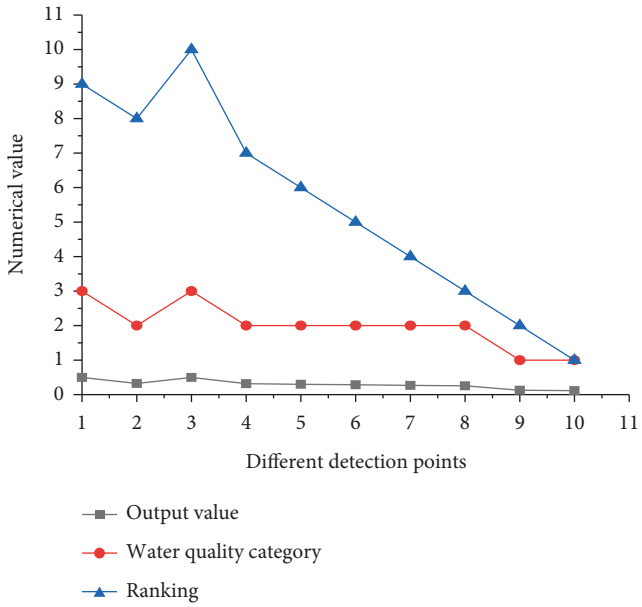

Figure 9: WQE results of Heihe wetland in Zhangye during the wet season.

is between 0.1 and 0.5, indicating that the water quantity and water quality of the wetland-scenic spot are greatly increased in the wet period. Hence, the scenic area of the Zhangye Heihe wetland is suitable for tourism during the wet season. During this time, the water quality is high, the climate is pleasant, and the passenger flow will increase.

4. Conclusion

Under the background of the rapid development of information technology, this work aims to develop and plan wetland ecotourism scientifically. Two single models are proposed using the time series of optimized FCA and the fuzzy grey MCM. The research implements the prediction model by optimizing the fuzzy GCA, and the feasibility of the research method has been verified. Then, based on the optimized fuzzy GCA, a hybrid wetland ecotourism DPM is proposed by combining two single models. The passenger flow in the Heihe wetland-scenic spot of Zhangye, from 2015 to 2019 is predicted. Further, a WQE model of wetland ecotourism spot based on DL BPNN is proposed to monitor the water quality in different water periods. The estimation accuracy of the hybrid model is higher than that of every two single models. Therefore, the hybrid DPM has better estimability, overcomes the estimation defects of a single model, and improves the accuracy and stability of estimation. The water quality of the ecotourism spots in the wet season is significantly better than that in the dry and flat seasons. This suggests that the tourism department should optimize the development planning according to the wetland-scenic spot's passenger flow and ecological environment to improve ecotourism economic benefits. Lastly, there are some deficiencies in this work. Mainly, the range and size of samples are relatively narrow. There are many wetland-scenic spots in China. However, only one wetland ecotourism spot is selected for the experiment. Meanwhile, there are few monitoring points for WQE, resulting in the low accuracy of the prediction model. The later research plan will expand the selection range of sample data and select more wetland ecotourism spots to verify the model.

Data Availability

The raw data supporting the conclusions of this article can be obtained from the corresponding author upon request.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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Research Article

Green Finance and Corporate Green Innovation: Based on China's Green Finance Reform and Innovation Pilot Policy

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Using data on China's A-share listed enterprises from 2012 to 2019, we investigate the impact of China's green finance reform and innovation pilot (GFRIP) policy on green innovation by the difference-in-difference (DID) method. The results show that the GFRIP policy has a significant role in promoting enterprises' green innovation. Heterogeneity analysis shows that the positive effect of the GFRIP policy on green innovation is only significant for heavily polluting enterprises, large enterprises, state-owned enterprises, and enterprises headquartered in regions with a low level of marketization. Debt financing is an important mechanism for the GFRIP policy to promote corporate green innovation; that is, the GFRIP policy alleviates corporate debt financing constraints and then promotes corporate green innovation. Our study provides theoretical and practical enlightenment for developing countries such as China to deepen reform of the green financial system and promote green innovation.

1. Introduction

To catch up economically, China has adopted the development strategy of prioritizing growth and actively promoting industrialization and urbanization to stimulate economic growth, which has caused serious environmental pollution problems. In the context of the global race toward green development and sustainable development, there has been a consensus to establish a green financial system. China has made some progress in developing green finance; however, some financial institutions still have concerns about the risks in the green industry. In 2017, China implemented the green finance reform and innovation pilot (GFRIP) policy in some provinces, which is viewed as a positive step toward developing green finance.

As the mainstay of technological innovation, it is crucial for enterprises to achieve green development in China. To promote enterprises' green innovation, governments generally use environmental regulation tools. However, there is disagreement over the consequences of environmental regulations. On the one hand, well-designed and appropriate environmental regulation policies are considered a contributor to corporate technological innovation [1–4], demonstrating the "Porter hypothesis" [5, 6]. Appropriate environmental regulation can lead to more innovative activities by firms, which increases their productivity and improves firms' profitability in the market. On the other hand, environmental regulations are believed to increase firms' costs and thus inhibit their technological innovation [7, 8]. In addition to environmental regulations, debt financing is essential for green innovation. Enterprises' innovative activities may face financing constraints [9–11]. Environmental regulations may affect the innovation activities of enterprises by easing or decreasing financing constraints.

The Chinese government attaches great importance to green finance's contribution to the economy. Green finance policies can realize the optimal allocation of financial resources, which is an important exploration for China to promote the development of a green economy by using market instruments such as financial supervision. The GFRIP policy complements traditional environmental

regulations. The Chinese government decided to select five provinces (regions) as the first batch of pilots for the GFRIP policy with local characteristics in June 2017, including Zhejiang Province, Jiangxi Province, Guizhou Province, Xinjiang Autonomous Region, and Guangdong Province. Under the guidance of unified macro policies, these regions have actively explored green financial standards, products, and services. Green financial policies with different characteristics have effectively guided the optimal allocation of financial resources; that is, green environmental protection projects have received more fund supplies, while heavily polluting firms (HPFs) are facing increasingly serious financing constraints.

Enterprises need continuous and stable financial support to achieve green innovation. Green finance policies promote the redistribution of financial resources among enterprises by means of strict audit conditions and credit quota management. The Porter hypothesis assumes that HPFs have a stronger incentive than non-heavily polluting firms (non-HPFs) to innovate to increase the "green" content of their products. It is more urgent for HPFs to eliminate the adverse effects of financial regulations on their business. An increasing number of developing countries are promoting green finance and implementing new measures to support green finance with the goal of supporting the sustainable development of enterprises. China has actively issued green bonds and green credit to support the green innovation of enterprises. However, enterprise green innovation and green investment are characterized by longer investment cycles, uncertain income, and imperfect information disclosure. This study reveals the impact of the GFRIP policy on enterprise green innovation. How does the GFRIP policy impact green innovation, and does it have different impacts on different kinds of enterprises? How does the GFRIP policy affect enterprises' green innovation? This study explores, for the first time, the effect of the GFRIP policy and the differences of its impacts and mechanisms among different enterprises using data on China's listed companies. We believe that this study has important theoretical and practical significance for green financial innovation, green financial reform pilot experiments in developing countries, and promoting the green development of enterprises.

Our research contributes to the current literature on two levels. First, this research complements the existing research into the economic effects of environmental regulations. The existing research on environmental policies focuses mainly on traditional environmental policies, including command and control regulations and market-oriented instruments, such as mandatory emission reduction targets imposed by enterprises and carbon emission trading. The GFRIP policy is a special environmental regulation policy. There is a lack of research on this policy's microeconomic effect and enterprises' innovation behavior. The study analyzes the impact of the GFRIP policy on green innovation and concludes that the policy positively impacts enterprises' green innovation by applying the DID model. Second, this paper provides a new perspective for related research on the GFRIP policy. We analyze the GFRIP policy from the point of view of enterprise innovation and provide more micro evidence for green finance policies. One of the objectives of the GFRIP policy is to promote the green transformation of enterprises and sustainable development. This study confirms the positive effect of the GFRIP policy on enterprises' green development and provides guidance for developing countries that are actively exploring the development of green finance.

2. Literature Review

Early research in this area focused on the impact of green financing policies and factors affecting green innovation in enterprises. Green finance includes a range of financial instruments and services, such as green credit, green bonds, green funds, fiscal policy, and green insurance. The Green Credit Guidelines issued in 2012 clearly defined the standards and principles of green credit policies of financial institutions. Liu, Wang, and Kai found that China's Green Credit Guidelines significantly reduced the debt financing of HPFs [12]. Green credit policy truly does have a "reward" effect for non-"two-high and one-high" enterprises and a "penalty" effect for "two-high and one-high" enterprises. According to Hao et al. [13], green credit policy has a favorable impact on heavy polluters in more market-oriented regions, particularly in developing countries. The influence of the green credit policy on HPFs is significantly positive, and this impact occurs mainly through increased credit restrictions [14]. Companies can improve their environmental performance by issuing green bonds, which has a beneficial effect on the company's stock value [15]. However, corporate green bonds do not carry a significant premium and benefit existing shareholders only [16]. Some studies examine the impact of green finance policies from the perspective of the main implementers of the policies. Green credit is effective in improving the credit risk management and core competitiveness of banks [17]. However, it has also been argued that the current low premium for corporate green bonds is not sufficient to convince investors to increase their support for the green bond market [18]. Current studies focus on single financial instruments. Relatively few studies evaluate and examine the comprehensive policy of green finance. Existing studies relating to the comprehensive policy of green finance focus mainly on the relationship between Tobin's q-measured value, the regional innovation level, and corporate social responsibility [19–21]. In conclusion, there is a lack of relevant research into green innovation in enterprises.

Research on green innovation originated in the 1990s and concerns mostly green technological innovation that reduces environmental pollution and utilizes fewer raw resources and energy. The appellation and definition of green technology often vary depending on the topic of study, for example, environmentally friendly technologies, energy-efficient technologies, renewable energy technologies, and eco-innovations. The World Intellectual Property Organization (WIPO) defines the broadest range of green innovations, including environmentally relevant pollutant disposal and climate change mitigation-related technologies. Hojnik and Ruzzier [22] believed that the main factors influencing firms' green innovation are command-and-control policies, market-oriented policies, and corporate

structure. Command-and-control policies include mandatory pollutant monitoring, environmental subsidies, and environmental enforcement [23, 24]; market-oriented policies include environmental rights trading and pollution charges [25, 26]; and the corporate structure involves corporate governance mechanisms and stakeholder pressure [27–30]. Wang and Qi confirmed the role of policy instruments and explored the resulting effects of various policy instruments in different industries and technologies [31]. Enterprises' innovation behavior is also related to their profitability. The profitability of the company can have a positive impact on green product innovation by affecting the legitimacy pressure of the company [32]. There is a positive correlation between environmental innovation and abatement pressures, in which environmental innovation is measured by the number of patents [33]. In addition, enterprise green development and innovation are also related to government decision-making and government behavior [34, 35], for example, the construction of high-tech zones and government-led smart cities in China. Research on the process and the results of enterprise innovation are rich, but research on green finance to promote enterprise green innovation is limited. This study takes the GFRIP policy as a perfect policy test to investigate the effect of green finance on enterprises' green innovation, which enriches relevant research.

3. Theoretical Analysis and Research Hypotheses

Technology innovation is a central component of the new growth theory [36]. Because innovation is long term and uncertain, the financial market allows companies to perform innovative activities. The debt financing of official banks will undoubtedly remain the main source of external financing for companies [37]. Faulkender and Petersen pointed out that capital markets can affect enterprises' capital structure decisions (ability to issue debt) [38]. Nanda and Nicholas revealed that, throughout the Great Recession, the number and quality of corporate patents were hardly influenced by financial difficulty, demonstrating an influential link between credit markets and corporate innovation [39]. Banking competition eases the credit constraints of enterprise innovation [40] and enhances the intensity of enterprise innovation [11]. However, Morck and Nakamura pointed out that the majority of banking-based financial systems hinder the effective flow of external funds into creative industrial technologies [41]. As creditors, banks tend to avoid risks for profitability reasons, and this inherent prejudice in the credit market prevents companies from pursuing innovative activities.

Bank loans are a critical source of capital to invest in company research and development (R&D). According to the social financing scale statistics released by the People's Bank of China, the proportion of bank loans to the total social financing scale was 60.26% at the end of 2020. The traditional financial industry can ignore investment project resources and environmental factors and focus on investment project profitability. Green finance can affect capital flow and promote financial investment from HPFs to high-efficiency industries. If banks and other financial institutions strictly regulate and raise the threshold for obtaining credit support for enterprises, enterprises' financing costs will increase. If the environmental protection information disclosure of enterprises is regarded as a condition for financial institutions to issue loans, the debt financing available to heavily polluting enterprises will be reduced. If financial institutions take the enterprises' environmental performance as a condition for obtaining loans, the debt available to HPFs will be reduced.

From the perspective of corporate development, corporate innovation has a high rate of failure and requires a large amount of R&D investment. Following the implementation of the GFRIP policy, financial institutions will take environmental performance into account when granting loans. Shareholders will be in turn more willing to encourage managers to strive for corporate green innovation. Limited by the available external R&D investment, enterprises are more willing to drive green development by improving efficiency.

The initial goal of the GFRIP policy is to make the efficient use of financial resources and achieve sustainable economic development. First, financial institutions are encouraged to establish divisions or subbranches to provide diversified financial services. Qualified microfinance and financial leasing companies can participate in green finance. Second, the GFRIP policy encourages the growth of green credit, and the exploration of credit and pledge financing for environmental rights and interests include the following: concession rights, project revenue rights, and sewage rights. The green finance pilot policy provides enterprises within the pilot areas with greater access to multiple sources of financial resources and can alleviate their financing constraints. Third, financial policies support industrial transformation. The GFRIP policy encourages enterprises in pilot areas to obtain financial resources in multiple ways that can alleviate their funding constraints. Hence, the following hypothesis is advanced:

> Hypothesis 1. Companies in the pilot province regions will experience more prominent green innovation performance.

Because of asymmetric information, financial institutions and enterprises face moral hazard and adverse selection problems. Financial resources have been unevenly allocated to different enterprise property rights, scales, and regions for a long time. Enterprises' green development requires financial support. The GFRIP policy will affect enterprises' green development by influencing the redistribution of financial resources. The GFRIP policy is not a specific plan but an overall plan, and pilot regions can develop local specific plans according to regional conditions. This policy will change the flow of financial resources in the region and affect enterprises' green development. The GFRIP policy not only assists firms in achieving energy conservation and emission reduction through provincial technology, but also encourages qualified financial institutions to provide green financial products and services in all

aspects to increase the proportion of direct financing for enterprises. Enterprise innovation will take a long time, and green finance policies will provide long-term financial support for enterprise development. Therefore, the GFRIP policy will alleviate corporate debt financing constraints by increasing the scale of debt financing for enterprises, thus facilitating the innovative development of green enterprises. Hence, the following hypothesis is developed:

> Hypothesis 2. The GFRIP policy influences enterprises' green innovation primarily by alleviating debt financing constraints.

The marginal costs of enterprises with different ownership structures are different, and enterprises will weigh the rising degree of the financing cost. State-owned enterprises (SOEs) often have a good relationship with the local government, so it is easier to obtain implicit government guarantees, and the risk of debt default is relatively low. SOEs have a long life and a stable banking relationship with banks. Therefore, there are great differences between SOEs and non-SOEs in obtaining bank loans. Brandt and Li also argued that non-SOEs are much less likely to obtain loans or that they obtain meager loans and face discriminatory behavior [42]. This difference is observed in companies of different sizes. Technology innovation is usually related to the scale of enterprises. Green innovation requires sufficient R&D, human capital, equipment, technology, and other resources. Large-scale enterprises have obvious advantages in capital, talent, platforms, etc. Small-scale enterprises are unable to maintain high adherence to policies. They make themselves vulnerable if they invest all their resources into one project. The GFRIP policy also has different impacts on enterprises with different pollution levels. Given limited R&D investment, HPFs will improve innovation efficiency to gain debt financing as soon as possible. The regional marketization level also affects the implementation effect of the GFRIP policy. Enterprises in regions with higher marketization levels have multiple financing channels. In addition to bank loans, enterprises' capital sources also include equity financing, green bonds, and other options. Hence, the following hypothesis is developed:

> Hypothesis 3. The GFRIP policy has a more significant impact on green innovation in large-scale enterprises, SOEs, HPFs, and enterprises located in areas with high levels of marketization.

4. Methods

4.1. Data Source. The data for this paper have two main sources: (1) data on corporate green innovation. In 2010, the WIPO established an online application to query environmental protection patents, namely, the "International Patent Classification Green List," which classifies green patents into seven broad categories. Data on corporate innovation in this study were obtained primarily from the Chinese Research Data Services Platform (CNRDS) database, which adheres to the World Intellectual Property Organization's green patent standard and comprehensively sorts and screens patents from the China National Intellectual Property Administration and Google Patents to determine the total number of green patent applications filed, as well as a detailed breakdown of grants granted to Chinese A-share listed companies. (2) Data on company characteristics: the main financial data of listed companies were obtained from the China Stock Market and Accounting Research (CSMAR) database.

This paper's sample is based on Chinese A-share listed companies during the period 2012–2019. A secondary selection is made to guarantee that all publicly available firm data are included by omitting the following: (1) to maintain the comparability of the sample, newly listed companies after 2012 are excluded; (2) due to the significant differences and noncomparability of accounting systems of enterprises of different natures, especially between the financial sector and other industries, the financial indicators of financial enterprises are not comparable to those of other industries, so the sample of listed companies in the financial sector is excluded; (3) companies listed as special treatment (ST and ST*) and particular transfer (PT) enterprises firms have been removed due to extraordinary financial performance; and (4) we winsorized continuous variables at the 2% level.

4.2. Variables

4.2.1. Explained Variables. Innovation inputs and innovation outputs are widely used in the literature to represent a company's innovation, with innovation inputs indicated mainly by firm R&D and related indicators. As patent data availability increases, and researchers become more devoted to examining patent information, patent data have advantages that make patents important indicators of innovation. Dang and Motohashi pointed out that patents are appropriate indicators of firm innovation [43]. A company's patent data can be divided into patent applications and patent authorizations, which are based on the patent implementation process. It takes a long time from patent application to patent authorization, and the patent may have an impact on the firm's economic performance and technological progress during this period. We use the total number of patent applications for green inventions to quantify the explanatory variable, which is firm's green innovation output (variable *Y*). Specifically, the natural logarithm of the number of indicators above plus 1 is taken to obtain lnPatent.

4.2.2. Independent Variable. The interaction term between Treat_i and Policy_t is the independent variable, where both Treat_i and Policy_t are dummy variables. The five provinces (regions) implementing the GFRIP policy were classified as the experimental group, whereas the control group consisted of the remaining provinces (regions). The GFRIP policy is designed as a dummy variable that is allocated a value of 0 before policy implementation, which corresponds to 2017 and earlier; however, the years following policy implementation are assigned a value of 1. We can effectively identify and quantify policy effects by focusing on the coefficient of the interaction term $\text{Treat}_i \times \text{Policy}_t$.

4.2.3. Control Variables. We took into account the following variables as control variables on the basis of the literature [14, 35, 44]. The control variables are described as follows: (1) asset: enterprise size is indicated by enterprises' total assets. Firm size is an important factor influencing firm innovation [45]. Larger organizations consistently invest in research and development and have a better success rate with innovation. (2) ROA: ROA is used to estimate the amount of net profit generated per unit of asset [19]. ROA represents the profitability of a company; companies with higher profitability have a greater willingness and ability to invest in innovation activities. (3) Debt: debt is defined as the ratio of a firm's total liabilities to total assets, which reflects the firm's leverage level. Corporate debt reflects the assessment of the company's creditworthiness by the market [46]. A moderately indebted operation may allow a firm to have more funds available for R&D innovation. (4) Tobin's Q: Tobin's Q represents a company's comparative performance. A higher Tobin's Q indicates that the company creates more social wealth and has a higher sense of innovation.

(5) Capital: capital is the ratio of total assets to revenue and represents a firm's reliance on capital investment. Equipment and technology are more important to more capital-intensive firms, which are likely to place greater emphasis on corporate innovation. (6) Largest: companies' organizational structure has a significant impact on operating performance and innovative behavior. Largest is the percentage of largest shareholder shares [47]. (7) Cash: cash demand for corporate R&D will increase over time [48]. This variable represents the ratio of cash and cash equivalents closing balance to current liabilities.

4.2.4. Mediating Variable. Corporate green innovation often has a long investment cycle, making it more difficult to gain long-term financial support. Whether the GFRIP policy can alleviate the debt financing constraints of enterprises, support their green projects, and influence their green innovation is the key question. The mediating variable is Floan, which is the ratio of the enterprise's long-term borrowing to total assets.

4.3. Regression Model. The DID method is commonly utilized to assess the consequences of government policies. The following model was constructed based on the DID method.

Model 1:

$$Y_{it} = \beta_0 + \beta_1 \text{Policy}_t + \beta_2 \text{Treat}_i \times \text{Policy}_t + \beta_3 \text{Treat}_i + \gamma \text{Controls}_{it} + \nu_t + \delta_i + \varepsilon_{it}. \quad (1)$$

Y_{it} represents a company' green innovation. The GFRIP policy was released in June 2017; considering that there is a certain lag in the implementation of the policy, this paper takes 2017 as the policy time. Policy_t is a dummy variable for policy implementation, taking a value of 1 for the post-implementation period (after 2017) and 0 for the pre-implementation period (2017 and earlier). Taking the GFRIP policy as a quasi-experiment, we assigned the sample companies located in the five provinces (regions) of the experimental area to the experimental group and the others to the control group. δ_i and ν_t denote the industry fixed effect and year fixed effect, respectively. ε_{it} is the random error term. Our main concern is the interaction term $\text{Treat}_i \times \text{Policy}_t$.

5. Data Analysis and Results

5.1. Descriptive Statistics. Table 1 shows the descriptive statistics for the major variables. The main explanatory variable (lnPatent) has a mean of 0.84, a maximum of 8.285, and a minimum of 0. It is obvious that the number of green invention patents varies widely between companies.

5.2. Basic Regression Analysis. As seen in Table 2, there is a strong association between the GFRIP policy and corporate green innovation. In both Columns (1) and (2), the coefficient of $\text{Treat}_i \times \text{Policy}_t$ is statistically significantly positive at the 5% level. After controlling for company-level factors such as company size and ROA, the estimated coefficient is 0.084.

Thus, there is a significant positive correlation between the GFRIP policy and corporate green innovation, which verifies Hypothesis 1. The GFRIP policy is conducive to increasing enterprises' green invention patents in pilot areas. It empowers local governments to adapt their policies to the local context and strengthen green innovations in enterprises through the rational allocation of financial resources. Therefore, the GFRIP policy can play a positive role in supporting enterprises' green transformation.

5.3. Reliability Test

5.3.1. Parallel Trend Test. The results of the parallel trend test are meaningful. We conducted the following research to enhance the robustness of our findings. Before the GFRIP policy, green patent applications in different zones should remain largely consistent in terms of time trends. In contrast, after the policy implementation, the parallel trends were broken, and a change in the green innovation trend among enterprises in the pilot provinces (regions) relative to the nonpilot provinces (regions) was observed. The results are shown in Figure 1. The dashed line represents the policy dividing line, and the estimated coefficient of Treat × Policy is apparently not significant to the left of the dashed line, that is, before the policy is implemented, but is strongly positive after implementation. This study passes the parallel trend test.

5.3.2. Placebo Test. A placebo test was conducted to further exclude other unknown factors and ensure that the GFRIP policies led to conclusions. We randomly selected five provinces (regions) from 31 provinces (regions) as the virtual experimental group and assigned the remaining provinces to the virtual control group. The regression was conducted according to the benchmark model, and this randomization process was repeated 500 times. The results are shown in Figure 2, which plots the probability density distribution of

Table 1: Descriptive statistics.

Variable	N	Mean	SD	Median	Min	Max
lnPatent	18791	0.84	1.31	0.000	0.000	8.285
Policy	19051	0.25	0.43	0.000	0.000	1.000
Treat	19051	0.28	0.45	0.000	0.000	1.000
Size	18789	22.30	1.36	22.152	14.942	28.636
Capital	18804	2.69	2.14	2.027	0.505	11.117
Big	18805	0.34	0.15	0.311	0.104	0.680
Debt	18805	0.45	0.21	0.439	0.072	0.864
Tobin's Q	18244	2.07	1.34	1.596	0.903	7.233
Cash	18805	0.74	1.09	0.347	0.031	5.763
ROA	18805	0.03	0.06	0.030	−0.184	0.152
Floan	19051	0.04	0.07	0.006	0.000	0.301

Table 2: Results of benchmark regression.

Variable	(1) lnPatent	(2) lnPatent
Treat × Policy	0.092**	0.084**
	(0.039)	(0.038)
Policy	0.346***	−0.102***
	(0.030)	(0.035)
Treat	−0.118***	−0.075**
	(0.043)	(0.037)
Size		0.532***
		(0.024)
Capital		−0.029***
		(0.007)
Big		−0.002*
		(0.001)
Debt		−0.173*
		(0.103)
Tobin's Q		0.117***
		(0.013)
Cash		0.002
		(0.013)
ROA		−0.073
		(0.235)
Constant	0.295	−11.068***
	(0.184)	(0.544)
Year	Yes	Yes
Industry	Yes	Yes
N	18775	18216
R^2	0.179	0.360

Note. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

the coefficients of the variable $\text{Treat}_i \times \text{Policy}_t$ and the corresponding distributions. If the distribution of the estimated coefficients of the variable $\text{Treat}_i \times \text{Policy}_t$ is approximately 0, it indicates that no significant factors were omitted from the research design, and the results of the benchmark analysis are more convincing. The coefficient estimates of the virtual regression are all approximately 0, while the benchmark regression's estimates are not included in the virtual regression results. Therefore, the research conclusion is not disturbed by any unobserved missing variables.

5.3.3. PSM-DID Test. This paper uses propensity score matching with the quantitative difference-in-differences (PSM-DID) method to improve the robustness of the

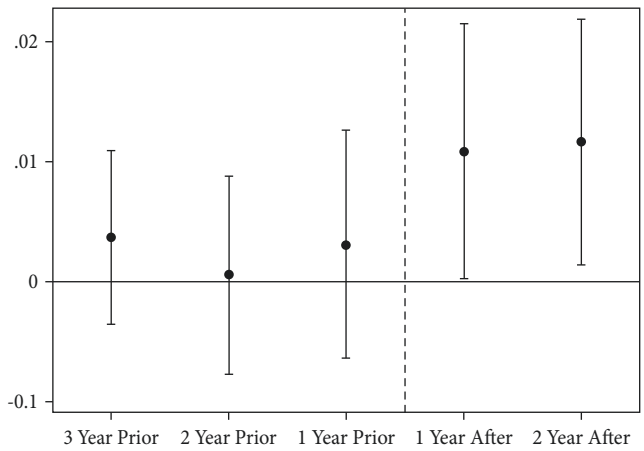

Figure 1: Results for common trend test.

benchmark regression results. We selected Asset, ROA, Debt, Tobin's Q, Capital, Largest, and Cash as covariates and identified variables matching the experimental group in the control group through nearest-neighbor matching within caliper. After matching the covariates, we used the PSM-DID method to test the causal relationship between the GFRIP policy and enterprise green innovation. Column (1) of Table 3 shows the regression results after PSM matching. The coefficient $\text{Treat}_i \times \text{Policy}_t$ is positive and significant, so the baseline results according to Model 1 are valid and reliable.

5.3.4. Alternative Measure of Corporate Green Innovation. Next, we sum the number of green invention patent applications and the number of green utility model patent applications and then take the natural logarithm of the above indicator plus 1 to obtain Gpatent2. Then, the explained variables are replaced by the proportion of green patent applications in all patent applications (Gpatent1) and Gpatent2, and the regressions are rerun, as shown in Columns (2) and (3) of Table 3. Even though the explained variables are replaced, the regression results in Table 3 are similar to those of the main regression. The coefficients of $\text{Treat}_i \times \text{Policy}_t$ are significantly positive at the levels of 5% and 10%. The above findings justify the selection of lnPatent as the main explained variable and indicate the stability of the findings and the effectiveness of the GFRIP policy to stimulate enterprises' green innovation.

5.3.5. Placebo Test by Replacing Different Policy Times. Considering that the results may be caused by other events prior to the GFRIP policy, this paper uses a placebo test by changing the policy implementation. We assume that policy implementation is moved forward by three years, and we select 2014, 2015, and 2016 as the time of virtual policy implementation. The results are shown in Columns (4)–(6) of Table 3. The coefficient estimates of $\text{Treat}_i \times \text{Policy}_t$ are not statistically significant, so the effect of virtual policy impact does not exist. In other words, the effect of the GFRIP policy on corporate green innovation in 2017 is robust, and the estimation results are more reliable.

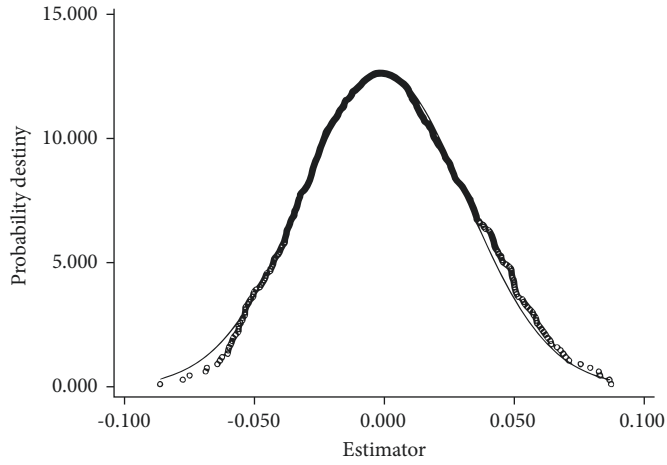

Figure 2: Results of placebo test.

6. Mechanism Analysis

Corporate green innovation activities are often characterized by long payback periods, information asymmetry, and high risk. Under the traditional financial model, it is challenging for enterprises and green projects to obtain long-term financial support, and they face serious problems of maturity mismatch and investment constraints. Green finance is essentially the rationing of financial resources based on environmental constraints. It aims to increase financing capacity and financial support for green projects, reduce financing costs for enterprises, improve the maturity structure of their debt financing, and thus promote their investment and technological innovation in green transformation.

Next, based on the benchmark analysis, we analyze the mediating effect in greater detail. The mechanism by which green finance policy affects corporate green innovation is examined based on debt financing. This study follows Yang et al. in employing the mediation effect test to construct the following model of the mediation effect [34].

Model 2:

$$M_{it} = \beta_0 + \alpha \,\mathrm{Treat}_i \times \mathrm{Policy}_t + \gamma \,\mathrm{Controls}_{it} + \nu_t + \delta_i + \varepsilon_{it}. \quad (2)$$

Model 3:

$$Y_{it} = \beta_0 + b \,\mathrm{Treat}_i \times \mathrm{Policy}_t + cM_{it} + \gamma \,\mathrm{Controls}_{it} + \nu_t + \delta_i + \varepsilon_{it}. \quad (3)$$

Variable M_{it} represents enterprises' debt financing constraints. Regarding the quantification of financing constraints, the KZ index, the WW index, and the SA index are widely used as indicators. Although the KZ index and SA index can also reflect corporate financing constraints, it is more appropriate to use the following indicator. The GFRIP policy has a significant impact on debt financing constraints, and the nonneutrality of long-term debt financing constraints is highlighted in this paper. Following Cao et al., this paper considers that enterprises' green innovation will last for a long time and that firms may be more inclined to use long-term debt obtained from financial institutions for innovation [49]. We use the ratio of long-term debt to total assets to present variable M_{it}, denoted as Floan. The other variables are consistent with the previous section. The mediators of the debt financing constraints of enterprises must be reflected in two aspects. First, Model (2) is introduced to test the relationship between the mediating variables and green finance pilot policy, that is, whether the implementation of the green finance pilot policy affects enterprises' debt financing, which is determined by whether the coefficient of $\mathrm{Treat}_i \times \mathrm{Policy}_t$ is significant. Second, the coefficient b in Model (3) will be smaller than the coefficient β_2 in Model (1).

Table 4 shows the regression results of debt financing constraints as a mediating variable. The estimated results in Columns (2) and (3) are 0.005 and 0.081, respectively. In Columns (1) and (3), the change in the regression coefficient indicates that the mediating effect exists. Compared with enterprises in nonpilot provinces (regions), enterprises in pilot provinces (regions) can obtain a larger scale of long-term debt financing. The GFRIP policy improves enterprises' green innovation by alleviating debt financing constraints. There is no doubt that the GFRIP policy has created more long-term debt for green projects and technological innovation, and more stable sources of financing and optimized capital structure have improved the willingness to carry out green innovation.

7. Further Discussion: Heterogeneity Analysis

7.1. Heterogeneity Analysis Based on Enterprise Ownership. Enterprises with different property rights face different financing constraints, which have different effects on corporate green innovation. SOEs have certain advantages in the allocation of financial resources, especially credit resources, while non-SOEs have long faced credit discrimination. This paper runs a grouped regression by enterprise ownership, distinguishing between a subsample of SOEs and non-SOEs. As indicated in Columns (1) and (2) of Table 5, the estimated result of the SOE subsample is positive at the 1% level, whereas the coefficient of the non-SOE subsample is not significant. The impact of the GFRIP policy is affected by enterprises' property rights, and the GFRIP policy has a greater impact on SOEs. On the one hand, enterprise

Table 3: Robustness test.

Variable	(1) PSM-DID	(2) Gpatent1	(3) Gpatent2	(4) $t = 2014$ lnPatent	(5) $t = 2015$ lnPatent	(6) $t = 2016$ lnPatent
Treat × Policy$_t$	0.076**	0.087**	0.043*	0.040	0.024	0.033
	(0.037)	(0.036)	(0.026)	(0.033)	(0.033)	(0.034)
Size	0.535***	0.349***	0.176***	0.311***	0.311***	0.311***
	(0.024)	(0.029)	(0.020)	(0.029)	(0.029)	(0.029)
Capital	−0.029***	−0.011*	−0.006	−0.010	−0.010	−0.010
	(0.007)	(0.007)	(0.004)	(0.007)	(0.007)	(0.007)
Big	−0.002	−0.003*	−0.001	−0.002	−0.002	−0.002
	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
Debt	−0.191*	−0.060	0.065	−0.123	−0.122	−0.123
	(0.104)	(0.096)	(0.066)	(0.096)	(0.096)	(0.096)
Tobin's Q	0.113***	0.178***	0.113***	0.026***	0.026***	0.026***
	(0.013)	(0.059)	(0.036)	(0.009)	(0.009)	(0.009)
Cash	0.001	−0.005	0.005	0.001	0.001	0.001
	(0.013)	(0.011)	(0.008)	(0.010)	(0.010)	(0.010)
ROA	−0.089	1.756	0.021	−0.166	−0.166	−0.164
	(0.234)	(1.196)	(0.809)	(0.173)	(0.173)	(0.173)
Constant	−11.143***	−6.752***	−3.442***	−6.100***	−6.102***	−6.099***
	(0.549)	(0.640)	(0.435)	(0.646)	(0.647)	(0.647)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	17797	18287	18287	17889	17889	17889
R^2	0.361	0.129	0.117	0.105	0.105	0.105

Note. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 4: Regression results of the mediating effect of debt financing.

Variable	(1) lnPatent	(2) Floan	(3) lnPatent
Treat × Policy	0.084**	0.005**	0.081**
	(0.038)	(0.002)	(0.036)
Floan			−0.494***
			(0.187)
Constant	−11.068***	0.047***	−7.840***
	(0.544)	(0.000)	(0.555)
Controls	YES	YES	YES
Year	YES	YES	YES
Industry	YES	YES	YES
N	18216	18805	18216
R^2	0.360	0.001	0.086

Note. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

innovation relies more on external financing, and the advantage of SOEs in obtaining financial resources generally increases the proportion of debt financing. On the other hand, China's green finance system started late and is still in the primary stage of development. The promotion of the GFRIP policy is gradually being explored. Green finance may be more effective in supporting green innovation and the green transformation of SOEs. The information is relatively more comprehensive, and the SOEs in the provinces with green finance pilot policies will benefit more. SOEs have higher policy sensitivity and easier access to comprehensive information. Therefore, in the process of gradually promoting green finance policies, we should pay more attention to non-SOEs to improve the overall effect of green finance in promoting enterprises' green transformation.

7.2. Heterogeneity Analysis Based on Pollution Levels. Enterprises' innovative behavior can effectively enhance their own environmental performance and green development capability. The GFRIP policy is an important extension and innovation in relation to traditional environmental regulations. It may have different impacts on enterprises with different pollution levels. In 2008, to further refine the classification of heavily polluting industries for environmental verification, the Ministry of Environmental Protection of the People's Republic of China issued the "Management List of Environmental Verification Industries for Listed Companies," and combined with the guidelines for industry classification of listed companies, we further divide the enterprises into HPFs and non-HPFs. Columns (3) and (4) of Table 5 show that the coefficient of the HPF

Table 5: Heterogeneity analysis results I.

Variable	(1) SOEs lnPatent	(2) Non-SOEs lnPatent	(3) HPFs lnPatent	(4) Non-HPFs lnPatent
Treat × Policy	0.129***	0.081	0.131**	0.058
	(0.049)	(0.049)	(0.063)	(0.045)
Size	0.403***	0.458***	0.468***	−0.151***
	(0.031)	(0.033)	(0.036)	(0.046)
Capital	−0.020*	−0.012	−0.030**	−0.096**
	(0.010)	(0.009)	(0.012)	(0.049)
Big	−0.005***	−0.005***	−0.001	−0.002
	(0.002)	(0.002)	(0.002)	(0.001)
Debt	−0.161	−0.043	−0.254	−0.158
	(0.130)	(0.123)	(0.161)	(0.134)
Tobin's Q	0.026*	0.090***	0.090***	0.129***
	(0.016)	(0.016)	(0.020)	(0.018)
Cash	−0.038*	0.002	0.000	0.000
	(0.021)	(0.014)	(0.018)	(0.017)
ROA	−0.324	0.199	−0.201	0.002
	(0.278)	(0.270)	(0.345)	(0.305)
Constant	−8.044***	−8.783***	−10.139***	−11.878***
	(0.695)	(0.764)	(0.776)	(0.687)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
N	7225	9322	6286	11518
R^2	0.123	0.284	0.265	0.392

Note. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 6: Heterogeneity analysis results II.

Variable	(1) Small-scale firms lnPatent	(2) Large-scale firms lnPatent	(3) Market < $p50$ lnPatent	(4) Market > $p50$ lnPatent
Treat × Policy	0.057	0.101**	0.107	0.140***
	(0.056)	(0.046)	(0.095)	(0.033)
Size	0.418***	0.381***	0.472***	0.413***
	(0.034)	(0.036)	(0.053)	(0.026)
Capital	−0.002	−0.011	−0.016	−0.007
	(0.012)	(0.008)	(0.014)	(0.008)
Big	−0.008***	−0.001	−0.006*	−0.005***
	(0.002)	(0.002)	(0.003)	(0.002)
Debt	−0.268	−0.255**	−0.394**	−0.266**
	(0.176)	(0.113)	(0.190)	(0.112)
Tobin's Q	0.053***	0.014*	0.015	0.026***
	(0.020)	(0.008)	(0.016)	(0.008)
Cash	−0.002	−0.024**	−0.053**	−0.009
	(0.024)	(0.011)	(0.022)	(0.011)
ROA	0.048	−0.595***	−0.610*	−0.308
	(0.338)	(0.196)	(0.356)	(0.194)
Constant	−8.204***	−7.205***	−9.362***	−8.088***
	(0.801)	(0.765)	(1.202)	(0.604)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
N	8768	8632	4041	13763
R^2	0.107	0.065	0.090	0.085

Note. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

subsample is significant at the 5% level. The reasons may be as follows: first, financial institutions regard the green performance of enterprises as an important criterion for granting credit after the implementation of the GFRIP policy. The financing threshold will thus be raised in the short term. With limited debt financing, HPFs are more motivated to enhance their green development by improving innovation efficiency. Second, the GFRIP policy aims to

achieve industrial green transformation and the coordinated development of the economy and ecology. This policy is a package that includes many subprojects, and different provinces (regions) can develop differentiated plans according to regional circumstances. For example, Guangdong Province supports the green upgrading of equipment and guides financial institutions to focus on supporting the transformation of highly polluting and energy-consuming enterprises, which provides conditions for green innovation in HPFs.

7.3. Heterogeneity Analysis Based on Corporate Size. Enterprise size reflects the degree of concentration of human capital, production materials, and products within the enterprise. The firm efficiency, financing capacity, and internal control of companies of different sizes differ greatly. We divided enterprises into large-scale enterprises and small-scale enterprises according to the 50th percentile of total assets and investigated whether the promotion effect of the GFRIP policy on enterprise green innovation differed among different enterprise sizes. The regression results for different samples are shown in Columns (1) and (2) of Table 6, which show that the GFRIP policy has different effects on different enterprise sizes. The estimated result is significantly positive at the 5% level for large-scale firms and insignificant for small-scale firms. A possible explanation for this result is that large-scale enterprises have more advantages in gaining financial support, and the current green financial system has a more significant incentive effect on large-scale enterprises. In addition, large-scale enterprises have stronger corporate environmental social responsibility, and credit resources introduced by the GFRIP policy will motivate large-scale enterprises to innovate.

7.4. Heterogeneity Analysis Based on Marketization Level. The degree of marketization of a region can increase or limit the financing channels and options for local firms. On the one hand, regions with higher levels of marketization tend to have more developed financial markets, which can improve the debt financing environment faced by firms and induce them to allocate their limited capital to innovative areas with long-term development value. On the other hand, a higher level of marketization can impact corporate innovation by increasing the anchoring effect of investors and optimizing their structure. In regions with lower levels of marketization, firms face limited financing options and may be more influenced by the policies of green finance demonstration zones. This paper uses the ranking of factor market development in the China Sub-Provincial Marketization Index Report (2021) to measure the degree of regional marketization. Based on the median value of the scores, the sample is divided into firms in regions with high marketization levels and firms in regions with low marketization levels. The results of the grouped regressions are shown in Columns (3) and (4) of Table 6. As seen from the results, the positive effect of implementing the green finance pilot policy on firms' green innovation output in regions with high marketization levels is significant at the 1% level.

8. Conclusions and Policy Implications

Green innovation is the essential support and chief motivation for green development and is of great significance in protecting the ecological environment. The GFRIP policy is an excellent quasi-experimental case to explore the association between green finance and enterprise green innovation and provides reliable insight for the development of green finance in developing countries. This paper finds that the GFRIP policy increases the green innovation of companies in pilot provinces (regions) more than that of companies in nonpilot provinces (regions). Furthermore, this study verifies the heterogeneous effects of firm pollution level, firm size, enterprise ownership and regional marketization level. The green innovation promotion effect of the GFRIP policy is more significant for SOEs, HPFs, large-scale enterprises, and firms in regions with high marketization levels. The above results show that the GFRIP policy can significantly promote enterprises' green innovation, but after policy promotion, attention should be given to small-scale enterprises and non-SOEs in the future. Our conclusions provide evidence for the implementation and promotion of green finance policy in developing countries.

The GFRIP policy seeks to enhance the promotion of green economic development and accelerate green innovation. Our findings provide some policy implications for governments and businesses. First, green finance can reduce environmental risks and promote the sustainable development of enterprises by providing diversified financial products and services to guide capital flows. Developing countries should support the diversification of financial instruments, including green bonds, green insurance, and green funds, and realize the coordinated development of green finance in breadth and depth. We should also consider the interests of nonstate-owned and small-scale enterprises in the distribution of financial resources. Commercial banks should, on the one hand, establish a credit management system that facilitates dynamic adjustments and, on the other hand, innovate green credit processes and services to enhance investment efficiency. Financial institutions should invest financial resources in green industries, pay more attention to enterprises' substantive green behavior in the policy implementation process, improve the rational allocation of green resources, and provide more opportunities and capital for HPFs to promote transformation. The government should support the establishment of a diversified green financial system and promote market-oriented green innovation. Second, enterprises should enhance their social responsibility. Enterprises in developing countries often solve micro-CSR issues, which means that real problems such as environmental protection and green governance are ignored [50]. Enterprises can improve their environmental responsibility by disclosing environmental protection information, improving internal governance, and obtaining more financial support from financial institutions to support their green transformation. Furthermore, stakeholders should increase their enthusiasm for ensuring the supervision of environmental decision-making by enterprises to prevent managers from using environmental

costs for personal gain and to reduce resource waste caused by inefficient environmental investment. By reducing principal-agent problems and improving investment efficiency, enterprises in developing countries can improve their green innovation and realize green transformation.

Data Availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Article

Research on the Green Production Motivation of New Agricultural Business Entities: Benefit Perception and Environmental Regulation

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The new agricultural business entities are key carriers of modern agriculture in China, and increasing their willingness to engage in green production is critical to the country's agricultural green transformation. The Economic and Social Man Hypothesis and Externality Theory are used to construct analysis models of the green production willingness of new agricultural business entities based on 106 survey data points from Shanghai to study the impact of benefit perception, environmental regulation, and their synergy on the green production willingness of new agricultural business entities. The results show that (1) benefit perception and environmental regulation can significantly improve the willingness of new agricultural business entities to engage in green production. Economic benefit perception, ecological benefit perception, guidance regulation, and restraint regulation are all important influencing factors. (2) There is a significant synergy between ecological benefit perception and environmental regulation in increasing the willingness of new agricultural business entities to engage in green production. Further research revealed that the synergistic item of ecological benefit perception and guidance regulation, as well as the synergistic item of ecological benefit perception and restraint regulation, significantly increases the willingness of new agricultural business entities to green production. The government should strengthen the perceptions of the economic and ecological benefit of new agricultural business entities to green production; change the incentive regulation and strengthen guidance regulation and restraint regulations; enhance the synergy between ecological benefit perception and guidance regulation; and enhance the synergy between ecological benefit perception and restraint regulation.

1. Introduction

Due to a heavy reliance on inputs such as chemical fertilizers and pesticides, China's agricultural total economic output has steadily increased since reform and opening [1]. However, widespread use of inputs such as fertilizers and pesticides has also led to increasing environmental degradation and resource scarcity [2]. This contradicts the United Nations' proposal for green development in 2002 and the concept of green development proposed at the Communist Party of China's 18th Central Committee's Fifth Plenary Session [3]. The extensive management methods of traditional agriculture in China are in urgent need of green innovation. To this end, relevant policies have been successively promulgated in recent years, from the Central Committee of the Communist Party of China to various ministries and commissions, emphasizing "adhering to the concept of agricultural green development" and "promoting agricultural green production methods." ([4] The green transformation of China's agriculture has yielded preliminary results as a result of a series of policies, but its extensive management methods, which are based primarily on resource consumption, have not been fundamentally altered. The difficulty in changing China's extensive agricultural management methods, as well as the agricultural high carbon emissions and nonpoint source pollution [5, 6], is due to agricultural business entities' lack of willingness to switch to green production [7].

Traditional farmers and new agricultural business entities (including large grain growers, family farms,

agricultural cooperatives, and leading enterprises) make up the majority of China's agricultural business entities. Traditional farmers are the microunit of agricultural production in China [2], but scholars have pointed out that they face a number of problems, including low risk tolerance, serious part-time jobs, smallholder economic awareness, and scattered and fragmented land, all of which impede their agricultural green production [8–10]. As a key cultivation subject in China's rural revitalization strategy, the overall number of new agricultural business entities has exploded in recent years. They not only avoid the aforementioned problems of limiting traditional farmers' green production, but they can also drive and control traditional farmers' green production [11, 12]. To summarize, increasing the willingness of new agricultural business entities to engage in green production is critical to promoting China's green transformation of agriculture, thereby realizing China's carbon peaking strategy and relieving environmental pressure.

2. Literature Review

As the core of civil production and an indispensable part of the national economy, agricultural industry plays a role in many aspects, but it also produces a large number of carbon emissions harmful to the environment [13, 14]. Agricultural green production is a method of production that not only increases agricultural production and profitability, but also reduces pollution and resource waste, with the goal of combining economic and ecological benefit [15]. The new agricultural business entities in China belong to "Economic and Social Man," which are both self-interested and altruistic [16]. Their perceptions of economic and ecological benefit of agricultural green production are the primary internal motivators influencing their willingness to green produce [17]. Furthermore, agricultural green production is categorized as an "external economy." However, China's market for "green agricultural products" is lagging, preventing new agricultural business entities from fully capitalizing on the positive externality of green agricultural production. The government can promote the development of agricultural green production by increasing the punishment for environmental damage and the reward for green production [18, 19]. Environmental regulation by the government has become an important external factor in the direction of agricultural green production [20–22]. Therefore, environmental regulation (guidance, incentive, and restraint) is the key external motivator influencing new agricultural business entities' willingness to engage in green production [23]. In conclusion, benefit perception and environmental regulation are important factors influencing the willingness of new agricultural business entities to produce green. Understanding how these two factors act is essential for increasing the willingness of new agricultural business entities to produce green products.

Academics have investigated the impact of benefit perception and environmental regulation on agricultural green production willingness. From the perspective of benefit perception, X H Zhao et al. discovered that traditional farmers' willingness to switch to green production is influenced by their perception of ecological benefit, but the study excluded economic benefit perception [24]; Y Z Huang et al. discovered that both economic and ecological benefit perceptions can encourage traditional farmers to switch to green production, but the impact mechanism of ecological benefit perception on traditional farmers' willingness to green production is difficult to explain due to the Cost-Benefit Theory's limitations [2]. From the perspective of environmental regulation, H L Zhang et al. and Y W Du et al. both found that guidance and incentive regulations can increase the willingness of traditional farmers to produce green products [23, 25]. In addition, D Liu and J Sun discovered that the combination of environmental regulation and market profit can motivate traditional farmers to produce green products. In an imperfect green market, environmental regulation can compensate for the lack of market profits [26].

This paper is based on the aforementioned research, and the potential marginal contributions are primarily reflected in the following: (1) the majority of current research on China's agricultural green production focuses on traditional farmers while ignoring the diversity of new agricultural business entities and their "leadership" role in promoting the green transformation of agriculture. The focus of this study will be on new agricultural business entities. (2) The majority of existing benefit perception research is based on traditional theories such as the Economic Man Hypothesis and the Social Man Hypothesis, which can only be investigated for the perception of economic or ecological benefit, but not both. This paper makes an attempt to improve by using the relatively new Economic and Social Man Hypothesis. (3) There is much existing literature on the willingness of agr1icultural green production based on benefit perception or environmental regulation. However, few scholars have studied the synergy between benefit perception and environmental regulation. This paper will attempt to conduct research from a synergistic perspective.

3. Theoretical Hypothesis

3.1. Benefit Perception and the Economic Social Man Hypothesis. According to the "Economic and Social Man Hypothesis," a man has self-interest, altruism, and detriment. In socialist market economic activities with Chinese characteristics, the behavior of "economic and social man" is primarily guided and regulated by altruism and dominated by self-interest [16]. According to the Economic and Social Man Hypothesis, the fundamental internal motivations that affect the social and economic activities of China's new agricultural business entities are self-interest and altruism. The United Nations Environment Program defines agricultural "green production" as combining economic and ecological benefit. The Economic and Social Man Hypothesis is used in this paper to investigate the impact of benefit perception on the willingness of new agricultural business entities to engage in green production. It is as follows: motivated by self-interest, the perception of economic benefit has a positive impact on the willingness of new agricultural business entities to engage in green production.

Motivated by altruism, the perception of ecological benefit has a positive impact on the willingness of new agricultural business entities to engage in green production. To summarize, the following hypotheses are proposed in this paper:

H1a: the willingness of new agricultural business entities to produce green is positively influenced by their perception of economic benefit

H1b: the willingness of new agricultural business entities to produce green is positively influenced by their perception of ecological benefit

3.2. Environmental Regulation and Externality Theory. According to the Externality Theory [27], externalities are classified as "external economy" or "external diseconomy." "External economy" refers to the economic behavior that has a positive and beneficial impact on others and the environment, whereas "external diseconomy" refers to the opposite [28]. According to the Externality Theory, agricultural green production belongs to the "external economy." However, China's current market for "green agricultural products" is imperfect, and fully capitalizing on its positive externalities is difficult. It is necessary to rely on government environmental regulation to promote green agricultural production [29]. Environmental regulation, which includes guidance regulation, incentive regulation, and restraint regulation, refers to the government's adoption of relevant regulatory policies to coordinate the ecological environment and economic development [30, 31]. Guidance regulation refers to the government's promotion of green agricultural production; incentive regulation refers to the government's subsidizing green production technology, green inputs, and rewarding agricultural green production; restraint regulation refers to the government promulgating a series of laws and regulations to restrict nongreen agricultural production. According to some studies, guidance regulation and incentive regulation are important in promoting traditional farmers' green production, but restraint regulation has little impact because traditional farmers are difficult to supervise and restrain [23, 32]. The new agricultural business entities, unlike traditional farmers, are large-scale operations, making it easier for the government to implement management and control regulations. As a result, this paper believes that environmental regulation and three regulatory tools (guidance, incentive, and restraint regulation) have a positive impact on new agricultural business entities' willingness to engage in green production. Based on the preceding analysis, this paper proposes hypotheses H2, H2a, H2b, and H2c:

H2: environmental regulation increases the willingness of new agricultural business entities to engage in green production

H2a: guidance regulation increases the willingness of new agricultural business entities to engage in green production

H2b: incentive regulation increases the willingness of new agricultural business entities to engage in green production

H2c: restraint regulation increases the willingness of new agricultural business entities to engage in green production

3.3. The Synergy of Benefit Perception and Environmental Regulation. Self-interest is human nature. Self-interest will drive new agricultural business entities to pursue the economic benefit of green production. However, China's market for "green agricultural products" is still developing, and the economic benefits of green production are not yet fully realized. Because the economic benefits of green production have yet to be realized, the government's use of environmental regulation to promote green production of new agricultural business entities rather than perfecting the "agricultural market" may cause resistance from new agricultural business entities to agricultural green production. As a result, this paper contends that the synergy between economic benefit perception and environmental regulation has a negative impact on new agricultural business entities' willingness to engage in green production. Altruism is human nature, and altruism will drive new agricultural business entities to pursue the ecological benefit of agricultural green production, which are obvious. The perception of ecological benefit will drive new agricultural business entities to obey environmental regulation promotion on the willingness of green production, and environmental regulation will amplify the positive impact of the perception of ecological benefit on the willingness of green production of new agricultural business entities. As a result, this paper contends that the synergy between ecological benefit perception and environmental regulation has a positive impact on new agricultural business entities' willingness to engage in green production. To summarize, hypotheses H3a and H3b are proposed:

H3a: the synergy between economic benefit perception and environmental regulation has a negative impact on new agricultural business entities' willingness to engage in green production

H3b: the synergy between ecological benefit perception and environmental regulation has a positive impact on new agricultural business entities' willingness to engage in green production

The synergy roadmap of benefit perception and environmental regulation is shown in Figure 1.

4. Materials and Methods

4.1. Data Collection. The research team distributed questionnaires on green production willingness to new agricultural business entities in nine major agricultural areas in Shanghai. First of all, the research team thoroughly explained the content, benefits, and drawbacks of agricultural green production to the new agricultural business entities under consideration, ensuring that they could make informed decisions. Then, the four agricultural green production technologies (including soil testing formula, green prevention and control, water-saving

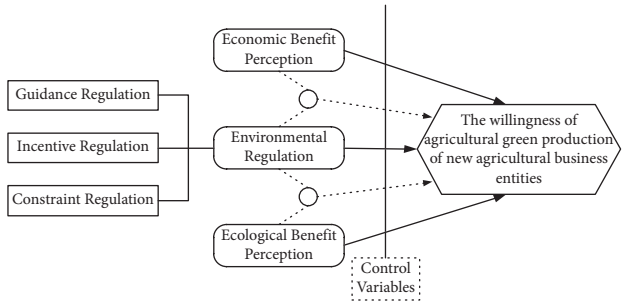

Figure 1: The synergy roadmap of benefit perception and environmental regulation.

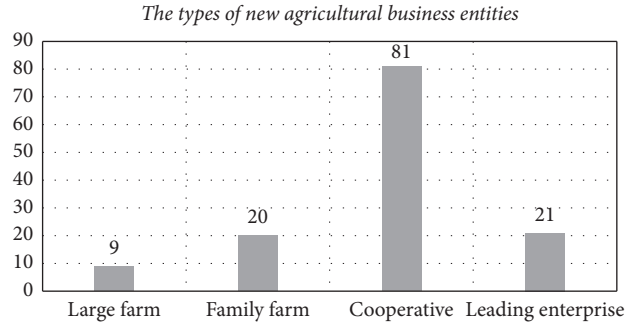

Figure 2: The types of new agricultural business entities under investigation.

irrigation, and straw returning) with regional applicability in Shanghai were introduced to the new agricultural business entities under investigation. Finally, the team inquired about each new agricultural business entity's personal situation as well as his or her willingness to use environmentally friendly production methods and reduce pesticide and fertilizer use. A total of 109 questionnaires were distributed, with 106 valid questionnaires recovered, for a 97.2 percentile recovery rate, among which are nine large grain farmers; 20 family farms; 81 cooperatives; and 21 leading enterprises. (In China, a new agricultural business entity can operate on a variety of scales.) The types of new agricultural business entities under investigation are shown in Figure 2.

4.2. Statistical Analysis. SPSS version 26.0 was used to test the data for reliability and validity, and Stata version 15 was used for regression analysis and correlation tests. In this paper, regression analysis on the questionnaires is performed using the Ordered Logit Model and the Ordered Probit Model. The Logit Model follows the logical distribution, while the Probit Model follows the normal distribution; both belong to the discrete selection Model. Both models can be used to investigate ordered variables, but the Ordered Logit Model is simpler and more efficient. Therefore, the survey data was empirically analyzed with the Ordered Logit Model and robustly tested with the Ordered Probit Model.

4.2.1. Ordered Logit Model. The variable Y is explained as "willingness of green production," and the score range is 1 to 5. Y is a multivalued ordered variable. Referring to other researchers, this paper investigated decision-making willingness using the Ordered Logit Model [33]. Model 1: regression based on economic and ecological benefit perceptions, guidance, incentive, and restraint regulations, and control variables. Environmental regulation variables are obtained in Model 2 by weighting the regression coefficient ratios of guidance, incentive, and restraint regulations in Model 1. Model 2: regression based on economic and ecological benefit perceptions, environmental regulation, and control variables. The expressions of Models 1-2 are as follows:

$$\frac{P(Y_i \le j \mid X)}{P(Y_i > j \mid X)} = \frac{P(Y_i \le j \mid X)}{1 - P(Y_i \le j \mid X)}, \quad j = 1, 2, 3, 4, 5. \tag{1}$$

Considering Ordered Logit function,

$$\begin{aligned} \operatorname{logit}(P(Y_i \le j \mid X)) &= \ln\left(\frac{P(Y_i \le j \mid X)}{P(Y_i > j \mid X)}\right) \\ &= \ln\left(\frac{P(Y_i \le j \mid X)}{1 - P(Y_i \le j \mid X)}\right), \quad j = 1, 2, 3, 4, 5. \end{aligned} \tag{2}$$

The Ordered Logit is defined as

$$\begin{aligned} &\ln\left(\frac{P(Y_i \le j \mid X)}{1 - P(Y_i \le j \mid X)}\right) \\ &= -\alpha_i + \sum \beta_i X_i + \varepsilon, \quad j = 1, 2, 3, 4, 5. \end{aligned} \tag{3}$$

Here, Y_i denotes the i-th new agricultural business entity's green production willingness; j denotes the willingness level; α_i denotes the intercept; β_i denotes the coefficient of the corresponding explanatory variable X_i; X_i denotes the i-th explanation that affects the green production willingness variable; and ε denotes the random error term.

Model 3 expands on Model 2 by including a decentralized environmental regulation and economic benefit perception synergy item, as well as a decentralized environmental regulation and ecological benefit perception synergy item. Model 3: regression based on economic and ecological benefit perceptions, environmental regulation, synergy item between environmental regulation and economic benefit perception, synergy item between environmental regulation and ecological benefit perception, and control variables. The expression of Model 3 is as follows:

$$\begin{aligned} \ln\left(\frac{P(Y_i \le j \mid X)}{1 - P(Y_i \le j \mid X)}\right) &= -\alpha_i + \sum \beta_i X_i \\ &+ \eta_1 (X_1 - \overline{X}_1)(X_1 - \overline{X}_3) \\ &+ \eta_2 (X_2 - \overline{X}_2)(X_1 - \overline{X}_3) \\ &+ \varepsilon, \quad j = 1, 2, 3, 4, 5. \end{aligned} \tag{4}$$

Here, η_1 denotes the coefficient of economic benefit perception and environmental regulation synergy after

decentralization; η_2 denotes the coefficient of ecological benefit perception and environmental regulation synergy after decentralization; X_1 represents the economic benefit perception; X_2 represents the ecological benefit perception; X_3 represents the environmental regulation; other relevant variables are the same as Models 1-2.

4.2.2. Ordered Probit Model. In this paper, the Ordered Probit Model is used to perform a robust test on Ordered Logit Models 1–3, and the maximum likelihood estimation method is used to regression the equation. The expression of Models 1-2 is as follows:

$$\mathrm{AGPW}_j^* = \sum \beta_j X_j + \varepsilon_j. \tag{5}$$

The expression of Model 3 is as follows:

$$\begin{aligned}\mathrm{AGPW}_j^* = {} & \sum \beta_j X_j + \eta_1 \left(X_1 - \overline{X}_1\right)\left(X_3 - \overline{X}_3\right) \\ & + \eta_2 \left(X_2 - \overline{X}_2\right)\left(X_3 - \overline{X}_3\right) + \varepsilon_j.\end{aligned} \tag{6}$$

$\mathrm{AGPW}_j{}^*$ is assumed to be a continuous recessive variable with r_1, r_2, r_3, and r_4 cut points. When $\mathrm{AGPW}_j{}^* < r_1$, the willingness of new agricultural business entities to adopt green production is very low; when $r_1 \le \mathrm{AGPW}_j{}^* < r_2$, the willingness of new agricultural business entities to adopt green production is low; ...; when $r_4 \le \mathrm{AGPW}_j{}^*$, the willingness of new agricultural business entities to adopt green production is very high. Although the value of $\mathrm{AGPW}_j{}^*$ cannot be determined, the selection result of AGPW_j in response to the green production willingness of the new agricultural business entities can be obtained. When the AGPW_j selection result is between 1 and 5, it means the following:

$$\mathrm{AGPW}_j = \begin{cases} 1, & \mathrm{AGPW}_j^* \le r_1, \\ 2, & \mathrm{r}_1 < \mathrm{AGPW}_j^* \le r_2, \\ 3, & \mathrm{r}_2 < \mathrm{AGPW}_j^* \le r_3, \\ 4, & \mathrm{r}_3 < \mathrm{AGPW}_j^* \le r_4, \\ 5, & \mathrm{r}_4 < \mathrm{AGPW}_j^*. \end{cases} \tag{7}$$

Here, AGPW_j denotes the willingness of new agricultural management entities to produce green; r_1, r_2, r_3, r_4, r_5 denote the threshold, satisfying $r_1 < r_2 < r_3 < r_4 < r_5$; other relevant variables are the same as those of the Ordered Logit Models 1–3.

4.3. Variables Description. The definition and description statistics of variables are shown in Table 1.

4.3.1. Explained Variable. "Agricultural green production willingness" refers to the willingness of new agricultural business entities to produce in a green manner during the agricultural production process. The explanatory variables are defined as 1–5, and the willingness to green production increases in turn.

4.3.2. Core Variables. Refer to C Y Yang et al.'s and Y Z Huang et al.'s studies on economic and ecological benefit perceptions [7, 34]. The average value of "the effect of green production on agricultural product output" and "the effect of green production on agricultural product prices" is used to assess how new agricultural business entities perceive the economic benefit of green production. The average value of "the improvement effect of green production on the rural ecological environment" and "the promotion effect of green production on the sustainable development of agriculture" was chosen as the perception index of new agricultural business entities on the ecological benefit of green production. Refer to X Y Zhao et al.'s and H L Zhang et al.'s studies on environmental regulation [8, 23]. The three questions chosen to assess the government's guidance, incentive, and restraint regulations of agricultural green production are "the government's guidance intensity for agricultural green production," "the government's incentive intensity for agricultural green production," and "the government's punishment intensity for nongreen production."

4.3.3. Control Variables. Referring to other scholars' research [35–37], choose "age," "number of annual agricultural training," "agricultural income to household income ratio," "cultivated land area," "frequency of communication with neighbors about agricultural green production," "green production risk," and "green production behavior of other people in the village" as control variables. Based on the differences between the four business types of new agricultural business entities, this paper introduces a new control variable "business scale."

5. Empirical Analysis

5.1. Model Check. Models 1–3 were tested for reliability and validity using SPSS 23. Models 1–3 have Cronbach's α of 0.728, 0.669, and 0.647, respectively, and reliability is greater than 0.6. Models 1–3 have KMO of 0.729, 0.722, and 0.636, respectively, and validity is greater than 0.6. Models 1–3 were found to be reliable and valid. STATA 15 was used to test Models 1–3 for collinearity. Models 1–3 have no multicollinearity issues because all VIF values are less than 4 (much less than 10). Finally, Models 1–3 can be estimated using the Ordered Logit Model.

5.2. Ordered Logit Regression Results for Models 1–3. The Ordered Logit Models 1–3 results are shown in Table 2 and Figure 3.

5.2.1. The Direct Impact of the Perceptions of Economic Benefit and Ecological Benefit on the Willingness of New Agricultural Business Entities to Engage in Green Production. The regression results of Models 1–3 show that the perception of economic benefit has a positive impact on the willingness of new agricultural business entities to green production at significance levels of 1%, 1%, and 5%. Hypothesis H1a is verified, and the self-interested view under

Table 1: Definition and description statistics of variables.

Variable	Connotation and assignment	Mean	Standard deviation
Green production willingness	Very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	4	0.088
Economic benefit perception = (A1 + A2)/2	A1 very low = 1; Low = 2; Normal = 3; High = 4; very high = 5 A2 very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	3.80	0.079
Ecological benefit perception = (B1 + B2)/2	B1 very low = 1; Low = 2; Normal = 3; High = 4; very high = 5 B2 very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	3.95	0.080
Guidance regulation	Very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	3.79	0.093
Incentive regulation	Very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	3.42	0.098
Restraint regulation	Very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	3.55	0.110
Age	Under 30 years old = 1; 30–40 years old = 2; 40–50 years old = 3; 50–60 years old = 4; over 60 years old = 5	2.75	0.092
Business scale	Large grain grower = 1; family farm = 2; professional cooperative = 3; big enterprise = 4	3.08	0.060
Training times per year	Did not participate = 1; 1–2 times = 2; 3–5 times = 3; 6–10 times = 4; 10 times or more = 5	2.95	0.839
Proportion of agricultural income	Below 10% = 1; 10%–40% = 2; 40%–60% = 3; 60–90% = 4; above 90% = 5	3.18	0.816
Cultivated area	0–6.67 hectares = 1; 6.67–20 hectares = 2; 20–33.33 hectares = 3; 33.33–66.67 hectares = 4; over 66.67 hectares = 5	2.62	0.839
Communication with neighbors about green production	No communication = 1; less communication = 2; Normal = 3; more communication = 4; frequent communication = 5	3.41	0.816
Green production risk	Very low = 1; Low = 2; Normal = 3; High = 4; very high = 5	2.99	0.821
Green production behavior of others	Very poor = 1; Poor = 2; Fair = 3; Good = 4; very good = 5	2.46	0.125

Table 2: Results of ordered logit regression models 1–3.

Variable	Model (1)	Model (2)	Model (3)
Economic benefit perception	1.014*** (0.371)	1.012*** (0.357)	0.954** (0.375)
Ecological benefit perception	0.623* (0.372)	0.623* (0.370)	0.792** (0.387)
Environmental regulation		1.003*** (0.353)	0.885** (0.371)
Guidance regulation	0.429 (0.352)		
Incentive regulation	0.068 (0.292)		
Restraint regulation	0.465** (0.232)		
Economic benefit perception × environmental regulation			−0.700 (0.500)
Ecological benefit perception × environmental regulation			1.105* (0.567)
Age	−0.250 (0.230)	−0.251 (0.221)	−0.292 (0.223)
Business entity scale	0.712** (0.346)	0.712** (0.345)	0.634* (0.358)
Training times per year	−0.124 (0.201)	−0.124 (0.201)	−0.188 (0.206)
Proportion of agricultural income	0.062 (0.165)	0.062 (0.165)	0.094 (0.167)
Cultivated area	−0.107 (0.181)	−0.107 (0.178)	−0.131 (0.183)
Communication with neighbors	−0.130 (0.233)	−0.130 (0.230)	−0.190 (0.237)
Green production risks	−0.207 (0.242)	−0.207 (0.242)	−0.165 (0.249)
Production behavior of others	−0.078 (0.196)	−0.077 (0.191)	−0.073 (0.198)
Pseudo R2	0.2310	0.2310	0.2457
LR chi2 (13)	60.27***	60.27***	64.09***

Notes: ***, **, and * indicate significant at a level of 1%, 5%, and 10%, respectively. The coefficients are outside the parentheses, and the robust standard errors are inside the parentheses.

the Economic and Social Man Hypothesis is confirmed. The regression results of Models 1–3 show that the perception of ecological benefit has a positive impact on the willingness of new agricultural business entities to produce green at significance levels of 10%, 10%, and 5%. Hypothesis H1b is verified, and the altruistic view under the Economic and Social Man Hypothesis is confirmed. Furthermore, in Models 1–3, the economic benefit perception has a greater impact coefficient on the willingness of new agricultural business entities to engage in green production than ecological benefit perception, confirming the judgment of socialist market economic activities with Chinese characteristics in the Hypothesis of Economic and Social Man—with altruism as the guide and adjustment dominated by self-interest.

5.2.2. The Direct Impact of Environmental Regulation on the Willingness of New Agricultural Business Entities to Green Production. According to the regression results of Model 1, the guidance regulation has a positive impact on the green production willingness of new agricultural business entities,

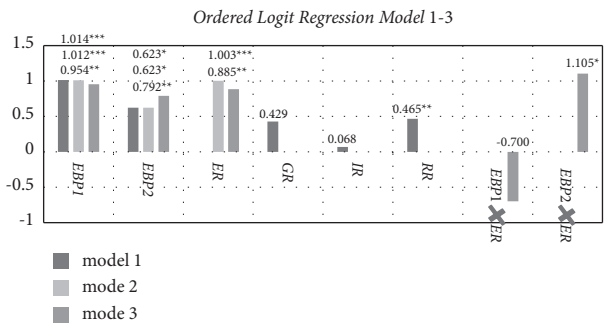

Figure 3: Results of the Ordered Logit Regression Models 1–3. Notes: EEP1 means economic benefit perception, EEP2 means ecological benefit perception, ER means environmental regulation, GR means guidance regulation, IR means incentive regulation, RR means restraint regulation, EBP1 × ER means the synergy between economic benefit perception and environmental regulation, EBP2 × ER means the synergy between ecological benefit perception and environmental regulation.

but it is not significant. The H2a hypothesis has not been verified. The lack of significance of guidance regulation in Model 1 could be attributed to the close relationship between ecological benefit perception and guiding regulation, which influences the significance of guidance regulation. Therefore, the impact of guidance regulation needs to be verified by the Model with the addition of synergies. The impact of incentive regulation on the willingness of new agricultural business entities to engage in green production is minor and insignificant. The H2b hypothesis has yet to be proven. The following factors could be at play: the total amount of agricultural green production subsidies is small; the threshold for receiving agricultural green production subsidies is low; and the input cost of new agricultural business entities to green production is high. Restraint regulation has a positive impact on the willingness of new agricultural business entities to engage in green production at the 5% significance level. The H2c hypothesis has been proven. According to the regression results of Models 2-3, environmental regulation has a positive effect on the green production willingness of new agricultural business entities at the 1% and 5% significance levels. The H2 hypothesis has been proven.

5.2.3. The Effect of Synergy between Benefit Perception and Environmental Regulation on the Willingness of New Agricultural Business Entities to Produce Green. According to the regression results of Model 3, the synergy item of economic benefit perception and environmental regulation has a negative impact on the green production willingness of new agricultural business entities, but it is not significant. The H3a hypothesis remains unproven. The reason for this is that as China's "green agricultural products" market has grown, the synergy effect of economic benefit perception and environmental regulation on the willingness of new agricultural business entities to produce green has weakened. The synergy item of ecological benefit perception and environmental regulation positively affects the green production willingness of new agricultural business entities at the 10% significance level. The H3b hypothesis has been proven.

Table 3: Regression results of Ordered Probit Models 1–3.

Variable	Model (1)	Model (2)	Model (3)
Economic benefit perception	0.603***	0.603***	0.559***
	(0.210)	(0.203)	(0.214)
Ecological benefit perception	0.233	0.233	0.394*
	(0.198)	(0.197)	(0.215)
Environmental regulation		0.500***	0.541***
		(0.173)	(0.177)
Guidance regulation	0.139		
	(0.176)		
Incentive regulation	0.098		
	(0.162)		
Restraint regulation	0.263**		
	(0.129)		
Economic benefit perception × environmental regulation			−0.353
			(0.251)
Ecological benefit perception × environmental regulation			0.571**
			(0.261)
Control variable	Control	Control	Control
Pseudo R2	0.2242	0.2242	0.2463
LR chi2 (13)	58.48***	58.48***	64.26***

5.2.4. The Impact of Control Variables on the Willingness of New Agricultural Business Entities to Adopt Green Production. According to the regression results of Models 1–3, the business scale has a positive impact on the green production willingness of new agricultural business entities at significance levels of 5%, 5%, and 10%. In other words, the higher the level of business scale is, the more eager the new agricultural business entities are to produce green.

5.3. Robustness Check. Ordered Probit Models 1–3 were used to test the robustness of Ordered Logit Models 1–3. Except for the ecological benefit perception in the Ordered Probit Models 1–2, whose direction is consistent with the Ordered Logit Models 1–2 but not significant, the other core variables' directions and significance are consistent. It is possible that the lack of significance of ecological benefit perception in Ordered Probit Models 1-2 is due to a synergy between ecological benefit perception and environmental regulation, which affects its significance in Ordered Probit Models 1-2. Both the Ordered Probit Model without environmental regulation and the Ordered Probit Model with covariables have significant regression results for ecological benefit perception, supporting this viewpoint. Therefore, the study's findings are fairly solid. The Ordered Probit Models 1–3 regression results are shown in Table 3 and Figure 4. (The control variables are the same as those in Table 2.)

5.4. Extended Analysis. In order to confirm the impact of guidance regulation on new agricultural business entities' green production intentions, as well as to further investigate the synergistic effect of various regulatory means and benefit

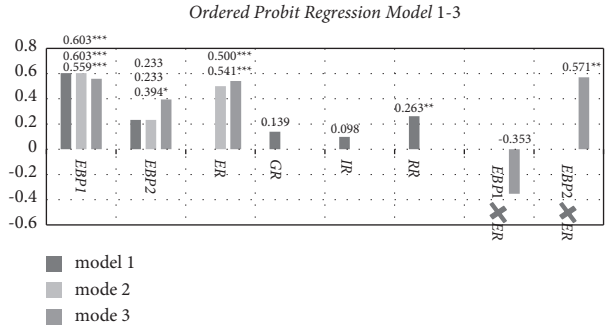

Figure 4: Results of the Ordered Probit Regression Models 1–3. Notes: The EBP1, EBP2, ER, GR, IR, RR, EBP1 × ER, and EBP2 × ER are the same as those in Figure 3.

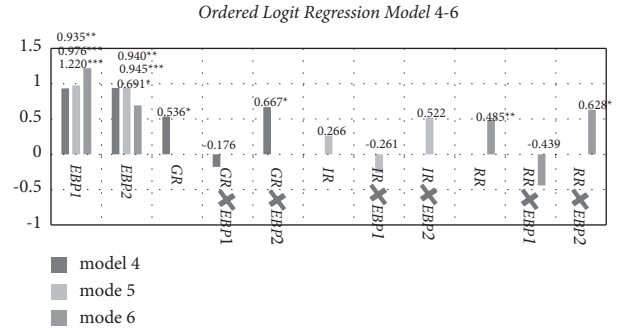

Figure 5: Results of Ordered Logit Regression Models 4–6. Notes: GR × EBP1 means the synergy between guidance regulation and economic benefit perception; GR × EBP2 means the synergy between guidance regulation and ecological benefit perception; IR × EBP1 means the synergy between incentive regulation and economic benefit perception; IR × EBP2 means the synergy between incentive regulation and ecological benefit perception; RR × EBP1 means the synergy between restraint regulation and economic benefit perception; RR × EBP2 means the synergy between restraint regulation and ecological benefit perception. The EBP1, EBP2, GR, IR, and RR are the same as those in Figure 3.

Table 4: Regression results of Ordered Logit Models 4–6.

Variable	Model (4)	Model (5)	Model (6)
Economic benefit perception	0.935** (0.392)	0.976*** (0.371)	1.220*** (0.357)
Ecological benefit perception	0.940** (0.380)	0.945*** (0.356)	0.691* (0.360)
Guidance regulation	0.536* (0.295)		
Guidance regulation × economic Benefit perception	−0.176 (0.368)		
Guidance regulation × ecological Benefit perception	0.667* (0.393)		
Incentive regulation		0.266 (0.256)	
Incentive regulation × economic Benefit perception		−0.261 (0.343)	
Incentive regulation × ecological Benefit perception		0.522 (0.420)	
Restraint regulation			0.485** (0.234)
Restraint regulation × economic Benefit perception			−0.439 (0.298)
Restraint regulation × ecological Benefit perception			0.628* (0.381)
Control variable	Controlled	Controlled	Controlled
Pseudo R2	0.2290	0.2132	0.2318
LR chi2 (13)	59.74***	55.61***	60.47***

perceptions, Models 4–6 are designed to introduce the synergy between various regulatory measures and two types of benefit perception. Cronbach's coefficients are 0.625, 0.622, and 0.646 for Models 4–6, respectively. The KMOs for Models 4–6 are 0.646, 0.626, and 0.628. All VIF values are less than 4. Therefore, Models 4–6 can be estimated using the Ordered Logit Model. The regression results for Models 4–6 are shown in Table 4 and Figure 5. (The control variables are the same as in Table 2).

The perceptions of economic and ecological benefit are still significant in the regression results of Models 4–6. The H1a and H1b hypotheses have been confirmed yet again. The results of Model 4 regression show that, at a 10% level of significance, guidance regulation has a positive impact on the willingness of new agricultural business entities to engage in green production, proving hypothesis H2a; and the synergistic item of guidance regulation and ecological benefit perception positively affect the green production willingness of new agricultural business entities at a significance level of 10%. The results of Model 6 regression show that the restraint regulation positively affects new agricultural business entities' willingness to engage in green production at a 5% significance level, proving hypothesis H2c; at a significance level of 10%, the synergistic item of restraint regulation and ecological benefit perception positively affect the green production willingness of new agricultural business entities.

6. Conclusion and Suggestion

The primary goal of this study is to determine how benefit perception and environmental regulation affect new agricultural business entities' willingness to produce green in China. The following was discovered: first, both economic benefit perception and ecological benefit perception have a significant role in promoting the willingness of new agricultural business entities to green production, and the driving effect of economic benefit perception is stronger than ecological benefit perception. The findings verify the "Economic and Social Man Hypothesis" that people are self-interested and altruistic, as well as the Hypothesis's

judgment on the behavior of "economic and social man" in the socialist market economy with Chinese characteristics. Second, environmental regulation can increase the willingness of new agricultural businesses to engage in green production. However, among the three regulatory measures, only the guidance and restraint regulations have a significant impact. Therefore, in environmental regulation, there is a phenomenon known as "relative system failure." Third, the synergy between ecological benefit perception and environmental regulation is also the key to influencing the willingness of new agricultural business entities to green production. The extended analysis finds that the impact of ecological benefit perception on new agricultural business entities' green production willingness is dependent to some extent on guidance and restraint regulations and that the impact of guidance and restraint regulations on new agricultural business entities' green production willingness is also influenced by ecological benefit perception. Fourth, the scale of business has a great influence on the green production willingness of new agricultural business entities. It means that the higher the level of business scale is, the more eager the new agricultural business entities are to produce green products.

Based on the preceding conclusions, the following recommendations are made: first, strengthen the perceptions of the economic and ecological benefit of new agricultural business entities to green production. Measures should be taken to improve the market for green agricultural products and encourage the development of environmental protection technology for increasing production in order to improve the economic benefits of green production and strengthen the perception of economic benefits. Measures such as regularly publicizing the improvement of the agroecological environment, testing, and feedback on the soil quality of planting areas should be taken to improve the perception of ecological benefit. Second, strengthen guidance and restraint regulations and adjust incentive regulation methods. Try to change the way agricultural green production subsidies are distributed—from a one-time direct subsidy to a series of standard-compliant subsidies while also increasing spiritual incentives for agricultural green production. Third, improve the connection between ecological benefit perception and guidance regulation, as well as the connection between ecological benefit perception and restraint regulation. The propaganda of agricultural green production in guidance regulation and the education of agricultural nongreen production in restraint regulation should be aimed at improving the perception of the ecological benefits of new agricultural business entities. Fourth, cultivate the new agricultural business entities with larger business scales. Application conditions should be relaxed, and policy support should be increased, to increase the proportion of cooperatives and leading enterprises in the new agricultural business entities.

Data Availability

All research data were obtained from in-depth interviews and questionnaires. All data included in this study are available upon request by contact with the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

The Impact of the "Belt and Road" Initiative on Accounting Conservatism of Energy-Intensive Enterprises under the Low-Carbon Background

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In recent years, the "Belt and Road" Initiative (BRI) has paid more and more attention to practicing the concept of green development. The concept of green development in the BRI will help promote the active response to climate change in the regions along the route and maintain global ecological security and is of great significance to the green transformation and development of energy-intensive enterprises. Using company-level data from China over the 2011–2020 period, we provide a comprehensive analysis of the impact of the BRI on energy-intensive enterprise accounting conservatism. We find that BRI has decreased the energy-intensive enterprise accounting conservatism, and this result continues to hold after a series of robustness tests. We also examine the effect of the RBI on accounting conservatism across company types and ages and find that the BRI is beneficial to energy-intensive state-owned enterprises (SOEs) and young companies. Furthermore, analysis reveals that BRI changes the accounting conservatism of energy-intensive enterprises mainly through debt financing, tax burden, and legal environment channels.

1. Introduction

In the context of global warming, controlling carbon emissions has become a public issue that all countries in the world must face together. China is the world's largest carbon emitter and faces enormous pressure to reduce emissions. The greenhouse gas emissions of major countries and regions in the world in 2019 are shown in Figure 1. At this stage, China is striving to increase its nationally determined contribution and has proposed a strategic goal of peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. Will controlling carbon emissions reduce corporate productivity? This is a common problem faced by energy-intensive enterprises characterized by high carbon emissions. Energy-intensive enterprises occupy an important position in China's economic system, and their development will have a direct impact on the fundamentals of China's economy and is of great significance to promoting the transformation and upgrading and high-quality development of energy-intensive enterprises. Therefore, in the context of low carbon, we should focus on the survival and development of energy-intensive enterprises.

1.1. Source: Rhodium Group. In the existing research, many scholars have studied the influence of policy systems and enterprise-level factors on the behavior and performance of energy-intensive enterprises such as low-carbon city pilot policy, green credit, environmental regulation, corporate social responsibility, and carbon emission reduction strategy [1–5]. Among them, the discussion on the policy and system level is the key point. However, looking at the existing research, the research on the impact of China's "Belt and Road" initiatives on the behavior of energy-intensive

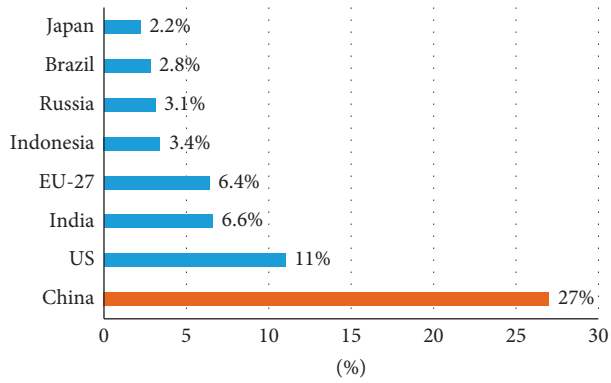

Figure 1: Greenhouse gas emissions in 2019.

enterprises is still relatively weak. In March 2022, the National Development and Reform Commission of the People's Republic of China issued the "Opinions on Promoting the Green Development of the Belt and Road Initiative," emphasizing the need to build a closer green development partnership and promote the building of a community of life between man and nature. This shows that China is taking clearer policy directions and more pragmatic measures to vigorously promote the response to global climate change and maintain global ecological security. This policy document also clearly emphasizes the need to deepen cooperation in the field of energy, technology, and equipment, promote energy-saving and low-carbon transportation tools such as new energy and clean energy vehicles and ships, and promote the intelligent transportation China scheme. The BRI is conducive to the green development of the regions along the route and will have an important impact on the transformation and upgrading and high-quality development of energy-intensive enterprises.

In 2013, China announced two collaborative initiatives: a "New Silk Road" economic belt and a twenty-first century "Maritime Silk Road." These initiatives are commonly known as the "Belt and Road" initiatives [6]. Existing studies have analyzed the social and economic effects of China's BRI from a macroeconomic perspective, such as international trade in goods, foreign investment, and industrial integration [6–8]. Enterprises are the ultimate vehicle for the implementation of China's BRI, so existing studies have considered related issues such as investment risk and financing constraints [9, 10]. These studies suggested that BRI will (i) help reduce the investment risks of companies investing in Belt and Road countries, (ii) ease the pressure of financial constraints, (iii) improve the level of corporate innovation, and (iv) help Chinese companies achieve the goal of industrial transformation and upgrading.

Overall, the BRI has yielded significant positive impacts on several enterprises. However, it is still necessary to strengthen the relevant research on the impact of the BRI on the development of energy-intensive enterprises. In this paper, we focus on the effect of BRI on accounting decisions of energy-intensive enterprises. The quality of accounting information (accounting conservatism) is related to the timeliness, accuracy, and effectiveness of information about the entire economic operation, and it is crucial for business entities and their stakeholders to make prudent business decisions. Ball et al. emphasized that the accounting conservatism of enterprises is closely related to institutional factors [11]. Therefore, it is important to investigate the quality of accounting information at the institutional level. Especially at the current stage, multiple factors such as the deepening of the concept of green development [12], the global economic downturn, and the frequent occurrence of political uncertainties all put forward higher requirements for the accounting conservatism of high pollution enterprises in order to improve enterprises' risk response-ability. This paper takes accounting conservatism as the object and constructs an analytical framework to examine the impact of BRI on energy-intensive enterprise accounting conservatism from the perspective of accounting decision-making for energy-intensive enterprise enterprises.

While focusing on China's listed A-share companies over the 2011–2020 period and taking the quasi-natural experiment formed by the BRI as the starting point, we investigate the impact of BRI on accounting conservatism of the energy-intensive enterprises. Empirical analysis presented in this paper shows that compared to the companies not supported by the BRI, the supported companies experienced a decrease in energy-intensive enterprises' accounting activism. A series of robustness tests confirm the validity of this conclusion. We also tested for heterogeneity with respect to the nature of property rights and the age of the company. Our results show that the BRI had a greater impact on accounting conservatism of state-owned and young energy-intensive enterprises. The analysis of the action mechanism shows that BRI has affected the accounting conservatism of energy-intensive enterprises through debt financing, tax burden, and legal environment.

This paper makes three important contributions to the existing literature. First, we combine macroeconomic policy and energy-intensive enterprise's decision-making behavior to examine the impact of the BRI on energy-intensive enterprise's accounting behavior, which offers new insights into the issue of how the BRI green development is affecting energy-intensive business activities. Second, by examining the impact of BRI on decision-making, this paper explores the impact of BRI on the soundness of accounting initiatives, which expands existing research that deals with the impact of BRI. Third, by taking a specific Belt and Road macroeconomic policy as the starting point, we analyze the influencing factors and economic consequences of accounting conservatism, which supplements the institutional level research on accounting conservatism.

2. Literature Review, Theoretical Analysis, and Research Hypothesis

2.1. Factors Affecting Accounting Conservatism. Accounting conservatism, which is also known as "prudence," requires accounting reports to respond more promptly and adequately to bad news than to good news, to confirm all foreseeable costs. Based on earlier studies, Watts developed a theory of accounting conservatism [13]. Watts's theory involves four factors: contracts, taxation, litigation,

and supervision. Watts's theory has attracted widespread attention from the academic community, and several studies have explored the robustness of the underlying factors.

2.1.1. Contracts. Company contracts are the most important factor that affects accounting conservatism. The contacts can involve debt and management compensation. With regard to the debt contracts, Watts argued that sound accounting information can reduce the debtor's opportunistic motivation to overestimate asset values or returns, thereby helping the creditors to identify potential risks at an early stage, which can avoid losses to the creditors [13]. Thus, creditors tend to have higher accounting conservatism. Existing studies find that accounting conservatism can significantly improve the efficiency of corporate debt financing, which also reduces the risk by increasing the maturity match between cash flow and debt. Ngoc and Manh found that financial leverage has a positive effect on accounting conservatism [14].

As far as the management compensation contracts are concerned, the principal-agent theory suggests that the asymmetry of shareholders and management objectives can lead to significant agency costs. Under the pay evaluation system based on accounting profits, company management has a strong incentive to overestimate the future cash flows of investment projects and to hide the potential investment losses because of their information advantage. Owing to the inflated financial statements, the management is able to extract higher compensations. Robust accounting principles can effectively reduce the moral hazard of management in the salary contract, thereby reducing agency costs and protecting the rights and interests of owners [15]. Conservative accounting practices can curtail the opportunistic behavior of managers, counter agency problems, and promote efficient contracting mechanisms. Haider et al., Wang et al., and Cui et al. showed that managerial ability is positively associated with accounting conservatism, which can restrain stock price collapses like good corporate governance [16–18].

2.1.2. Taxation. Accounting conservatism tends to reduce the taxable income of energy-intensive companies because losses and expenses are declared promptly but assets and gains reporting is delayed [13]. Thus, accounting conservatism has implications for corporate tax liability. Owing to the tax incentive, energy-intensive enterprises are more likely to practice accounting conservatism. Lara et al. showed that taxation and regulation induce not only unconditional conservatism but conditional conservatism as well [19]. Choi and Choi argued that accounting conservatism can also contribute to tax avoidance [20].

2.1.3. Litigation and Supervision. From the perspective of legal litigation, energy-intensive companies will have more litigation cases when their assets or earnings are overvalued, which in turn will bring higher litigation costs [21]. Because of this, management tries their best to avoid litigation and choose robust accounting practices to protect energy-intensive corporate interests. Because accounting conservatism reduces litigation costs by underestimating assets or profits. Shawn et al. argued that firms that are about to be delisted tend to be more conservative in reporting earnings to avoid litigation risk [22].

From the perspective of accounting supervision, if energy-intensive companies overestimate assets or earnings, the cost of accounting supervision by regulatory bodies will decrease. Accounting conservatism will reduce the cost of government supervision by underestimating assets or income and hence the supervisors will require sound accounting information. Thus, litigation and accounting supervision-related factors promote accounting conservatism. The quality of the legal system and the strength of supervision tend to have a significant impact on accounting conservatism. Xu found that in areas with a better legal environment, companies are more likely to face lawsuits due to violations of regulations [23]. At the same time, companies also have to face stricter accounting supervision by government regulatory agencies, which will increase the need for companies to increase accounting stability. On the contrary, in areas where law enforcement is weak and investor protection is weak, companies have lower accounting stability. In addition to the legal system-related factors, recent studies also highlight other system-related factors (e.g., property rights, political shocks, political connections, and macroeconomic policies) that affect accounting conservatism. Dai and Ngo found that political uncertainty leads to greater information asymmetry among the contracting parties to the firm, resulting in an increased demand for accounting conservatism [24]. Bu et al. found that political uncertainty can lead to a significant decrease in accounting conservatism [25].

This paper aims to extend the existing literature, which deals with the effect of institutional factors on accounting conservatism. We examine the effect of a new industrial policy (i.e., China's BRI) on energy-intensive accounting conservatism.

2.2. Theoretical Framework and Research Hypothesis. As an important industrial policy in the context of economic transformation and low-carbon green development, China's BRI is a significant regulatory tool, which is used for both allocations of scarce resources as well as achievement of strategic goals [26, 27]. Ball et al. argued that the national system can also have a decisive influence on the choice of corporate accounting policies [11]. The previous study on the four influencing factors of accounting conservatism, including contract, tax, litigation, and supervision, found that the debt contract and compensation contract in the contract factor, the tax burden corresponding to the tax factor, and the legal system corresponding to the litigation and regulatory factors can all effectively explain the differences in the quality of accounting information of enterprises. Based on existing studies [28–30], it can be argued that the BRI influences the energy-intensive corporate accounting decisions through four channels that affect corporate debt

contracts, executive compensation, the tax burden, and the legal environment.

First, in relation to the debt contracts, Watts pointed out that debt contracts are the original source of accounting conservatism [13]. The BRI can change the energy-intensive enterprises' demand for accounting conservatism by influencing the relationship between the contractual parties. In the Chinese financial system, banks play a dominant role in credit contracts, and the banks are regulated by the reform process of the banking industry. Government intervention will change the credit flow and scale of the banking industry [31]. As an important tool for the Chinese government to further deepen the reform and open up and advocate low-carbon green development, the BRI received strong support from governments at all levels. Since the First Belt and Road Bankers Roundtable was held in 2017, the Industrial and Commercial Bank of China has cooperated with members of the BRBR Mechanism to implement 55 Belt and Road projects with the total amount of loans reaching USD 42.7 billion [26]. Many banks in China are also actively deploying the BRI to provide credit support for Chinese enterprises to go global.

The BRI affects debt covenants in their relations, with the government playing an "implicit guarantor" role [32], thereby reducing the bank's requirement both for the timely detection of the debtor's financial difficulties motives and for the financial soundness of the enterprise. There is an alternative relationship between implicit government guarantee and accounting conservatism. Kim et al. pointed out firms with connections to politicians have greater access to long-term debt and lower accounting conservatism than firms without such ties [33].

On the other hand, energy-intensive enterprises supported by policies not only can get more credit resource rationing but can also receive government financial subsidies, tax incentives, and other resource preferences. The acquisition of more resource support greatly reduces the possibility of enterprises getting into financial difficulties, and the protection of the principal and the interest of the company's claims has been improved, thereby reducing creditors' demand for corporate accounting robustness. Based on this, we believe that BRI will reduce the need for energy-intensive enterprises accounting robustness through a debt contract path.

Therefore, the research hypothesis is as follows:

> *Hypothesis (1a)*: the BRI will reduce the accounting conservatism of energy-intensive companies by changing debt covenants.

Second, in relation to the executive compensation channel, the compensation contract is another contractual factor that results from accounting conservatism. Accounting conservatism can reduce the moral hazard of executives in the contractual remuneration relationship and protect the interests of owners by underestimating assets or returns. However, the free cash flow hypothesis maintains that the agency cost increases with free cash flows, and hence the availability of free cash flow provides an incentive to the management to increase their compensation by manipulating the company performance reports. Lee et al. found that the potential agency costs of capital expenditure are arguably higher for high-free cash flow firms, and stronger monitoring by the board of directors can lead to higher level accounting conservatism thereby confirming the agency cost of cash flows hypothesis [34, 35]. The BRI has resulted in a large amount of bank credit, government subsidies, tax incentives, and other policy resources to support energy-intensive enterprises [31, 35]. Policy resources have resulted in energy-intensive companies generating large free cash flows. According to the agency cost of free cash flows hypothesis, management will have more incentive to grab higher salaries. Under the assessment system linking the salary and performance, the management will have an incentive to choose radical accounting policies to confirm assets or income in advance and thus improve the energy-intensive enterprises' financial performance. Such an improvement in company performance can facilitate the goal of higher salaries. Thus, the BRI will reduce the need for energy-intensive enterprises accounting robustness through the executive compensation path.

Therefore, the research hypothesis is as follows:

> *Hypothesis (1b)*: the BRI will reduce the accounting conservatism of energy-intensive companies by increasing executive compensation.

The third channel concerns the tax burden, which is another important aspect of an energy-intensive enterprise's accounting robustness. To reduce their tax burden, energy-intensive enterprises tend to delay recognizing income, which is consistent with the need for accounting robustness. Choi and Choi found that the tax burden can have a positive impact on the accounting stability of enterprises and the tax burden can thus significantly improve the accounting system [20]. These studies show that a heavier tax burden improves corporate accounting robustness, and the BRI will reduce energy-intensive enterprises' tax burden through various tax incentives, which will reduce the need for accounting robustness. For example, energy-intensive industries affected by the BRI will enjoy specific tax incentives such as tax relief, additional tax deductions, and tax rebates. In October 2017, the State Administration of Taxation of China issued the "Going Global" Tax Guidelines. The Guidelines enumerate 83 matters involved in the "going out" of enterprises in detail from the four aspects of tax policy, tax treaties, management regulations, and service measures in accordance with applicable subjects, policy (agreement) provisions, applicable conditions, and a policy basis. Enterprises affected by the BRI have given corresponding tax incentives. Based on this, the BRI will reduce the need for energy-intensive enterprises accounting robustness through the tax burden path.

Therefore, the research hypothesis is as follows:

> *Hypothesis (1c)*: the BRI will reduce the accounting conservatism of energy-intensive companies by reducing the tax burden.

The fourth channel concerns the legal environment. From the perspective of litigation and supervision, the legal environment is also a fundamental factor affecting

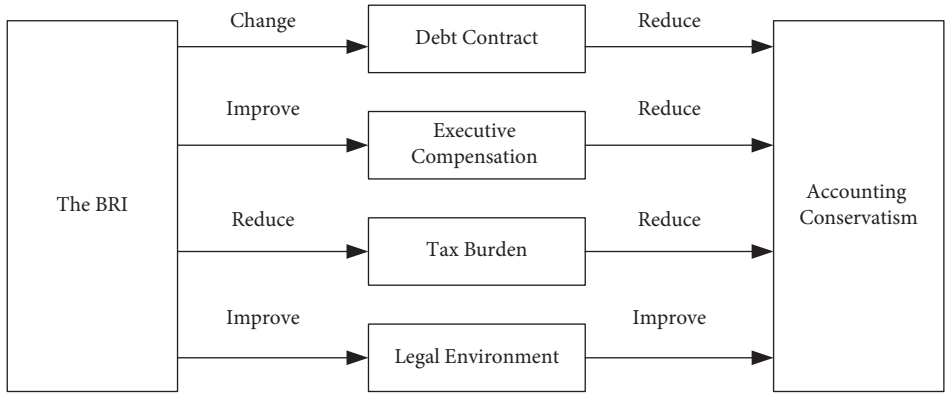

Figure 2: The theoretical framework of how the BRI affects accounting conservatism.

accounting conservatism. On the one hand, the legal environment affects the need for accounting conservatism of energy-intensive enterprises through litigation costs. If the legal system is relatively complete and the enforcement power is high, the probability that management will be sued for inflated assets or surplus will increase, which will lead to higher litigation costs. In order to reduce litigation costs, management tends to choose more stable accounting policies.

On the other hand, the legal environment will influence the demand for accounting conservatism of energy-intensive enterprises through political supervision. In a better legal environment in a country or region, government regulators will be forced by public opinion to demand accounting conservatism. Moy et al. empirically found that the institutional environment index positively correlates with corporate accounting conservatism [36]. The better the legal environment, the higher the marketization process, and the stronger the corporate accounting conservatism. Foo et al. pointed out that improvement in China's domestic legal system can effectively prevent political risk by building the Maritime Silk Road [37]. The BRI helps to further optimize the legal environment in all regions along the route. Based on this, the BRI will increase the demand for accounting robustness of energy-intensive enterprises through the legal environment.

Therefore, the research hypothesis is as follows:

> *Hypothesis (1d)*: the BRI will improve the accounting conservatism of energy-intensive companies by improving the legal environment.

Based on the above discussion, the expected link between the BRI and accounting conservatism is shown in Figure 2.

In Figure 2, based on the contract channel of accounting conservatism, the BRI will change the relationship between the two sides of the debt contract, mainly relying on the government to provide "implicit guarantees" for energy-intensive enterprises and enable energy-intensive enterprises to get more policy support resources, which will reduce the demand for accounting conservatism. The BRI will also motivate the executives to grab high salaries by increasing the free cash flow, which will reduce the need for accounting conservatism.

Secondly, based on the tax burden channel of accounting conservatism, the BRI will reduce the tax burden of energy-intensive enterprises through the implementation of various preferential tax policies, which will reduce the need for accounting conservatism.

Finally, based on litigation and supervision-related factors, the BRI will improve the need for accounting robustness by improving the legal environment of the regions along the route.

Since the improvement of the legal environment is a complex systematic project, the effect may not be significant in the short term. Therefore, we believe that through improving the legal environment, the BRI will have a relatively weak effect on accounting conservatism. Combining the four channels, the BRI will reduce the need for accounting conservatism.

Therefore, the research hypothesis is as follows:

> *Hypothesis (2)*: the BRI will significantly reduce the accounting conservatism of energy-intensive enterprises.

3. Research Design

3.1. Model Design and Definition of Variables. In recent years, the difference in differences (DID) models has been widely used to estimate the economic effects of policies. The reasons are summarized as follows: (1) It can largely avoid the trouble of endogenous problems: compared with the microeconomic entities, policies are generally exogenous, so there is no reverse causality problem. In addition, the use of fixed effects estimation also alleviates the problem of omitted variable bias to a certain extent. (2) To evaluate the policy effect under the traditional method, it is mainly by setting a dummy variable of whether the policy occurs or not and then performing regression. In comparison, the model setting of the double-difference method is more scientific and can more accurately estimate the policy effect. (3) The principle and model setting of the double-difference method is very simple, easy to understand and apply, and are not as daunting as methods such as spatial measurement.

We use the DID model to investigate the effect of BRI on the robustness of accounting conservatism. In March 2015,

Table 1: Definition of variables.

Variable type	Symbol	Definition
Explained variable	*C_score*	Using Khan and Watts's (2009) model of company level accounting conservatism, the accounting conservatism index of the sample is calculated. The larger the value, the higher the company's accounting conservatism.
Explanatory variables	*Treat*	For energy-intensive enterprises involved in BRI, the value is 1; 0 otherwise.
	Inyear	In 2015, the RBI "vision and action" was promulgated, in 2015 and after 2015, the value is 1; 0 otherwise.
Control variable	*Firm size*	Natural logarithm of total assets.
	SOE	If the enterprise is a state-owned enterprise, the value is 1; 0 otherwise.
	MB	Equity market value/equity book value.

the Chinese government issued the vision and action to promote the joint construction of the Silk Road Economic Belt and the 21st century Maritime Silk Road (hereinafter referred to as the vision and action), marking that the "Belt and Road" initiative has entered a pragmatic stage from the top-level design. Therefore, we regard the promulgation of the vision and action in 2015 as a quasi-natural experiment. In our model, energy-intensive enterprises/companies involved in BRI are the treatment group and nonenergy-intensive enterprises not involved in BRI are the control group. Regarding the scope of energy-intensive enterprises, referring to China's "Guidelines for Industry Classification of Listed Companies (Revised in 2012)" and the "Notice of the General Office of the National Development and Reform Commission on Effectively Doing a Good Job in Launching the National Carbon Emissions Trading Market," we select petrochemical, chemical, building materials, steel, nonferrous metals, etc., papermaking and electric power industry enterprises as energy-intensive enterprises.

The DID regression equation is as follows:

$$C\_\text{score}_{it} = \beta_0 + \beta_1 \text{Treat}_{it} \times \text{Inyear}_{it} + \beta_2 \text{Treat}_{it} + \beta_3 \text{Inyear}_{it} + X_{it} + \varepsilon_{it}, \quad (1)$$

where, following Khan and Watts [38], C_score_{it} represents the accounting conservatism score of the i-th company in year t. Treat_{it} is a variable for enterprise grouping, energy-intensive firms that are involved in BRI are the treatment groups and for these firms $\text{Treat}_{it} = 1$; energy-intensive firms that are not involved in BRI are the control group and for these firms $\text{Treat}_{it} = 0$. $\text{Inyear}_{it} = 0$ is time grouping variables, before the BRI was promulgated in 2015 (i.e., from 2011–2014), $\text{Inyear}_{it} = 0$; the year and after the year of the promulgation of the BRI (i.e., 2015–2020), $\text{Inyear}_{it} = 1$. X_{it} is ta vector of control variables, which includes the firm size (Size), the firm type (i.e., state-owned (SOE) or non-SOE), market to book value (MB).ε_{it} is the usual error term.

Based on our hypothesis, β_1 is expected to be negative and statistically significant.

The definitions of the variables are presented in Table 1.

3.2. Sample Selection and Data Sources. We focus on the 2011–2020 period, which involves a window of four years before and after the BRI. The sample consists of A-share listed companies in China. After excluding the companies with incomplete data or missing data, and negative equity, we were left with 353 energy-intensive companies involving 2,225 sample observations. The corporate code of the "Belt and Road" concept version of this paper is sourced from the Zhejiang RoyalFlush Network Technology Co., Ltd (China) (Flush Data Center, https://data.10jqka.com.cn). The "Belt and Road" concept stocks mainly cover two industrial chains. The first industrial chain includes industries such as building materials and cement, ports and shipping, coal, electricity, and gasoline; the second industrial chain includes engineering construction, machinery and equipment, and other industries. It can be seen from this that the Belt and Road concept stocks are basically energy-intensive industries. The other financial data comes from the China Stock Market & Accounting Research Database (China Stock Market & Accounting Research Database, https://www.gtarsc.com). To eliminate the influence of extreme values, 1% winsorize processing was performed on the main continuous variables. In addition, we use company-level clustered standard errors.

3.3. Descriptive Statistical Analysis of the Data. Table 2 presents the descriptive statistical results of the main variables. The average value of accounting conservatism is 0.038, the median is 0.033, the standard deviation is 0.065, the minimum is −0.077, and the maximum is 0.172, which shows lots of variation in accounting conservatism across enterprises over the sample period. The Treat mean of 0.071 indicates that 7.1% of the energy-intensive companies included in the sample were impacted by or involved in the BRI.

4. Empirical Results and Analysis

4.1. Univariate Analysis. Table 3 reports the changes in corporate accounting conservatism of energy-intensive companies before and after the BRI. As the table shows, prior to the BRI, the corporate accounting robustness of the treatment and control groups significantly differed (t-value of 11.67, significant at the 1% level). Specifically, compared with the control group, the average accounting robustness of the treatment group companies was 0.012 higher. This is because the treatment group involves essentially foreign investment companies, and these companies have higher requirements for the quality of accounting information. After the implementation of the BRI, there was still a significant difference in accounting conservatism between the

Table 2: Descriptive statistics of the data.

Stats	*N*	Mean	Median	SD	Min	Max
C_score	2,225	0.038	0.033	0.065	−0.077	0.172
Treat	2,225	0.071	0.000	0.256	0.000	1.000
Size	2,225	22.165	22.016	1.159	20.422	24.621
SOE	2,225	0.382	0.000	0.486	0.000	1.000
MB	2,225	0.618	0.622	0.231	0.222	1.007

Table 3: The BRI and accounting conservatism: univariate *t*-test results.

		Treatment group (1)	Control group (2)	Difference (1)-(2)	*t*-test (1)-(2)
C_score	Before the BRI	0.045	0.033	0.012	11.67***
	After the BRI	0.024	0.014	0.010	3.77***

Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

treatment and control groups (*t*-value of 3.77, significant at the 1% level). Compared to prior initiatives, the difference between the treatment and control groups after the BRI decreased (from 0.012 after the first initiative to 0.010). Table 3 also shows that the BRI reduced the level of accounting robustness of the treatment group companies and the accounting conservatism gap between the treatment and control groups also decreased, indicating a preliminary verification of our hypothesis.

4.2. DID Estimation Results. Table 4 reports the DID estimation results of the impact of the BRI on corporate accounting conservatism of energy-intensive companies. Column 1 presents the regression results after including the control variables in the benchmark regression model. The estimated coefficient of Treat × Inyear is −0.005 is significant at the 10% level. Column 2 presents the regression results after including the industry dummy. However, the estimated coefficient of Treat × Inyear has not changed, but the significance of the statistical significance of the variable has increased to 5%, indicating that after controlling for the industry there was a significant reduction in the accounting conservatism of enterprises when compared with companies not affected by the BRI in the same industry. The DID estimation results in Table 4 show that the BRI has decreased the accounting conservatism of energy-intensive enterprises and hence our Hypothesis (2) is supported.

4.3. Robustness Test

4.3.1. Parallel Trend Test. The DID model has a strict premise constraint of the same trend assumption, that is, the control group and the treatment group have the same change trend before the occurrence of the natural event. Therefore, in order to test the rationality of the DID model in this paper, this paper firstly conducts the same trend test on the accounting conservatism of the experimental group and the control group, and the results are shown in Figure 3. The parallel trend test found that before the implementation of the Belt and Road Initiative, the data change trends of the treatment group and the control group were the same, and

Table 4: The BRI and accounting robustness: DID estimation results.

	(1)	(2)
Treat × Inyear	−0.005*	−0.005**
	(−1.84)	(−2.12)
Treat	0.001	0.001
	(0.34)	(0.27)
Inyear	0.032***	0.032***
	(42.46)	(42.33)
Size	−0.043***	−0.043***
	(−62.54)	(−61.36)
SOE	0.006***	0.008***
	(3.38)	(4.92)
MB	0.118***	0.117***
	(54.04)	(52.8)
Industry	No	Yes
_Cons	0.897***	0.907***
	(61.38)	(51.79)
N	2,225	2,225
Adjusted *R*-square	0.178	0.185

Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

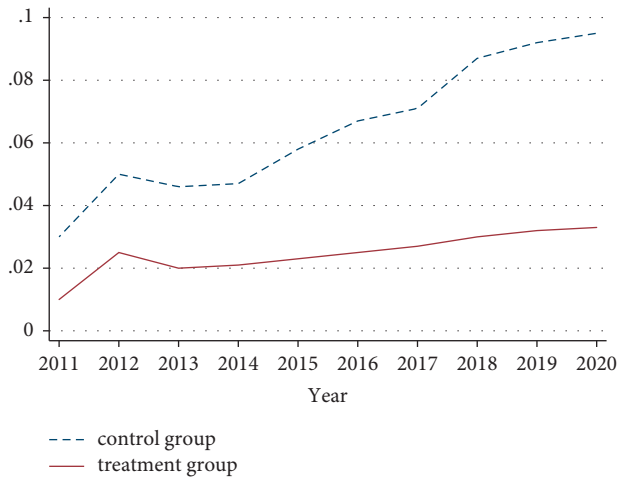

Figure 3: The parallel trend test of accounting conservatism.

there were significant differences in the change trends after the implementation of the initiative, and the results passed the parallel trend test.

4.3.2. Propensity Score Matching Test. Since the policy itself may be selected nonrandomly, to avoid the resulting endogeneity problem, equation (1) was reestimated using a propensity score matching (PSM) based DID technique (i.e., PSM-DID). We started by using the firm size (Size), firm ownership (SOE), and the market-to-book ratio (MB) as covariates and used Treat as the dependent variable to perform probit regression, which yielded the propensity score. We then used the nearest neighbor matching method in a group of companies not supported by the BRI, which will be selected for 1-to-1 matching with supported companies. Column 1 in Table 5 reports the PSM-DID regression results. The estimated results show that the estimated coefficient of Treat × Inyear (−0.006) is significant at the 10% level, indicating that the BRI reduced the accounting conservatism level of energy-intensive companies. Thus, our hypothesis continues to be supported by PSM-DID estimation (i.e., our main conclusion is robust to the choice of estimation technique).

4.3.3. Using Alternative Proxy Variables. To further investigate the robustness of our main result, following Givoly and Hayn, among others, we used the opposite of the ratio of nonoperating accruals to total assets at the end of the period to measure the robustness of corporate accounting conservatism of energy-intensive companies [39]. The larger the index, the higher the corporate accounting conservatism. Column 2 in Table 5 reports the regression results after replacing the proxy variables. Specifically, return on assets (ROA), the age of the enterprise (Age), and the largest shareholder shareholding ratio (Top1) were included as the new control variables. The estimated coefficient of Treat × Inyear is −0.010, which is statistically significant at the 10% level. This result shows that the BRI decreases the accounting conservatism of enterprises. In short, our main result concerning the negative impact of the BRI on accounting conservatism continues to hold.

4.3.4. Removing the Observations in the Year of the Policy Impact. The empirical results presented so far are based on the 2011–2020 sample period. The sample includes 2015, the year when the BRI was promulgated. The period 2011–2014 covers the pre-policy change period and the 2015–2020 period is the post-policy change period. Because the implementation may take some time, it is useful to remove the policy impact year data (i.e., 2015) from our sample. Column 3 of Table 5 reports the regression results after removing the pilot 2015 data from the sample. The estimated coefficient of Treat × Inyear is −0.006, which is statistically significant at the 5% level. Thus, our main result is also robust with respect to the inclusion or exclusion of the 2015 data when policy change took place.

4.3.5. Controlling the Characteristics of Provinces (Company Location). China's BRI mainly focuses on certain provinces (e.g., Xinjiang, Shanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Heilongjiang, Jilin, Liaoning, Guangxi, Yunnan, Xizang, Shanghai, Fujian, Guangdong, Zhejiang, Hainan, and Chongqing). Thus, location of the of energy-intensive companies can play an important role in whether they will be supported by the BRI. As a robustness check, equation (1) was re-estimated after taking into account company locations (i.e., whether companies included in the sample are located in identified provinces). Column 4 of Table 5 reports the regression results. The estimated coefficient of Treat × Inyear is −0.005, which is statistically significant at the 5% level. Once again, our main conclusion continues to hold.

4.3.6. Instrumental Variables Estimation to Account for Potential Endogeneity. To account for potential endogeneity, in this Section, we present the instrumental variables (IV) estimation results. The IVs must meet the following conditions: the selected instrumental variables must be exogenous variables, and the instrumental variables must be directly related to the explanatory variables, but do not directly affect the explained variables. Following Duranton et al., Agrawal et al., and Yu, we use the ancient "Silk Road" provinces (Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang) as the IV because BRI is based on the ancient "Silk Road" [40–42]. This variable and the explanatory variables are directly related, but the ancient "Silk Road" and the accounting conservatism of modern enterprises are not directly related, so the ancient "Silk Road" satisfies the selection conditions of instrumental variables. Specifically, for provinces located along the ancient "Silk Road" route, the instrumental variable IV takes the value of 1; 0 otherwise. As this IV aims to account for endogeneity in the interaction term Treat × Inyear in equation (1), we use the interaction term IV × Inyear as an IV for Treat × Inyear. The first-stage regression results are shown in column 1 of Table 6. The estimated coefficient of IV × Inyear is positive and statistically significant at the 1% level, indicating that the selected instrumental variables are strongly correlated with the explanatory variables. The p value corresponding to the Kleibergen–Paap rk LM statistic is 0.000, indicating that there is no problem of insufficient identification of instrumental variables. The Kleibergen–Paap rk Wald F statistic and Cragg–Donald Wald F statistic are greater than the Stock–Yogo weak ID test critical value of 16.38 at the 10% level, rejecting the null hypothesis of a weak IV. The second-stage regression results are shown in column 2 of Table 6, where the estimated coefficient of the interaction term Treat × Inyear is statistically significant at the 10% level, which indicates that our main empirical result is not affected by potential endogeneity.

5. The Impact of the BRI on Accounting Conservatism across Firm Ownership and Age

The empirical results presented so far show that the BRI reduces the robustness of corporate accounting conservatism of energy-intensive companies. Since the BRI is mainly led by the government and SOEs are heavily involved in the

Table 5: The robustness test.

	Accounting conservatism			
	PSM-DID	Using alternative proxy variables	Removing the 2015 pilot data	Controlling province characteristics
	(1)	(2)	(3)	(4)
Treat × Inyear	−0.006*	−0.010*	−0.006**	−0.005**
	(−1.69)	(−1.87)	(−2.16)	(−2.06)
Treat	0.006	−0.008	0.002	0
	(1.39)	(−1.40)	(0.72)	(−0.09)
Inyear	0.026***	0.012***	0.037***	0.032***
	(10.73)	(7.5)	(46.92)	(42.06)
Control	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
_Cons	0.973***	−0.428***	0.920***	0.899***
	(27.86)	(13.70)	(55.33)	(50.8)
N	443	2,193	1,955	2,225
Adjusted *R*-square	0.203	0.076	0.185	0.185

Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 6: Potential endogeneity: instrumental variable estimation.

Variable	First stage return Treat × Inyear	Second stage return C_score
	(1)	(2)
IV × Inyear	0.175***	
	(20.19)	
Treat × Inyear	−0.027*	
		−1.83
Treat	−0.010***	0.002**
	(−3.55)	(2.33)
Inyear	0.055***	0.032***
	(19.93)	(25.57)
Size	0.016***	0.047***
	(10.18)	(92.5)
SOE	0.015***	0.011***
	(4.82)	(11.09)
MB	0.022***	0.101***
	(3.08)	(46.47)
Industry	Yes	Yes
_Cons	−0.401***	0.997***
	(11.22)	(83.38)
Kleibergen–paap rk *LM* statistic	73.45	
	[0.000]	
Kleibergen–paap wald rk *F* statistic	84.54	
	{16.38}	
Cragg–Donald Wald *F* statistic	407.54	
N	2,225	2,225

Note. The values in round brackets underneath the estimated coefficients are the estimated *t*-values; the symbols *, **, and ***, respectively, represent significance at the 10%, 5%, and 1% levels. Values inside the square brackets ate the corresponding *p* values, and the value inside the curly bracket { } is the Stock–Yogo weak IV test critical value at the 10% level.

BRI, the government will not hesitate to intervene to protect its economic interests. Thus, different types of energy-intensive companies may be affected in different ways by the BRI. In this section, we examine the heterogeneity of the relationship between the BRI and accounting conservatism of energy-intensive companies across ownership structures and the age of the company.

5.1. Ownership Structure. First, from the perspective of shareholder-management contracts, SOEs of energy-intensive companies face more serious insider control problems than private enterprises. Insiders tend to have more opportunities to manipulate accounting information and use company funds for personal gains, which adversely affects the quality of accounting information. The BRI increased the

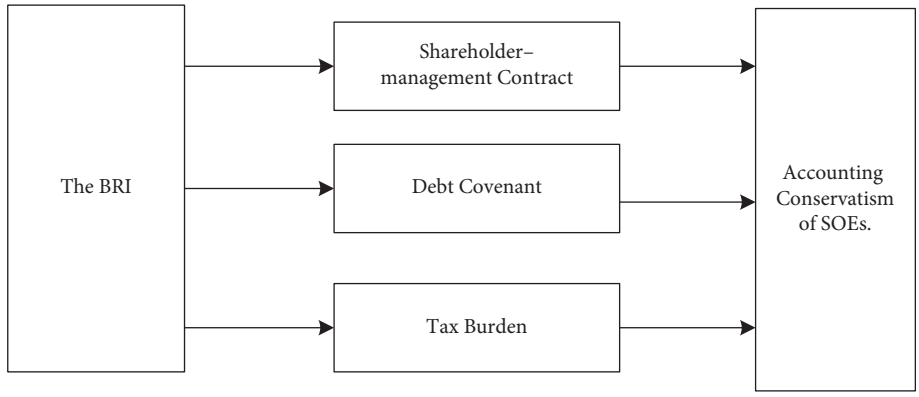

Figure 4: The impact of the BRI on the accounting conservatism of SOEs.

cash inflows to supported companies and hence SOEs are more likely to face more serious agency cost problems, which has implications for accounting conservatism.

Second, from the perspective of debt covenant, due to government backing, SOEs of energy-intensive companies tend to have fewer financial constraints. SOEs can get bank loans relatively easily and are not forced to provide high-quality accounting information.

Third, from the view of the tax burden, the higher the proportion of state-owned shares, the heavier the corporate tax burden. Consequently, the effect of the BRI in reducing corporate tax burdens will be more prominent among SOEs, and its impact on the accounting conservatism of SOEs is likely to be more significant. Thus, it can be argued that the BRI has a stronger impact on the accounting conservatism of SOEs. The expected link between the BRI and accounting conservatism of SOEs is shown in Figure 4.

To test this idea, we estimate the following regression equation:

$$\begin{aligned} C\_\text{score}_{it} = {} & \beta_0 + \beta_1 \text{Treat}_{it} \times \text{Inyear}_{it} \times \text{SOEs}_{it} \\ & + \beta_2 \text{Treat}_{it} \times \text{Inyear}_{it} \\ & + \beta_3 \text{Treat}_{it} + \beta_4 \text{Inyear}_{it} + X_{it} + \varepsilon_{it}. \end{aligned} \tag{2}$$

In equation (2), the coefficient β_1 is going to be our main concern. We expect β_1 to be negative and statistically significant. The estimation results are shown in Table 7. The estimated coefficient of Treat × Inyear × SOE in column 1 of Table 7 is −0.011, which is statistically significant at the 5% level confirming that the BRI has a more negative impact on the accounting conservatism of China's SOEs energy-intensive companies.

5.2. The Role of the Company Age. First, from the perspective of corporate debt financing needs, young energy-intensive companies tend to have less asset collateral compared to mature companies. Moreover, banks expect young companies to provide a higher quality of accounting information, which is also affected by the industrial policies of the Belt and Road countries. Thus, the response to accounting conservatism of young companies may be different from their matured counterparts.

Second, from the perspective of executive compensation contracts, young companies need to retain more cash to expand. The size of the energy-intensive companies and the increase in the free cash flow can increase the agency's cost. Furthermore, the internal control systems of young enterprises tend to be less robust. Consequently, management may have more incentive to grab excess compensation by lowering the quality of accounting information. We believe that the impact of the BRI on corporate accounting conservatism will be more significant for young companies. The expected link between the BRI and accounting conservatism of young companies is shown in Figure 5.

In this section, we report the estimation results after spiting the sample into young and mature enterprises. The median firm age was used to split the sample. Estimation results are reported in columns 2 and 3 of Table 7, where the estimated coefficient of Treat × Inyear for young companies is −0.01, which is significant at the 1% level. While the estimated coefficient of Treat × Inyear for mature companies is negative, it is statistically insignificant. These results suggest that the BRI mainly decreases the accounting conservatism of Chinese energy-intensive companies mainly through its effect on younger enterprises.

6. Evaluating the Channels through Which the BRI Affects Accounting Conservatism

The analysis presented in Section 2.2 suggests that the BRI can affect the corporate accounting conservatism of energy-intensive companies through four channels (i.e., corporate debt financing, executive compensation, tax burden, and legal environment). The empirical results presented in Section 4 show that the BRI has a negative and statistically significant impact on the corporate accounting conservatism of energy-intensive companies in China. In this section, we aim to empirically evaluate the role of each of the four channels. Specifically, we estimate the following regression equation:

$$\begin{aligned} C\_\text{score}_{it} = {} & \beta_0 + \beta_1 \text{Treat}_{it} \times \text{Inyear}_{it} \times \text{Path}_{it} \\ & + \beta_2 \text{Treat}_{it} \times \text{Inyear}_{it} \\ & + \beta_3 \text{Treat}_{it} + \beta_4 \text{Inyear}_{it} + \text{Path}_{it} + X_{it} + \varepsilon_{it}, \end{aligned} \tag{3}$$

Table 7: The impact of the BRI on accounting conservatism: results of the heterogeneity test.

	Ownership differences	Company age differences	
		Young enterprises	Mature enterprises
	(1)	(2)	(3)
Treat × Inyear × SOEs	−0.011**		
	(−2.52)		
Treat × Inyear	0.002	−0.010***	−0.002
	−0.52	(−2.70)	(−0.77)
Treat	0	0.001	−0.002
	(−0.02)	−0.33	(−0.42)
Inyear	0.032***	0.041***	0.025***
	−42.36	−37.55	−25.28
Control	Yes	Yes	Yes
Industry	Yes	Yes	Yes
_Cons	0.907***	0.807***	1.095***
	−51.77	−32.59	−44.9
N	2,225	1,213	1,012
Adjusted *R*-square	0.185	0.196	0.22

Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

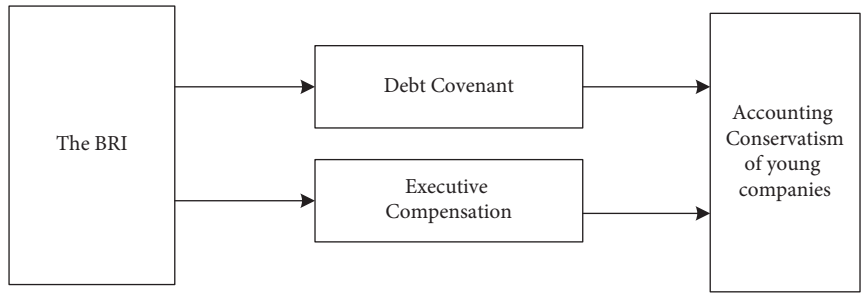

Figure 5: The impact of the BRI on the accounting conservatism of young companies.

where path represents the four channels, namely debt financing, executive compensation (Pay), tax burden (Tax), and legal environment (Law). Debt financing is log[bankloan/1 − bankloan] and bankload = [short − term borrowings + long − term borrowings + due within one year of long − term borrowings/period end liabilities]; executive compensation (Pay) is the logarithm of the total remuneration of the top three executives; tax burden (Tax) is the nominal tax rate; the legal environment (Law) is the second-level indicator "the legal environment of corporate operations" [43].

Table 8 reports the estimation results. Column 1 of Table 8 shows the role of the debt financing channel, where the estimated coefficient of Treat × Inyear × Bankloan is −0.039, which is significant at the 1% level. This result indicates that, through changes in corporate debt financing contracts, the BRI reduces the corporate accounting conservatism, which is consistent with the earlier theoretical analysis. Hence, Hypothesis (1a) is supported.

Column 2 of Table 8 shows the estimation results concerning the role of the executive compensation channel. The estimated coefficient of Treat × Inyear × Pay is −0.001, which is statistically insignificant, indicating that the BRI has not led to a significant (i) decrease in executive pay or (ii) increase in corporate accounting conservatism. We also examined the role of executive compensation channel across ownership (i.e., SOEs vs. non-SOEs) and found the effect to be statistically insignificant across company ownership (Estimation results across company ownership are available upon reasonable request). In other words, as far as the role of executive compensation is concerned, whether a company is SOE or nonSOE does not matter. This result could be attributed to the fact that, in addition to stricter salary control of SOEs, energy-intensive companies supported by the BRI are mainly foreign investment enterprises. These enterprises involve multinational salary contracts. Different countries have different ownership structures, regulatory systems, and tax policies and hence the overall impact is statistically insignificant. Thus, the uncertainty caused by the differences in these external institutional factors can have a complex impact on compensation contracts [36, 44]. For example, some countries have relatively strong regulatory systems and information disclosure requirements, which greatly reduces the opportunities for corporate executives to capture "salary dividends" through the BRI thereby neutralizing the executive compensation channel.

Column 3 of Table 8 shows the estimation results for the tax burden channel, where the estimated coefficient of Treat × Inyear × Tax is −0.119, which is significant at the 10% level. These results show that corporate accounting conservatism does significantly change through changes in

Table 8: Channels through which the BRI affects accounting conservatism.

	Accounting conservatism			
	Debt financing (1)	Executive compensation (2)	Tax burden (3)	Legal environment (4)
Treat × Inyear × Bankloan	−0.039*** (−4.05)			
Treat × Inyear × Pay		−0.001 (−0.41)		
Treat × Inyear × Tax			−0.119* (−1.73)	
Treat × Inyear × Law				0.024** (2.07)
Treat × Inyear	−0.015*** (−2.58)	0.015 (0.31)	−0.019*** (−6.75)	−0.100** (−2.19)
Bankloan	0.0668*** 3.04			
Pay		0.005*** (5.07)		
Tax			0.327*** (14.05)	
Law				0.253*** (10.54)
Control	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
_Cons	0.907*** (51.92)	0.863*** (43.41)	0.683*** (35.9)	0.960*** (54.95)
N	2,225	2,225	2,225	2,179
Adjusted *R*-square	0.186	0.188	0.116	0.208

Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

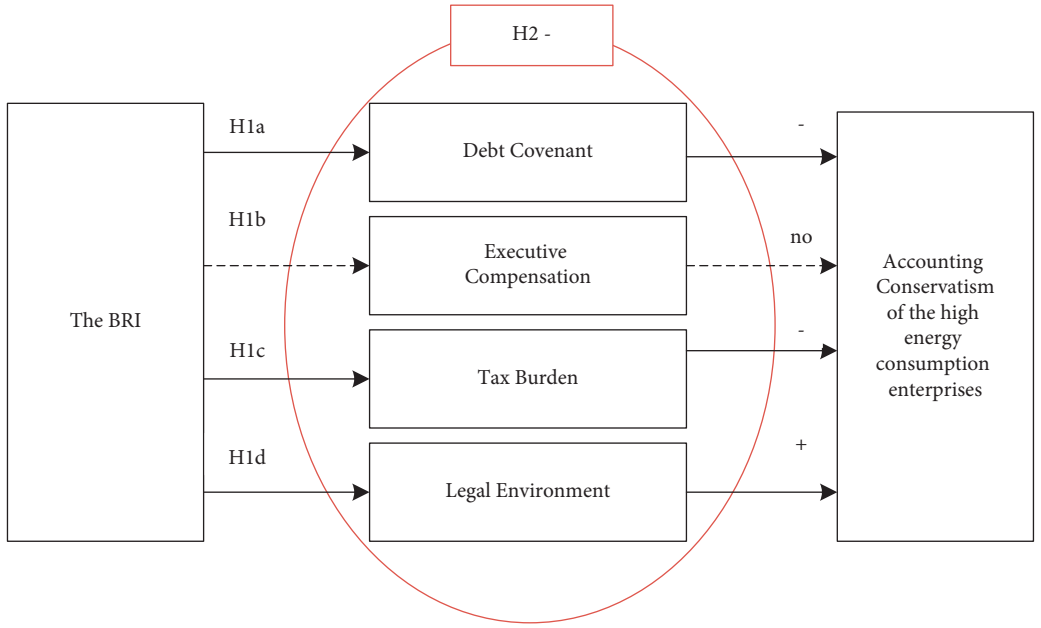

Figure 6: The impact of the BRI on the accounting conservatism of the energy-intensive enterprises.

corporate tax burden. This finding verifies the theoretical analysis of previous studies. Hence, the Hypothesis (1c) is supported.

Column 4 of Table 8 shows the estimation results for the legal environment channel. The estimated coefficient of Treat × Inyear × Law is 0.024, which is significant at the 5% level, indicating that the BRI can improve corporate accounting conservatism through improvement to the domestic legal environment. Hence, the Hypothesis (1d) is supported.

The regression results in Table 8 show that the BRI mainly changes the corporate accounting conservatism of the energy-intensive companies through the debt financing, tax burden, and legal environment paths. The path and results of the BRI affecting corporate accounting conservatism are shown in Figure 6.

7. Conclusion and Policy Implications

Using company-level data from China over the 2011–2020 period, this paper provides a comprehensive analysis of the impact of the "Belt and Road" Initiative (BRI) on corporate accounting conservatism of energy-intensive companies. We find that BRI has decreased the accounting conservatism of energy-intensive companies and this result continues to hold holds after a series of robustness tests. We also examine the effect of the RBI on accounting conservatism across company types and ages and find that the BRI is beneficial to state-owned and young energy-intensive companies. Furthermore, analysis reveals that BRI changes corporate accounting conservatism of energy-intensive companies mainly through the debt financing, tax burden, and legal environment channels. In overall terms, we find that the BRI has made a statistically significant impact on the behavior of Chinese energy-intensive companies.

Our empirical findings have some important policy implications.

First, the quality of accounting information is crucial for business decision-making. In the context of the ever-changing international economic structure, the impact of macro-system factors on the robustness of corporate accounting has become increasingly significant. With the steady progress of the BRI, its economic and social effects are being gradually realized. However, the existing literature has paid more attention to the macroeconomic impact of the implementation of the initiative but its impact on financial decision-making of enterprises and corporate accounting, as well as on the green development of enterprises has not received much attention. We find that BRI reduces the accounting conservatism of energy-intensive companies, which highlights the importance of a more comprehensive and prudent understanding of the economic consequences of the initiative.

Second, the effect of the BRI on accounting conservatism varies across types of enterprises and thus there is a need for government departments at all levels to continuously improve the policies and procedures affecting macro-level control. There is an urgent need for policies, which improve the efficiency of high energy consumption. The government should improve the ability of precise policy implementation and formulate policies and measures suitable for the development of the industry according to the characteristics and policy needs of energy-intensive enterprises. At the same time, the government should improve the comprehensive application ability of policy tools and improve the landing effect of policy dividends under the BRI.

Third, this paper finds that the Belt and Road Initiative is conducive to the expansion of financing scales for supported companies. However, in practice, there is still a large funding gap for enterprises along the Belt and Road. There is huge potential for infrastructure construction and capacity cooperation along the Belt and Road, and the financing gap needs to be filled urgently. At this stage, bank borrowings and equity funds provide strong financial support to companies involved in foreign investment. There is a need for expanding financing modes including new international financing models. In the early stages of the BRI, the focus was on helping developing countries improve their infrastructure. To promote further development of BRI-related enterprises, technological exchanges and increased investment in R&D are highly desirable.

Fourth, improvement in the legal environment is conducive to improvement in corporate accounting conservatism in energy-intensive companies. The legal environment has become an important driving force of the BRI. Therefore, China and other countries along the BRI should further strengthen the construction of the legal environment and create a good business environment for the development of foreign-funded enterprises, so as to attract more funds and enterprises to enter the domestic market under the BRI. Through the construction of a legal environment, the BRI will play a better role as a bridge.

Fifth, under multiple factors such as the deepening of the concept of green development, the global economic downturn, and the frequent occurrence of political uncertainties, the energy-intensive enterprises supported by the BRI tend to reduce the accounting conservatism of enterprises. This result is not what we expected. Therefore, in order to avoid this phenomenon, the government should further strengthen the accounting supervision of energy-intensive enterprises supported by the BRI, and further cultivate the risk management ability of entrepreneurs. The management of enterprises should further improve the prudence of accounting decisions, so as to resolve risks before they actually occur and prevent risks, so as to improve risk response-ability and market competitiveness.

Finally, the most important point is that in the process of building the "Belt and Road," we must continue to practice the concept of green development, promote the construction of ecological civilization, actively respond to climate change, and maintain global ecological security. Under the green development concept of the BRI, countries, and regions along the BRI need to focus on helping energy-intensive enterprises achieve green development, transformation, and upgrading in the process of developing energy-intensive industries.

Data Availability

The simulation experiment 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.

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