Uncertainty and Operations Research

Xiang Li
Xiaofeng Xu *Editors*

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Uncertainty and Operations Research

Decision analysis based on uncertain data is natural in many real-world applications, and sometimes such an analysis is inevitable. In the past years, researchers have proposed many efficient operations research models and methods, which have been widely applied to real-life problems, such as finance, management, manufacturing, supply chain, transportation, among others. This book series aims to provide a global forum for advancing the analysis, understanding, development, and practice of uncertainty theory and operations research for solving economic, engineering, management, and social problems.

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Contents

Project Risk Management for Real Estate Companies Under the New Policy

Liu Hui and Zhou Hanxu

Abstract The loss of the Evergrande Group has brought a crisis to China's real estate enterprises. To comprehensively and objectively analyze the risk factors of real estate projects and maximize the prevention of project risks, this paper takes the risk of real estate projects under the new policy as the research object, uses the HHM-DEMATEL-ISM model, and summarizes the research on the new policy of real estate industry based on the analysis of traditional risk factors, systematically The risk of real estate projects is identified systematically and comprehensively, and the identified risk factors are analyzed quantitatively, and each risk factor is divided into levels and represented more visually with graphics. The results show that corporate decision-making errors, risks in the bidding stage, and price fluctuations in the property market are important in the evaluation system of corporate risk factors; legal policy changes and epidemic factors are the root causes of most risks. Based on the research results, this paper proposes five countermeasures: enriching financing methods and strengthening cash flow management; implementing scientific and prudent decision-making; speeding up the "rent-purchase" supply-side structural reform proposed by the conference; actively promoting the establishment of a long-term mechanism for the real estate industry; and making good arrangements for

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epidemic-related prevention and control and work plans. We will provide a reference for the healthy development of real estate enterprises and contribute to the long-term stability of the whole real estate industry.

Keywords New real estate policy · Real estate enterprise project risk management · HHM-DEMATEL-ISM model

1 Introduction

In early December 2021, the Central Economic Work Conference was held in Beijing, which emphasized "stability and progress in a stable manner", proposed "renting and raising, and strengthening rental protection", and insisted that "houses are for the living, not for speculation", and promote new urbanization with people as the core, and promoted the realization of housing for all people. To promote a new type of urbanization with people at its core, and to promote the realization of housing for all people. Under the social environment of healthy and stable economic development, the real estate industry, as a national pillar industry, plays a decisive role in the national economy, so the development goal is to promote the healthy development and virtuous cycle of real estate in China. Events such as Evergrande Group's broken capital chain and Tongzhou school district housing cut-offs have sounded the alarm for governments and real estate enterprises around the world, and the government has introduced many policies to ensure the stable development of the real estate market, with high-quality state-owned enterprises merging and acquiring rotten properties, rectifying down payment loans, encouraging de-stocking and so on. To sum up, scientific identification of risk influencing factors of real estate projects and maximum prevention of project risks are of great significance to promote the healthy and stable development of the real estate market.

2 Review of Relevant Research Literature

Foreign scholars have conducted more comprehensive research on real estate project risk management, from project risk identification, impact factor evaluation, risk action path, risk warning prevention, and other dimensions. By examining the correlation structure of real estate project risks, Giesecke and Weber [1] found that risk factors can be hierarchically classified. Zanetti [2] derives the close-form expression of relative risk aversion when households receive utility from real estate. He finds that real estate wealth can reduce risk aversion due to the cushioning channel. After investigating the evolution of real estate prices in the United States over the past 20 years, Kallberg et al. [3] believed that improper lending by financial institutions was a major factor in real estate-related risks. Later, Pavlov et al. [4], Sun et al. [5] proved this view by studying the interbank market risk caused by real estate loan losses. In addition, housing prices are also an important factor influencing financial risk. By estimating a group of multivariate logit models, Yim and Mitchell [6] used fuzzy assessment, decision tree, and hybrid neural network to predict the behavior of the real estate market. Bourassa et al. [7] used indicator measurement and capital asset pricing model to identify real estate risks, believing that a simple price-to-rent ratio is a reliable method to measure housing price bubbles. Melser and Hill [8] used a flexible smooth spline feature model to estimate individual housing risk in the Sydney area.

In contrast, China focused more on the study of project risk factors as well as evaluation indicators, and Uyunna et al. [9] used the ISM-HHM model to identify the relationship between subsystem risks and risk factors in subsystem risks, and constructed a hierarchical relationship diagram between risks. Shiyu et al. [10] used the HHM method to identify the all-round and multi-level risks of the production line cross-country transfer project based on the introduction of the background of the production line cross-country transfer project from five aspects: project management, project phase, functional department, risk factors, and risk objects, and came up with a risk list of the production line cross-country transfer project. Pengcheng and Wei [11] used the HHM method to identify the risks in cross-regional major engineering projects, discussed the economic, social, and environmental aspects, and constructed a cross-regional major engineering project risk list by combining the whole life cycle. Foot et al. [12] based on the HHM framework for infrastructure PPP projects, identified the risks existing in urban infrastructure projects from three aspects, namely, economic subsystem, social subsystem, and environmental subsystem, and identified a master list of project risks from project decision to operation handover process by combining the whole life cycle of the project. Huishan and Qianqian [13] applied the DEMATEL method to calculate the centrality and causality of 13 major risk sources affecting construction workers' unsafe behaviors. The initial matrix M in the ISM method was obtained by applying the modified threshold λ to remove the redundant factors, and the ISM model was established. The DEMATEL-ISM integrated model was used to classify all factors into three categories according to the hierarchical structure, and the internal relationship between each category of factors and the key factors were derived. Qiangnian et al. [14] applied the DEMATEL-ISM method to identify the factors that constrain the development of assembled buildings, applied the DEMATEL method to calculate the centrality and causality of each factor, used the ISM to construct a multi-level recursive structure model among the factors, coupled the two models to construct a combined model, and sorted out the logical and hierarchical relationships among the factors and the relative The logical and hierarchical relationships and relative importance of each factor were clarified through the combined model.

3 Construction of HHM-DEMATEL-ISM Project Risk Identification Model

3.1 *Identifying Real Estate Project Risks Under New Policies Using HHM Methodology*

This paper studies real estate project risks based on the HHM method analyzes risk types and identifies risks from the perspective of the whole project life cycle. By combing and summarizing the literature related to real estate project risk management, it is concluded that the types of real estate project risks under the new policy are divided into economic, natural, social, and organizational factors of the project, which means that risks are identified from four perspectives: economic, natural, social and organizational. Therefore, the HHM framework of real estate project risks under the new policy is constructed as shown in Fig. 1.

3.2 *Determining the Impact Relationship Between Risks Using the DEMATEL Method*

(1) The risks of real estate projects identified by the HHM method are numbered B1, B2,…, BN.
(2) A certain gradient is set, and the direct influence matrix P $\left(P = [P_{ij}]_{n\times n}\right)$ is constructed by scoring each risk factor through the expert group questionnaire combined with the resounding relationship between each risk factor. Where P_{ij} indicates the degree of direct influence of risk B_i on B_j.
(3) Normalizing the direct impact matrix P yields the normalized direct impact matrix Q

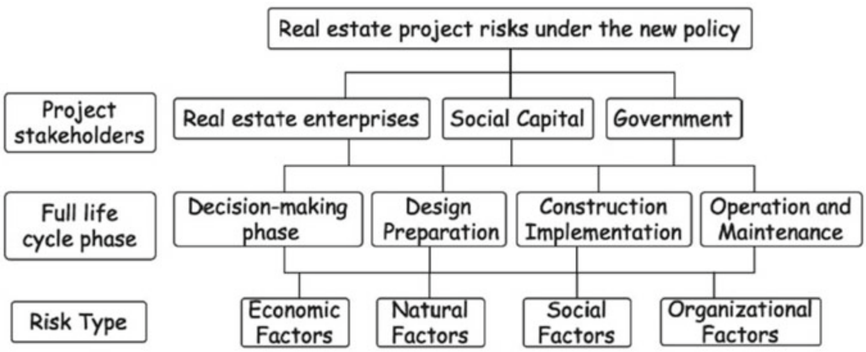

Fig. 1 HHM framework for real estate project risk under the new policy

$$Q = \frac{1}{\max\limits_{0<i<n} \sum_{j=1}^{n} P_{ij}} P \tag{1}$$

(4) Based on the normalized direct impact matrix Q, the integrated impact matrix T is obtained

$$T = Q(E - Q)^{-1} \tag{2}$$

(5) Calculate the impact degree and impacted degree of each risk. The sum of the elements of each row of the matrix gets the impact degree D_i of each risk, and the sum of the elements of each column gets the impact degree C_i of each risk, with the following formula.

$$D_i = \sum_{j=1}^{n} T_{ij} (i = 1, 2, \ldots, n) \tag{3}$$

$$C_i = \sum_{i=1}^{n} T_{ij} (i = 1, 2, \ldots, n) \tag{4}$$

(6) The influence degree of each risk and the influenced degree are added together to obtain the centrality M_i of the risk, and the influence degree of each risk and the influenced degree are subtracted to obtain the cause degree R_i of the risk, which is calculated as follows:

$$M_i = D_i + C_i (i = 1, 2, \ldots, n) \tag{5}$$

$$R_i = D_i - C_i (i = 1, 2, \ldots, n) \tag{6}$$

(7) Calculate the overall risk impact matrix S, using the integrated impact matrix T derived from the DEMATEL method. Since each risk corresponds only to the risk itself and the impact of the risk on itself is not considered, the impact of the risk on itself can be replaced by the unit matrix E, reflecting the overall impact degree of the risk

$$S = (T + E)^{-1} \tag{7}$$

3.3 Representation of the Relationship and Hierarchy Among Risks Using the ISM Model

(1) The reachability matrix K can be obtained from the overall impact matrix S

$$K_{ij} = \{1|S_{ij} \gg \lambda\}(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n) \quad (8)$$

$$K_{ij} = \{0|S_{ij} < \lambda\}(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n) \quad (9)$$

where λ generally takes the value of 0–0.2

(2) Determine each risk-accessible set X_i and prior set Y_i, and their intersection $X_i \bigcap Y_i$. The accessible set X_i represents all risk factors influenced by B_i, and the prior set Y_i represents all risk factors that have an impact on B_i.

$$X_i = \{B_j|B_j \in A,\ K \neq 0\}\ (i = 1, 2, \ldots, n; j = 1, 2, \ldots, n) \quad (10)$$

$$Y_i = \{B_j|B_j \in A,\ K \neq 0\}\ (i = 1, 2, \ldots, n; j = 1, 2, \ldots, n) \quad (11)$$

(3) Verify that $X_i = X_i \bigcap Y_i$ holds, and if it does, the B_i corresponds to the risk at that level, and row i is removed in the reachable matrix X and column j.
(4) Repeat Eqs. (9) and (10) until all risks are classified into levels. Based on the levels of each risk classification, draw a risk ladder hierarchy diagram.

4 Case Studies

Based on the risk system identified by the project, we designed an expert questionnaire to collect data from the project managers of real estate enterprises and academic experts in the field of engineering management on the correlation between the risk factors of real estate projects under the new policy. The DEMATEL method is used to calculate the weights of each risk of real estate projects under the new policy, and the ISM method is used to clarify the interactions between the risks of real estate projects under the new policy, and finally to establish a hierarchical model of the risks of real estate projects under the new policy.

(1) The risks of real estate projects under the new policy analyzed according to the HHM method are shown in Table 1.
(2) Establishing the direct impact matrix. The direct influence matrix was established by establishing the influence relationship between each risk through the expert questionnaire method. The values in the table indicate the degree of influence of the risk factors in this row on the risk factors in this column: 0 represents no influence; 1 represents weak influence; 2 represents moderate influence; 3

Table 1 Table of risk factors of real estate projects under the new policy

Project risk management for real estate companies under the new policy	Tier 1 indicator	Secondary indicator
	Economic factors risk A_1	Unreasonable financing B_1
		Corporate decision mistakes B_2
		Cash flow breakdown B_3
		Asset and liability risk B_4
		Real estate price turmoil B_5
		Inflation B_6
	Natural factors risk A_2	Harsh construction environment B_7
		Natural disaster emergencies B_8
		Hydroclimatically unsuitable B_9
	Social factors risk A_3	Change in purchasing policy B_{10}
		Bad market culture B_{11}
		Insufficient land supply B_{12}
		Changes in laws and regulations B_{13}
		Poor security order B_{14}
		Epidemic factors B_{15}
	Organizational factors risk A_4	Bidding stage risks B_{16}
		Construction phase risks B_{17}
		Claims risk B_{18}

represents strong influence. The direct impact matrix was established as shown in Table 2.

(3) $\max\limits_{0<i<n} \sum_{j=1}^{n} P_{ij} = 31$, normalize the direct matrix P as shown in Table 3.

(4) Through the calculation, the integrated impact matrix T is derived, and T represents the integrated impact between each risk factor of the real estate project, as shown in Table 4.

(5) Calculate the degree of influence D and the degree of being influenced C of each risk factor according to the integrated influence matrix T, and further calculate the centrality M and the cause R, as shown in Table 5; and draw the M-R scatter plot, as shown in Fig. 2.

Table 2 Direct impact matrix P

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}	B_{17}	B_{18}
B_1	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0
B_2	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	3	2	0
B_3	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	2	3	2
B_4	3	2	3	0	1	0	0	0	0	0	0	0	0	0	0	2	0	1
B_5	1	1	1	1	0	1	0	0	0	1	2	1	0	0	0	1	0	1
B_6	1	1	1	1	2	0	0	0	0	1	0	0	0	0	0	2	0	0
B_7	1	2	0	0	1	0	0	2	0	0	0	0	0	1	0	1	3	2
B_8	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	2	3
B_9	1	2	0	2	0	0	2	1	0	0	0	0	0	1	0	2	2	1
B_{10}	1	3	0	1	3	1	0	0	0	0	1	0	0	0	0	2	1	1
B_{11}	2	2	0	2	2	0	1	0	0	2	0	0	0	3	0	2	2	2
B_{12}	1	2	0	0	3	0	2	0	0	3	1	0	0	1	0	2	1	2
B_{13}	1	3	0	0	2	0	0	0	0	3	0	1	0	2	0	2	2	3
B_{14}	1	2	1	1	2	1	0	0	0	1	0	0	0	0	0	1	3	2
B_{15}	3	3	1	1	3	1	1	0	0	3	1	1	1	3	0	3	3	3
B_{16}	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	1
B_{17}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
B_{18}	1	0	2	2	1	0	0	0	0	0	0	0	0	0	0	1	1	0

(6) According to the expert interview research take $\lambda = 0.05$, build the reachable matrix X, as shown in Table 6.
(7) The reachable matrix X is simplified by the formula, as shown in Table 7.

From Table 7, B17 satisfies $X_i = X_i \bigcap Y_i$, so B17 is the first level of risk factor. The rows and columns where B17 is located are deleted to get the higher level reachable matrix, and step 3.3 (3) is repeated to simplify the reachable matrix, B1, B2, and B16 satisfy $X_i = X_i \bigcap Y_i$, so B1, B2, and B16 are the second level risk factors. The rows and columns where B1, B2, and B16 are located are deleted to get a higher-level reachable matrix, and step 3.3 (3) is repeated. B3, B4, B5, and B18 satisfy $X_i = X_i \bigcap Y_i$i, so B3, B4, B5, and B18 are the third-level risk factors. The rows and columns where B3, B4, B5, and B18 are located are deleted to get the higher level reachable matrix, and step 3.3 (3) is repeated. B8 and B10 satisfy $X_i = X_i \bigcap Y_i$, so B8 and B10 are the fourth-level risk factors. Delete the rows and columns where B8 and B10 are located to get the higher level reachable matrix, repeat step 3.3 (3), B6 and B7 satisfy $X_i = X_i \bigcap Y_i$, so B6 and B7 are the fifth levels risk factors. Delete the rows and columns where B6 and B7 are located to get the higher level reachable matrix, repeat step 3.3 (3), B14 satisfies $X_i = X_i \bigcap Y_i$, so B14 is the sixth level risk factor. Delete the rows and columns where B14 is located to get the higher level reachable matrix, repeat step 3.3 (3), B9 and B11 satisfy $X_i = X_i \bigcap Y_i$, so B9 and B11 are the risk factors of the seventh level. Delete the rows and columns where B9 and B11 are

Table 3 Direct impact matrix Q of normalization

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
B_1	0.00	0.06	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
B_2	0.06	0.00	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
B_3	0.06	0.06	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.00
B_4	0.10	0.06	0.10	0.00	0.03	0.00	0.00	0.00	0.00	0.00
B_5	0.03	0.03	0.03	0.03	0.00	0.03	0.00	0.00	0.00	0.03
B_6	0.03	0.03	0.03	0.03	0.06	0.00	0.00	0.00	0.00	0.03
B_7	0.03	0.06	0.00	0.00	0.03	0.00	0.00	0.06	0.00	0.00
B_8	0.00	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00
B_9	0.03	0.06	0.00	0.06	0.00	0.00	0.06	0.03	0.00	0.00
B_{10}	0.03	0.10	0.00	0.03	0.10	0.03	0.00	0.00	0.00	0.00
B_{11}	0.06	0.06	0.00	0.06	0.06	0.00	0.03	0.00	0.00	0.06
B_{12}	0.03	0.06	0.00	0.00	0.10	0.00	0.06	0.00	0.00	0.10
B_{13}	0.03	0.10	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.10
B_{14}	0.03	0.06	0.03	0.03	0.06	0.03	0.00	0.00	0.00	0.03
B_{15}	0.10	0.10	0.03	0.03	0.10	0.03	0.03	0.00	0.00	0.10
B_{16}	0.03	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
B_{17}	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
B_{18}	0.03	0.00	0.06	0.06	0.03	0.00	0.00	0.00	0.00	0.00

	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}	B_{17}	B_{18}
B_1	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00
B_2	0.00	0.00	0.00	0.00	0.00	0.10	0.06	0.00
B_3	0.00	0.00	0.00	0.00	0.00	0.06	0.10	0.06
B_4	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.03
B_5	0.06	0.03	0.00	0.00	0.00	0.03	0.00	0.03
B_6	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
B_7	0.00	0.00	0.00	0.03	0.00	0.03	0.10	0.06
B_8	0.00	0.00	0.00	0.03	0.00	0.00	0.06	0.10
B_9	0.00	0.00	0.00	0.03	0.00	0.06	0.06	0.03
B_{10}	0.03	0.00	0.00	0.00	0.00	0.06	0.03	0.03
B_{11}	0.00	0.00	0.00	0.10	0.00	0.06	0.06	0.06
B_{12}	0.03	0.00	0.00	0.03	0.00	0.06	0.03	0.06
B_{13}	0.00	0.03	0.00	0.06	0.00	0.06	0.06	0.10
B_{14}	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.06
B_{15}	0.03	0.03	0.03	0.10	0.00	0.10	0.10	0.10
B_{16}	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.03
B_{17}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
B_{18}	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00

Table 4 Integrated impact matrix T

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
B_1	0.01	0.07	0.04	0.04	0.01	0.00	0.00	0.00	0.00	0.00
B_2	0.08	0.02	0.07	0.04	0.01	0.00	0.00	0.00	0.00	0.00
B_3	0.09	0.08	0.02	0.08	0.08	0.01	0.00	0.00	0.00	0.00
B_4	0.12	0.09	0.11	0.02	0.05	0.00	0.00	0.00	0.00	0.00
B_5	0.06	0.06	0.05	0.05	0.02	0.04	0.00	0.00	0.00	0.04
B_6	0.05	0.05	0.04	0.04	0.08	0.00	0.00	0.00	0.00	0.04
B_7	0.05	0.08	0.02	0.02	0.04	0.01	0.00	0.06	0.00	0.00
B_8	0.02	0.04	0.05	0.05	0.04	0.01	0.00	0.00	0.00	0.00
B_9	0.06	0.09	0.02	0.08	0.01	0.00	0.06	0.04	0.00	0.00
B_{10}	0.06	0.12	0.02	0.05	0.11	0.04	0.00	0.00	0.00	0.01
B_{11}	0.10	0.10	0.03	0.09	0.09	0.01	0.03	0.00	0.00	0.07
B_{12}	0.06	0.10	0.02	0.02	0.12	0.01	0.07	0.00	0.00	0.11
B_{13}	0.06	0.13	0.03	0.03	0.09	0.01	0.00	0.00	0.00	0.11
B_{14}	0.06	0.09	0.05	0.05	0.08	0.04	0.00	0.00	0.00	0.04
B_{15}	0.15	0.16	0.07	0.07	0.15	0.05	0.04	0.00	0.00	0.12
B_{16}	0.04	0.04	0.01	0.01	0.04	0.00	0.00	0.00	0.00	0.00
B_{17}	0.00	0.00	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00
B_{18}	0.05	0.02	0.08	0.07	0.04	0.00	0.00	0.00	0.00	0.00

	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}	B_{17}	B_{18}
B_1	0.00	0.00	0.00	0.00	0.00	0.08	0.05	0.01
B_2	0.00	0.00	0.00	0.00	0.00	0.11	0.09	0.02
B_3	0.01	0.00	0.00	0.00	0.00	0.09	0.12	0.08
B_4	0.00	0.00	0.00	0.00	0.00	0.09	0.03	0.05
B_5	0.07	0.03	0.00	0.01	0.00	0.06	0.03	0.05
B_6	0.01	0.00	0.00	0.00	0.00	0.08	0.02	0.01
B_7	0.00	0.00	0.00	0.03	0.00	0.05	0.12	0.09
B_8	0.00	0.00	0.00	0.03	0.00	0.02	0.08	0.11
B_9	0.00	0.00	0.00	0.04	0.00	0.09	0.10	0.06
B_{10}	0.04	0.00	0.00	0.00	0.00	0.10	0.06	0.05
B_{11}	0.01	0.00	0.00	0.10	0.00	0.10	0.11	0.09
B_{12}	0.04	0.00	0.00	0.04	0.00	0.10	0.07	0.09
B_{13}	0.01	0.04	0.00	0.07	0.00	0.10	0.10	0.12
B_{14}	0.01	0.00	0.00	0.00	0.00	0.06	0.12	0.08
B_{15}	0.05	0.04	0.03	0.11	0.00	0.16	0.16	0.15
B_{16}	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.04
B_{17}	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.07
B_{18}	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.01

Table 5 Centrality reason degree

	D	C	M	R
B_1	0.32	1.11	1.43	−0.79
B_2	0.44	1.32	1.76	−0.88
B_3	0.66	0.76	1.42	−0.10
B_4	0.56	0.81	1.37	−0.25
B_5	0.56	1.07	1.63	−0.51
B_6	0.43	0.27	0.70	0.16
B_7	0.58	0.21	0.79	0.37
B_8	0.46	0.11	0.57	0.35
B_9	0.64	0.00	0.64	0.64
B_{10}	0.66	0.54	1.20	0.12
B_{11}	0.95	0.25	1.20	0.70
B_{12}	0.87	0.13	1.00	0.74
B_{13}	0.90	0.03	0.93	0.87
B_{14}	0.68	0.43	1.11	0.25
B_{15}	1.50	0.00	1.50	1.50
B_{16}	0.29	1.38	1.67	−1.09
B_{17}	0.14	1.41	1.55	−1.27
B_{18}	0.38	1.18	1.56	−0.80

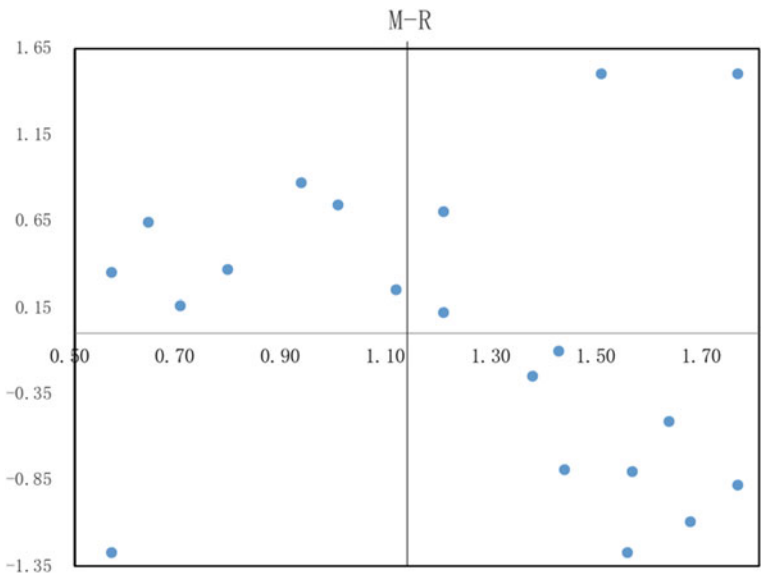

Fig. 2 Scatterplot of centrality and causality

Table 6 Reachable matrix X

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}	B_{17}	B_{18}
B_1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
B_2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
B_3	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1
B_4	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
B_5	1	1	1	1	0	1	0	0	0	1	1	0	0	0	0	1	0	1
B_6	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0
B_7	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1
B_8	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1
B_9	1	1	0	1	0	0	1	1	0	0	0	0	0	1	0	1	1	1
B_{10}	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	1	1	1
B_{11}	1	1	0	1	1	0	0	0	0	1	0	0	0	1	0	1	1	1
B_{12}	1	1	0	0	1	0	1	0	0	1	1	0	0	1	0	1	1	1
B_{13}	1	1	0	0	1	0	0	0	0	1	0	1	0	1	0	1	1	1
B_{14}	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	1	1	1
B_{15}	1	1	1	1	1	1	1	0	0	1	1	1	0	1	0	1	1	1
B_{16}	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
B_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
B_{18}	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0

located to get the higher level reachable matrix, repeat step 3.3 (3), B12 satisfies $X_i = X_i \bigcap Y_i$, so B12 is the eighth level risk factor. Delete the rows and columns where B12 is located to get the higher level reachable matrix, repeat step 3.3 (3), B13 and B15 satisfy $X_i = X_i \bigcap Y_i$, so B13 and B15 are the risk factors of the ninth level. According to the above analysis, a risk hierarchy diagram of real estate projects is drawn, as shown in Fig. 3.

5 Conclusions and Recommendations

5.1 Conclusions

According to the DEMATEL model to calculate the centrality between the risk factors of real estate projects under the new policy, it can be seen that the three factors located in the top three are B2, B16, and B5, indicating that the enterprise's decision-making errors, the risks in the bidding stage and the price fluctuations in the property market are in an important position in the enterprise's risk factor evaluation system. And according to the calculated cause degree, it is found that the cause degree of these three important risk factors are −0.88, −1.09, and −0.51, all of which are <0 indicating

Table 7 One-level decomposition structure

	X_i	Y_i	$X_i \cap Y_i$
B_1	2, 3, 4, 16, 17	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 18	2, 3, 4, 16
B_2	1, 3, 4, 16, 17	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	1, 3, 4, 16
B_3	1, 2, 4, 5, 16, 17, 18	1, 2, 4, 5, 6, 8, 14, 15, 18	1, 2, 4, 5, 18
B_4	1, 2, 3, 5, 16, 18	1, 2, 3, 5, 6, 8, 9, 10, 11, 14, 15, 18	1, 2, 3, 5, 18
B_5	1, 2, 3, 4, 6, 10, 11, 16, 18	3, 4, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18	3, 4, 6, 10, 11, 16, 18
B_6	1, 2, 3, 4, 5, 10, 16	5, 10, 14, 15	5, 10
B_7	1, 2, 5, 8, 16, 17, 18	9, 12, 15	–
B_8	2, 3, 4, 5, 17, 18	7, 9	–
B_9	1, 2, 4, 7, 8, 14, 16, 17, 18	–	–
B_{10}	1, 2, 4, 5, 6, 11, 16, 17, 18	5, 6, 11, 12, 13, 14, 15	5, 6, 11
B_{11}	1, 2, 4, 5, 10, 14, 16, 17, 18	5, 10, 12, 15	5, 10
B_{12}	1, 2, 5, 7, 10, 11, 14, 16, 17, 18	13, 15	–
B_{13}	1, 2, 5, 10, 12, 14, 16, 17, 18	–	–
B_{14}	1, 2, 3, 4, 5, 6, 10, 16, 17, 18	9, 11, 12, 13, 15	–
B_{15}	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 14, 16, 17, 18	–	–
B_{16}	1, 2, 5, 17, 18	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 18	1, 2, 5, 18
B_{17}	18	1, 2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18	18
B_{18}	1, 3, 4, 5, 16, 17	3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17	3, 5, 16, 17

that they are risk factors that are more easily affected. Combined with the ISM model to analyze the risk hierarchy, the upper-level risk factors of B2, B16, and B5 factors are analyzed to avoid risks at the source as much as possible.

Analyzing the ladder level model of real estate project risks established by the ISM method, the risk factors at the highest level are B13 legal policy changes and B15 epidemic factors, which are the root cause of most risks; for B2, B16, B5 three important risk factors directly influenced by B1 financing unreasonable, B10 home purchase policy changes, for which enterprises need to pay more attention.

At this stage, China's economic development trend is based on stable, healthy, and benign development, and the market policies and laws, and regulations introduced by the national and local governments play an important role in risk avoidance and steady development of the real estate industry. As an important and common risk factor faced by real estate companies, property price fluctuations have become more

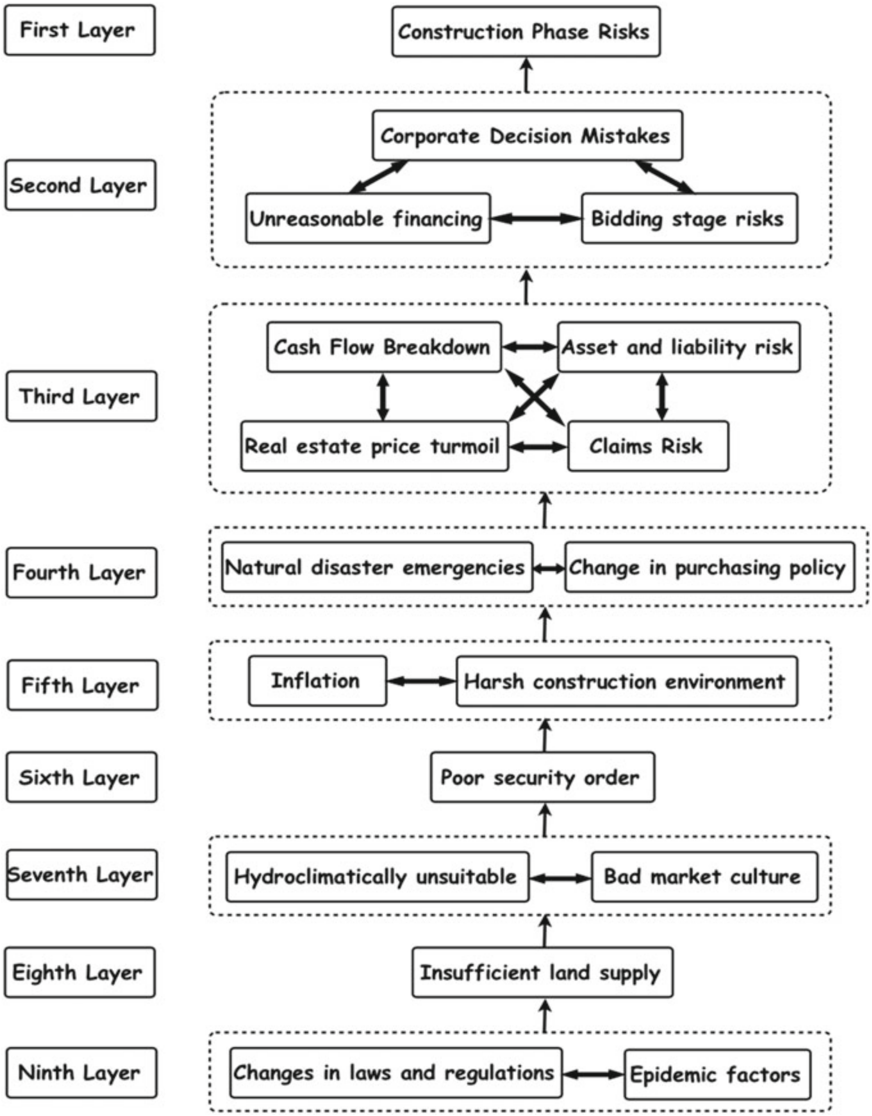

Fig. 3 Hierarchy of risk factors for real estate projects

moderate under the policy of "seeking progress stably", and the fever of "speculation on property prices" has gradually subsided. The real estate industry, as a pillar industry of national development, a virtuous cycle, healthy development is the long-term plan.

5.2 Suggestions for Countermeasures

In response to the new positive development policies proposed by the Central Economic Work Conference, and combined with the analysis results of the HHM-DEMATEL-ISM model, we study the risk problems faced by real estate enterprises and put forward the following countermeasure suggestions.

First, enrich financing methods and strengthen cash flow management. Enterprises can choose the most appropriate financing methods according to their situation and improve the diversification of financing methods. Seek the help of professional practitioners in the financial industry to make reasonable forecasts and plans for cash flow to ensure that each fund can maximize its effectiveness and avoid the phenomenon of large amounts of wasted funds.

Second, scientific and prudent decision-making. Every decision of the enterprise is crucial, even related to the survival of the enterprise, scientific and professional analysis and research before making decisions, and several expert discussions before making decisions. When making decisions, we should prepare for the worst and make plan B.

Third, accelerate the "rent-to-own" supply-side structural reform. Actively implement the "house is for living, not for speculation" proposed by the 19th National Congress, establish a housing system under the new policy in the new period, accelerate the supply-side structural reform, and stabilize housing prices.

Fourth, actively promote the establishment of a long-term mechanism for the real estate industry. The problems faced by real estate companies are not only limited to the real estate market but also involve several areas such as population, land, and taxation. The establishment of a long-term mechanism for the real estate industry can only be achieved by implementing basic issues through administrative and legislative initiatives so that the real estate industry can develop stably in the long term.

Fifth, make arrangements for prevention, control, and work plans related to the epidemic. Nowadays, epidemics are still frequent throughout the country, and it is important to do a good job of prevention and control in strict accordance with the requirements of epidemic prevention and control, but also to do a good job of responding to adequate emergencies to reduce as much as possible the impact of force majeure factors such as epidemics.

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A Study of Low Carbon Dual-Channel Supply Chain Pricing Under Retailer's Fairness Concern

Ruihua Sun and Miao Hu

Abstract Currently, consumers' preference for low carbon is increasing, consumers' preference for online shopping continues to grow, manufacturers are actively developing online channels to gain new profit growth and thus increase competition between channels, retailers as rational people value fairness in revenue distribution, manufacturers and retailers need to consider the above aspects to determine their optimal prices fully. This paper develops a three-stage decision model based on a low-carbon dual-channel supply chain. It considers factors such as consumers' low-carbon preferences and product greenness. Research the optimal pricing for manufacturers and retailers when retailers make centralised decisions under fairness neutrality, decentralised decisions and decentralised decisions under fairness concern. And Analysis the effects of consumers' low-carbon preferences, offline market shares and retailers' fairness concerns on optimal pricing and maximum profits are analysed through numerical simulation. Research has shown that the optimal decision and maximum profit for manufacturers and retailers are influenced by offline market share, consumer low carbon preferences and the level of retailer's fairness concern. The variables have different effects on the final decision variables in different situations.

Keywords Equity concerns · Low carbon · Dual-channel supply chain · Pricing research

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1 Introduction

Greenhouse gas emissions have caused widespread concern around the world, and international efforts to combat climate change and achieve carbon reduction have become an inevitable trend and global consensus. Industry is an important source of anthropogenic carbon emissions, and supply chain activities generate large amounts of carbon dioxide, which is a direct hazard to the environment. Out of concern for environmental issues and to better meet the low carbon needs of consumers, more and more manufacturers are producing and manufacturing green and low carbon products. With the popularity of the internet, the rapid development of e-commerce and the rise of online shopping(Dominici et al. 2021), more and more manufacturers are opening up online channels to sell their products. Manufacturers can differentiate their sales by selling high quality products through retailers and low quality products through direct sales channels, such as COACH, GAP, NIKE (Li et al. 2018). At the same time, public attention to environmental protection is increasing, and as the concept of low carbon gradually becomes more popular, environmentally conscious consumers will consider the carbon footprint of a product when making product purchases (Liu et al. 2017). When green costs are above a threshold, manufacturers will not open direct sales channels to sell their products (Li et al. 2016). When consumer preference for low carbon is high and the initial carbon footprint of the product is low, it is profitable to introduce dual-channel supply (Ghosh et al. 2020). However, there is a conflict of interest between online and offline channels, and manufacturers selling their products through online channels can cause competition between retailers and manufacturers (Wang and Song 2020). When consumers have low-carbon preferences, task-sharing contracts between manufacturers and retailers to reduce emissions can help supply chain members achieve a win–win situation (Ghosh et al. 2020). A concern for fairness in profit distribution can lead to additional profits for the supply chain (Pan et al. 2019), and the utility of retailers is related to their own level of fairness concerns, with too much fairness concern leading to customers switching to online channels for product purchases, and too little fairness concern leading to a reduction in their own bargaining power, resulting in a loss of self-interest (Sharma and Jain 2019). Unlike retailers' uniform pricing, direct sales channels can help increase manufacturers' profits when retailers adopt individualised pricing strategies, but can lead to a loss of profit for retailers (Li et al. 2018). When production is insufficient, manufacturers need to make reasonable channel allocations and engage in dual-channel coordination to respond to retailers' complaints about inadequate supply (Xiao and Shi 2016).

2 Literature Review

Ji and Zhang et al. compare single manufacturer production reduction strategies with joint reduction strategies and find that joint reduction is beneficial to both manufacturers and retailers, and that retailers have an incentive to make low-carbon efforts when consumers have low-carbon preferences (Ji et al. 2017). Li and Wang et al. first assume that prices and carbon emission levels depend on market demand, and investigate the optimal decisions of low-carbon closed-loop supply chains under different game structures (Li et al. 2017). Liu and Li et al. study the performance of single-channel and dual-channel supply chains and find that the low-carbon strategies of supply chain members depend on product substitutability and basic channel demand (Liu et al. 2017). Equilibrium pricing under retailers' equity concerns and use centralised decision making as a benchmark to analyse pricing strategies under decentralised decision making (Dai et al. 2019). Qu introduced fair concern behaviour into his study of two-channel supply chains and found that when a manufacturer is fair concerned, it is unable to maximise profits by regulating wholesale prices alone, but its own fair concern behaviour has a smaller impact on retailers' profits but positively affects its own earnings (Qu 2016). Han and Wang et al. found that consumers' low-carbon preferences and government low-carbon subsidies contribute to supply chain operations, while manufacturers' equity concerns lead to a preference for increasing their returns from low quality and low prices, which would have a negative effect on supply chain operations (Wang et al. 2020). In contrast, Sharma and Jain explored the impact of retailers' equity concerns on pricing strategies and maximum profitability and found that retailers' equity concerns do not always contribute to their own efficiency, and that when the level of equity concerns exceeds a certain threshold, it leads customers to switch to online channels for product purchases (Sharma and Jain 2019). Li and Guo et al. constructed a two-channel closed-loop supply chain model consisting of a risk-averse retailer and a risk-neutral manufacturer to analyse the effects of risk aversion and fairness concern on the maximum profit and optimal pricing decisions of the retailer and manufacturer in three scenarios: the retailer does not have fair concern behaviour, the retailer has fair concern behaviour and the manufacturer does not consider it, and the retailer has fair concern behaviour and the manufacturer considers it (Li et al. 2021). Yu and Wang et al. studied ordering decisions and coordination in three contexts: retailer fairness concerns, manufacturer fairness concerns, and both fairness concerns, and found that manufacturers need to compensate retailers to some extent in order to maintain cooperation with them (Yu et al. 2019).

3 Problem Description and Model Construction

The subject of this paper is the low-carbon dual-channel supply chain, in which manufacturers develop and produce green products and sell them through online and traditional wholesale channels. Retailers sell them through their offline channels after wholesaling them from manufacturers. As the dominant player in the game, the manufacturer can use its advantages in terms of access to information and profitability to set prices first. The retailer can then set its selling price based on the manufacturer's pricing. Centralised decision-making where manufacturers and retailers no longer aim to maximise their profits but to maximise the profitability of the supply chain as a whole, with pricing shared by both parties. When the retailer is concerned about fairness, the manufacturer, as the dominant player, can fully understand and give total weight to this retailer's behaviour by pricing first. The retailer then obtains the manufacturer's pricing and sets the selling price in its context. This paper considers three scenarios of centralised decision making under retailer equity neutrality, decentralised decision making and decentralised decision making under retailer's fairness concern to address the following questions: (1) What is the optimal pricing for manufacturers and retailers in the three scenarios? (2) What is the impact of different consumer preferences on manufacturers' and retailers' pricing and maximum profitability? (3) What is the impact of different market shares on manufacturers' and retailers' pricing and maximum profitability?

This paper constructs a two-channel supply chain model with a single manufacturer and a single retailer. There are two ways for manufacturers to generate revenue: by selling green products directly to consumers at a price p_m through online channels and, on the other hand, by selling products wholesale to retailers at a w price through traditional channels. Retailers can only sell wholesale products to consumers p_r ($p_r > w$) through offline channels to generate revenue. Figure 1 illustrates the structure of a dual-channel supply chain.

In this paper, we refer to the studies of Wang et al. (2012), Zou and Guangyu (2018), Yan et al. (2020). They assumed that consumers demand Dm in the online channel and Dr in the offline channel. Demand in online versus offline channels is influenced by market share, manufacturer pricing, retailer pricing and consumer low carbon preferences. The demand functions for each of the two channels are as follows.

$$D_m = (1 - \gamma)a - p_m + \theta g + \delta p_r \quad (1)$$

$$D_r = \gamma a - p_r + \theta g + \delta p_m \quad (2)$$

A is the sum of the demand in the online and offline channels γ ($0 < \gamma < 1$) is the share of offline channel demand. θ ($0 < \theta < 1$) is consumers' low carbon preference. δ ($0 < \delta < 1$) is the cross-price influence coefficient, which indicates how pricing interacts between manufacturers and retailers.

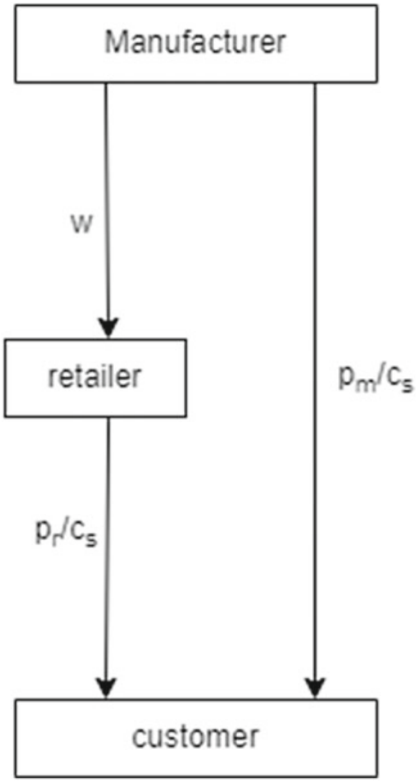


Fig. 1 Dual-channel supply chain structure

The development and production of green products by manufacturers requires capital investment, where the cost of research and development is positively related to the greenness of the product. Let the unit production cost of the green product be c. The price per unit sold is cs. Product greenness is g. The development cost of the product is βg2, where β > 1. The manufacturer profits through both online and wholesale channels, and its profit function is the sum of the revenue from online product sales at pm and the revenue gained from wholesale to retailers at w minus production costs, selling costs and R&D costs, which can be expressed as

$$\pi_m = (p_m - c - c_s)D_m + (w - c)D_r - \beta g^2 \tag{3}$$

The profit function for a retailer selling products through the offline channel is the revenue gained from selling the product at the price of pr minus the cost of selling the product and the cost of purchase, which can be expressed as

$$\pi_r = (p_r - w - c_s)D_r \tag{4}$$

Total supply chain profit is the sum of manufacturer and retailer profits. So that it can be expressed as

$$\pi = (p_m - c - c_s)D_m + (p_r - c - c_s)D_r - \beta g^2. \tag{5}$$

4 Analysis of Decision Making in Different Situations

As a basis for subsequent numerical simulations, this chapter explores the optimal pricing of manufacturers and retailers in three scenarios: centralised decision making under fair neutrality, decentralised decision making under fair neutrality, and decision making under retailer fairness concerns. In addition, as product greenness is an endogenous variable in the model, it also needs to be considered when exploring manufacturers' and retailers' optimal decisions.

4.1 Centralised Decision Making Under Fair Neutrality

One manufacturer and one retailer cooperate under centralised decision-making, and both seek to maximise the overall profitability of the supply chain. Taking the first-order partial derivative of the supply chain as a whole yields

$$\frac{\partial \pi}{\partial p_m} = a(1-\gamma) + c + c_m + g\theta - 2p_m + \delta p_r + \delta(w - c) + \delta(p_r - c_r - w) \tag{6}$$

$$\frac{\partial \pi}{\partial p_r} = a\gamma + c + c_r + g\theta + \delta p_m - 2p_r + \delta(p_m - c - c_m) \tag{7}$$

$$\frac{\partial \pi}{\partial g} = -2g\beta + \theta(w - c) + \theta(p_m - c - c_m) + \theta(p_r - w - c_r) \tag{8}$$

The Hessian matrix of the profit function for the supply chain as a whole is

$$\left|H\left(\prod (p_m, w, g)\right)\right| = \begin{bmatrix} -2 & 2\delta & \theta \\ 2\delta & -2 & \theta \\ \theta & \theta & -2\beta \end{bmatrix}$$
$$= 4\left(2\beta\delta - 2\beta + \theta^2\right)(\delta + 1) \tag{9}$$

The first-order principal subformula of this Hessian matrix is -2. The second-order sequential principal subformula is $4(1 - \delta)(1 + \delta) > 0$. The third-order sequential principal subformula is $4(\delta+1)\left(\theta^2 - 2\beta + 2\beta\delta\right)$ positive and negative are unknown. Therefore, the Hessian matrix is negative only when the third-order sequential principal equation is negative only if $\theta^2 < 2\beta(1-\delta)$ satisfying the condition that the overall profit function of the supply chain has an optimal solution. The optimal value of the centralised decision can be obtained by letting $\frac{\partial\pi}{\partial p_m} = 0$, $\frac{\partial\pi}{\partial p_r} = 0$, $\frac{\partial\pi}{\partial g} = 0$, respectively, and finding the optimal value of the centralised decision by the system of cubic equations

$$p_{m1}^* = \frac{(c+c_s)\left[\beta(\delta-1)+\theta^2\right]}{\theta^2-2\beta+2\beta\delta} + \frac{a\theta^2(1-2\gamma)+4a\beta(\gamma-1-\delta\gamma)}{4(\delta+1)\left(\theta^2-2\beta+2\beta\delta\right)} \tag{10}$$

$$p_{r1}^* = \frac{(c+c_s)\left[\theta^2+\beta(\delta-1)\right]}{\theta^2-2\beta+2\beta\delta} + \frac{a\theta^2(2\gamma-1)+4a\beta(\delta\gamma-\delta-\gamma)}{4(\delta+1)\left(\theta^2-2\beta+2\beta\delta\right)} \tag{11}$$

$$g_1^* = -\frac{\theta[a+2(\delta-1)(c+c_s)]}{2\left(\theta^2-2\beta+2\beta\delta\right)}. \tag{12}$$

4.2 *Decentralised Decision Making Under Fair Neutrality*

When the retailer is fair neutral, both the manufacturer and the retailer are rational decision-makers seeking to maximise their interests. The manufacturer is the dominant player in the supply chain and makes its own decisions based on the retailer's optimal profit first. This paper uses a reverse recursive approach. The first step is the manufacturer uses its advantage to speculate on the retailer's pricing and then determines its actual selling price and wholesale price. The third step is for the retailer to determine its selling price.

In the first step, The manufacturer obtains the retailer's profit function by its advantage in access to information and uses it to speculate on the retailer's pricing, i.e. to find the first and second-order derivatives of the retailer's profit function, respectively, determine the maximum value of the retailer's profit function, and then make the first-order derivative zero and speculate on the retailer's selling price.

$$\frac{\partial\pi_r}{\partial p_r} = c_s - 2p_r + w + a\gamma + \delta p_m + g\theta \tag{13}$$

$$\frac{\partial^2\pi_r}{\partial^2 p_r} = -2 \tag{14}$$

The second-order partial derivative is <0, which is a concave function, and there is an optimal solution. Let the first-order partial product be equal to 0 to obtain

$$p_{r2} = \frac{c_s + w + a\gamma + \delta p_m + g\theta}{2} \tag{15}$$

In the second step, since the prices of both the online and offline channels are affected by the manufacturer's pricing and the retailer's pricing, the manufacturer will substitute the projected retailer's pricing into its profit function to determine its own optimal decision and obtain the first-order partial derivative of $p_m, \quad w, \quad g$ is

$$\frac{\partial \pi_m}{\partial p_m} = g\theta - p_m - \frac{\delta(c-w)}{2} - a(\gamma - 1) + \frac{\delta(c_s + w + a\gamma + \delta p_m + g\theta)}{2} - \left(\frac{\delta^2}{2} - 1\right)(c + c_s - p_m) \tag{16}$$

$$\frac{\partial \pi_m}{\partial w} = \frac{c}{2} - \frac{c_s}{2} - \frac{c\delta}{2} - \frac{c_s\delta}{2} + \frac{a\gamma}{2} + \delta p_m + \frac{g\theta}{2} - w \tag{17}$$

$$\frac{\partial \pi_m}{\partial g} = -2\beta g - \frac{\theta(c-w)}{2} - \frac{\theta(\delta+2)(c + c_s - p_m)}{2} \tag{18}$$

The Hessian matrix of p_m, w, g is

$$\left|H\left(\prod_m (p_m, w, g)\right)\right| = \begin{bmatrix} \delta^2 - 2 & \delta & \frac{\theta(\delta+2)}{2} \\ \delta & -1 & \frac{\theta}{2} \\ \frac{\theta(\delta+2)}{2} & \frac{\theta}{2} & -2\beta \end{bmatrix} = \frac{(\delta+1)\left(8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2\right)}{2} \tag{19}$$

The first-order principal subformula is $\delta^2 - 2 < 0$. The second-order principal subformula is $2 - 2\delta^2 > 0$. The third-order principal subformula is $8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2$, and positive and negative are unknown. The Hessian matrix's condition is negative definite and is satisfied only when $8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2 < 0$ the manufacturer's profit has a maximum value. Letting the first-order partial derivative equal 0, we can obtain as

$$p_{m2}^* = \frac{\left(8\delta\theta^2 + 2\delta^2\theta^2 + 8\beta\delta^2 + 6\theta^2 - 8\beta\right)(c + c_s) + a\theta^2(1 - 2\gamma) + 8a\beta(\gamma - 1) - 8a\beta\delta\gamma}{2(\delta+1)\left(8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2\right)} \tag{20}$$

$$w_2^* = \frac{4\beta(c - c_s)(\delta - 1) + \theta^2(3c + c\delta + a\gamma)}{8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2} + \frac{a\left(4\beta\delta + \theta^2\right)(\gamma - 1) - a\delta\theta^2}{(\delta+1)\left(8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2\right)} \tag{21}$$

$$g_2^* = -\frac{\theta\left[(\delta+3)(\delta-1)(c + c_s) + a\gamma(\delta - 2) + 2a\right]}{8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2} \tag{22}$$

In the third step, after the manufacturer determines its pricing, the retailer as a follower can only decide on its own sales price according to the manufacturer's pricing, so the manufacturer's optimal online sales price, the optimal wholesale price, and the optimal product greenness are substituted into p_{r2} to obtain the retailer's optimal pricing p_{r2}^* as

$$p_{r2}^* = \frac{\sigma_2(c + c_s)}{\sigma_1} + \frac{a\theta^2(2\delta + 3)(2\gamma - 1) + 4a\beta\sigma_3}{2\sigma_1(\delta + 1)} \tag{23}$$

where, $\sigma_1 = 8\beta\delta - 8\beta + \delta\theta^2 + 3\theta^2$, $\sigma_2 = 3\theta^2 - 3\beta + 2\beta\delta^2 + \delta\theta^2$, $\sigma_3 = 2\delta\gamma + \delta^2\gamma - 3\gamma - 2\delta$.

4.3 Decision Making Under Retailer Fairness Concerns

In this case, there is fairness concern behaviour on the retailer's part. It is assumed that market information is symmetrical and that the manufacturer has sufficient ability and willingness to value this behaviour on the retailer's part. In this paper, a coefficient λ is introduced to represent the degree of fairness concern of the retailer. In this case, the retailer's utility function is

$$U_r = (1 + \lambda)\pi_r - \lambda\pi_m \tag{24}$$

Assuming that the manufacturer does not behave with fair concern and is only concerned with its earnings, its utility function is the same as its profit function and is

$$U_m = \pi_m \tag{25}$$

This model also uses a backward recursive approach, where the first step is to derive the retailer's utility function and make the derivative equal to 0 to obtain the manufacturer's inferred retailer sales price as

$$\begin{aligned}\frac{\partial U_m}{\partial p_r} &= (\lambda + 1)(c_s - p_r + w) - \lambda(c - w)\\ &\quad + (\lambda + 1)(a\gamma - p_r + \delta p_m + g\theta) + \delta\lambda(c + c_s - p_m)\end{aligned} \tag{26}$$

$$p_{r3} = \frac{\delta p_m + a\gamma + g\theta + w + c_s}{2} + \frac{\lambda(w - c) + \delta\lambda(c + c_s - p_m)}{2(\lambda + 1)} \tag{27}$$

In the second step, the manufacturer's profit function is related to the retailer's pricing. The manufacturer substitutes the presumed retailer's pricing p_{r3} with its utility function to determine its optimal decision.

$$\frac{\partial U_m}{\partial p_m} = c + c_s - 2p_m + g\theta - a(\gamma - 1) - (c - w)\delta$$
$$+ \frac{\delta^2(c + c_s - p_m)(\lambda - 1) - \delta(c - w)(\lambda - 1)}{2(\lambda + 1)} + \frac{\delta(a\gamma + \delta p_m + g\theta + c_s + w)}{2} \tag{28}$$

$$\frac{\partial U_m}{\partial w} = \frac{a\gamma + g\theta - c_s - c + \delta c + \delta c_s}{2} \tag{29}$$

$$\frac{\partial U_m}{\partial g} = -2\beta g - \frac{\theta(\delta + 2)}{2}(c + c_s - p_m) - (c - w)\frac{\theta}{2} \tag{30}$$

The Hessian matrix of p_m, w, g is

$$|H(U_m(p_m, w, g))| = \begin{bmatrix} -\frac{-\delta^2+2\lambda+2}{\lambda+1} & \frac{\delta(2\lambda+1)}{\lambda+1} & \frac{\theta(\delta+2)}{2} \\ \frac{\delta(2\lambda+1)}{\lambda+1} & -\frac{2\lambda+1}{\lambda+1} & \frac{\theta}{2} \\ \frac{\theta(\delta+2)}{2} & \frac{\theta}{2} & -2\beta \end{bmatrix}$$
$$= \frac{(\delta + 1)\left[8\beta(\delta - 1)(2\lambda + 1) + \theta^2(\delta + 5\lambda + 3\delta\lambda + 3)\right]}{2\lambda + 2} \tag{31}$$

The first-order principal subformula is $-\frac{2-\delta^2+2\lambda}{\lambda+1} < 0$. The second-order principle subformula is $\frac{2(2\lambda+1)(1-\delta)(1+\delta)}{\lambda+1} > 0$. The third-order principal subformula is $\frac{(\delta+1)\left[8\beta(\delta-1)(2\lambda+1)+\theta^2(\delta+5\lambda+3\delta\lambda+3)\right]}{2\lambda+2}$ positive, and the negative is unknown. The condition that the Hessian matrix is negative definite is only satisfied when the third-order principal is <0 and when there is a maximum value of the manufacturer's utility function.

Let the first-order partial derivative of the manufacturer's utility function equal 0. The optimal value p_{m3}^*, w_3^*, g_3^* is as follows

$$p_{m3}^* = \frac{\left(2\theta^2\left[(3 + 5\lambda) + \delta^2(3\lambda + 1) + 4\delta(1 + 2\lambda)\right] + 8\sigma_4(\delta + 1)\right)(c + c_s)}{2(\delta + 1)\left(8\sigma_4 + \theta^2\sigma_3\right)}$$
$$+ \frac{8a\beta(\gamma - \gamma\delta - 1)(1 + 2\lambda) + a\theta^2(1 - 2\gamma)(1 + \lambda)}{2(\delta + 1)\left(8\sigma_4 + \theta^2\sigma_3\right)} \tag{32}$$

$$w_3^* = \frac{8\beta[(c_s - \mathrm{c}) + \delta\lambda(\mathrm{c} + \mathrm{c_s}) - \lambda(3c - c_s)](1 - \delta) + 2c\theta^2\sigma_3}{2\left(8\sigma_4 + \theta^2\sigma_3\right)}$$
$$+ \frac{8a\beta\sigma_6 + 16a\beta\delta\lambda(\gamma - 1) + a\theta^2(2\delta\gamma - 2 - \delta + 4\gamma)(\lambda + 1)}{2(\delta + 1)\left(8\sigma_4 + \theta^2\sigma_3\right)} \tag{33}$$

$$g_3^* = -\frac{\theta\left[\left(2\delta - 3 - 5\lambda + \delta^2 + 2\delta\lambda + 3\delta^2\lambda\right)(c + c_s) + 2a(1 + 2\lambda) + a\gamma(3\lambda + 1)(\delta - 1)\right]}{8\sigma_4 + \theta^2\sigma_3} \tag{34}$$

In the third step, after the manufacturer has set the price, the retailer sets its selling price based on the manufacturer's pricing in the market. Substituting p_{m3}^*, w_3^*, g_3^* into p_{r3} gives

$$p_{r3}^* = \frac{\left[2\sigma_4(\delta + 1) + \theta^2\sigma_3\right](c + c_s)}{8\sigma_4 + \theta^2\sigma_3} + \frac{\sigma_5(1 + 2\lambda) + a\theta^2[\delta(2 + 5\delta\lambda) + 3(1 + 2\lambda)](2\gamma - 1)}{2(\delta + 1)\left(8\sigma_4 + \theta^2\sigma_3\right)} \tag{35}$$

where,

$\sigma_3 = \delta + 5\lambda + 3 + 3\delta\lambda,$

$\sigma_4 = \beta(2\lambda + 1)(\delta - 1),$

$\sigma_5 = 4a\beta\left(2\delta\gamma + \delta^2\gamma - 2\delta - 3\gamma\right),$

$\sigma_6 = \delta\gamma - \gamma - \gamma\lambda - \delta^2\gamma\lambda - \delta.$

5 Numerical Example

This paper uses MATLAB R2020b to simulate the model to visualise numerically. We analyse the above model trends to investigate the impact of consumers' low carbon preference level and offline market share on manufacturers' and retailers' decision variables and profit functions at different levels of retailer equity concern. Referring to the numerical simulations in the literature (Han et al. 2021; Wang et al. 2021; Su and Wang 2021) and the previous assumptions, let a = 1000, c = 10, cs = 5, β = 7, δ = 0.4, θ = 2, γ = 0.5.

5.1 *Effect of θ on Optimal Solutions Under Different λ*

This section analyses the impact of consumer low carbon preferences and retailer fairness concerns on optimal pricing and maximum profitability for manufacturers and retailers. Figures 2, 3 and 4 shows that consumers' common carbon preference positively affects the manufacturer's optimal online sales price, the wholesale price, and the retailer's optimal sales price. Increasing consumers' low carbon preference leads to more significant values for the above decision variables. And when the degree of consumer low-carbon preference is the same, the stronger the retailer's equity concern, the smaller the optimal value of each decision variable. We also found that increased retailer fairness concerns have a minor impact on the manufacturer's online channel optimal selling price and retailer selling price, while there is a more significant impact on the manufacturer's optimal wholesale price. It is because the paper assumes that the market is symmetrical in terms of information and that

Fig. 2 Effect of θ on p_m

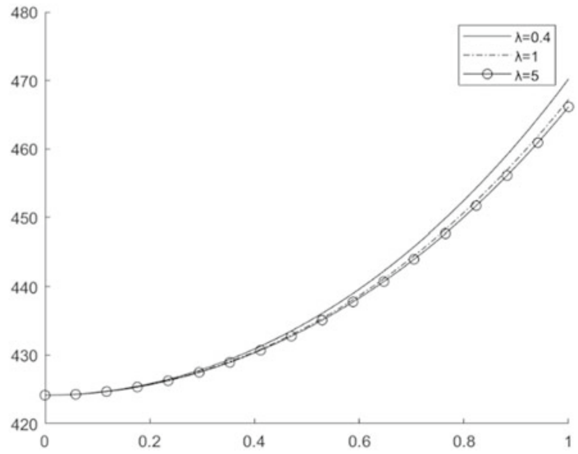
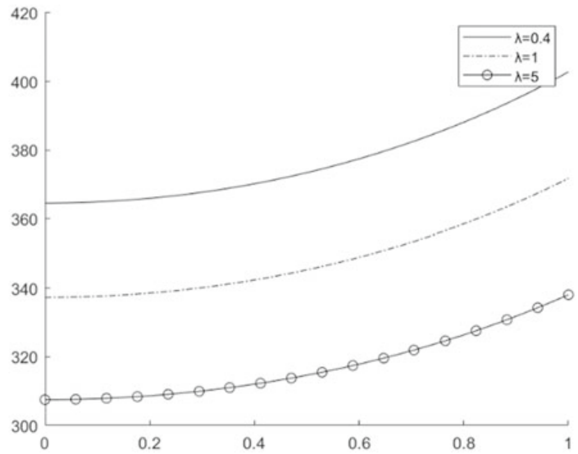


Fig. 3 Effect of θ on w



manufacturers have sufficient access to information and the willingness to give total weight to the fairness concerns of retailers. Thus, when retailers' equity concerns increase, manufacturers will reduce their wholesale prices to some extent to meet retailers' needs for a balanced distribution of revenue.

Figures 5 and 6 show that the degree of consumer preference for low carbon has a positive effect on the maximum profit for both manufacturers and retailers, with the maximum profit for both increasing with the degree of consumer preference for low carbon. It is mainly due to increased consumer low carbon preference, which boosts product demand and improves optimal pricing for manufacturers and retailers, increasing maximum profitability. When consumer low-carbon preferences are at the same level, increased retailer's fairness concern will reduce the manufacturer's maximum profit and increase the retailer's maximum profit. Manufacturers respond to retailers' needs for fairness in the distribution of earnings in the market by lowering

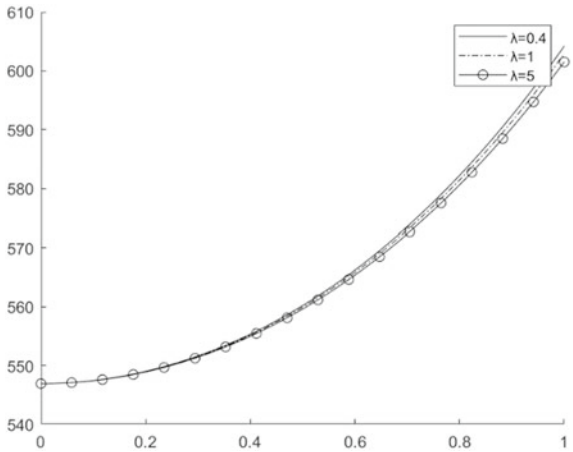


Fig. 4 Effect of θ on p_r

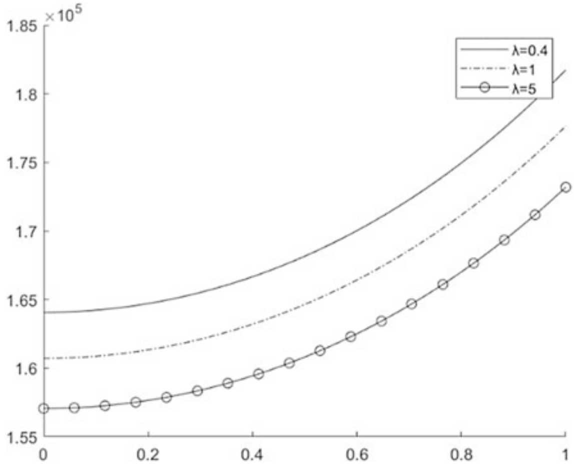


Fig. 5 Effect of θ on π_m

wholesale prices, leading to lower earnings for themselves. As a result, retailers' increased focus on fairness in revenue distribution can help them grow their profits.

5.2 Effect of γ on Optimal Solutions Under Different λ

In addition to consumer low-carbon preferences, changes in market share in the offline channel can lead to changes in optimal pricing for manufacturers and retailers. Figures 7, 8 and 9 simulate the impact of offline market share on manufacturer and retailer optimal pricing through numerical simulation while setting different levels of fairness concern to explore the impact of fairness concern on manufacturer

Fig. 6 Effect of θ on π_r

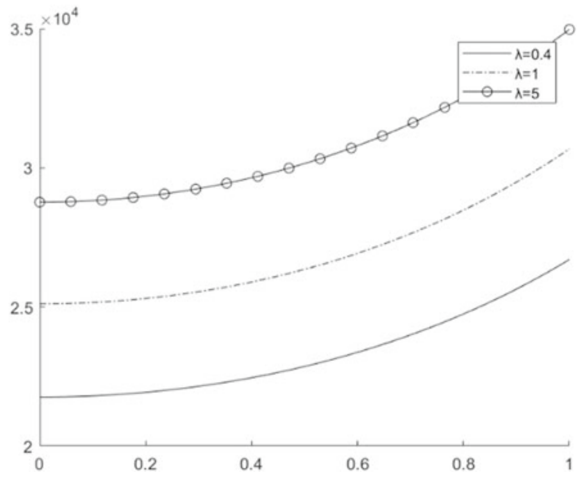
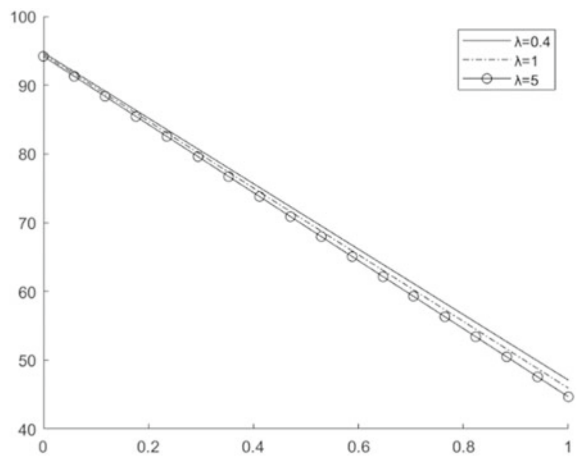


Fig. 7 Effect of γ on p_m



and retailer optimal pricing given the same market share. As offline market share increases, the manufacturer's optimal online selling price decreases, the optimal wholesale price increases, and the retailer's optimal selling price increases. When offline market shares are equal, the stronger the retailer's equity concern, the lower the manufacturer's optimal online selling price, the optimal wholesale price and the retailer's optimal selling price, with the reduction in the manufacturer's optimal wholesale price being particularly significant. As shown in Fig. 3, the degree of consumer low carbon preference affects the manufacturer's optimal wholesale price to the same extent, although the degree of equity concern varies.

As shown in Figs. 10 and 11, as offline market share increases, the maximum profit for manufacturers continues to decrease, and the maximum profit for retailers continues to increase. For the same market share, the stronger the retailer's equity

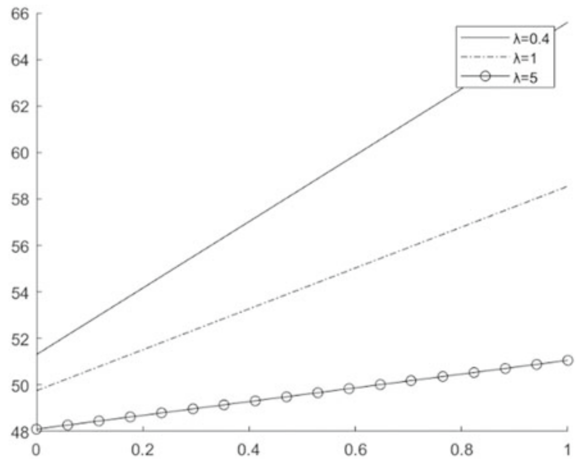


Fig. 8 Effect of γ on w

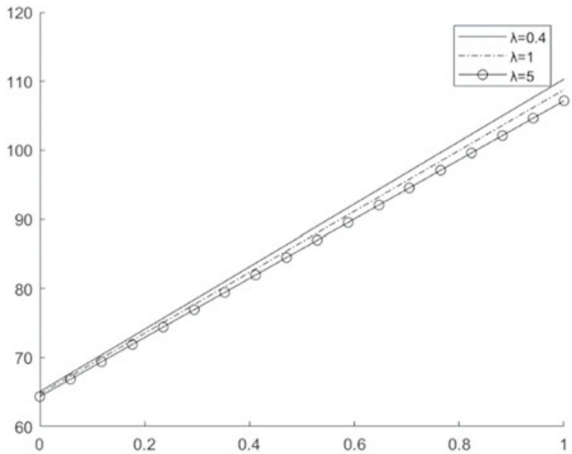


Fig. 9 Effect of γ on p_r

concern, the higher the maximum profit available to itself, and the lower the maximum profit for the manufacturer. When the offline market share is small, the manufacturer's maximum profit is very close for different levels of retailer equity concern. As the offline market share increases, the level of retailer equity concern has an increasing impact on the manufacturer's maximum profit. Combining Figs. 10 with 11 reveals that the maximum profit for the manufacturer is always higher than the maximum profit for the retailer when there is a low level of retailer equity concern, even when the offline market share is increasing. And as the retailer's fairness concern grows, the maximum profit gap between the manufacturer and the retailer continues to decrease for the same offline market share. When the retailer's fairness concern

Fig. 10 Effect of γ on π_m

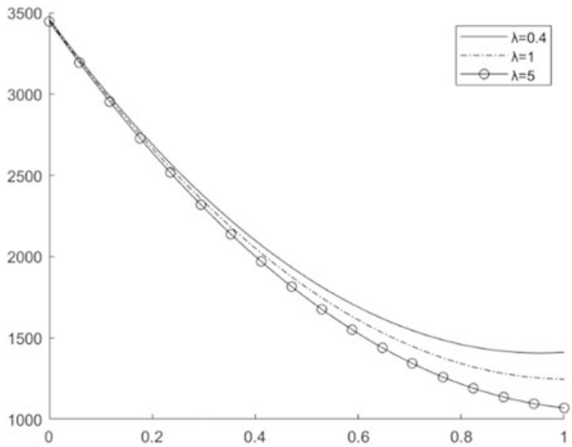
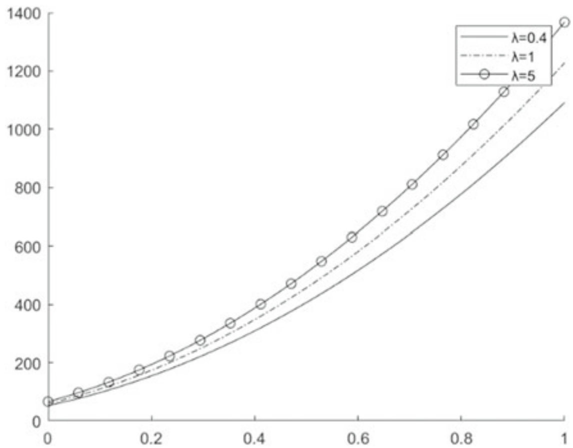


Fig. 11 Effect of γ on π_r

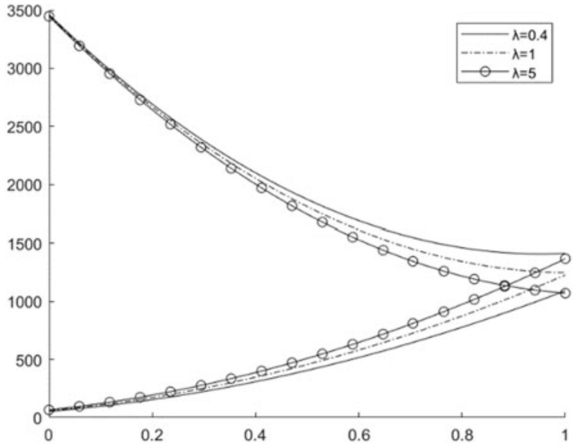


is more significant than one, the retailer's maximum profit will exceed the manufacturer's maximum profit as the offline market share continues to increase. The maximum profit difference between the two parties will continue to grow (Fig. 12).

6 Conclusion

In this paper, the low-carbon dual-channel supply chain is the subject of a study. The Stackelberg three-stage game model is constructed by considering exogenous variables such as the degree of consumers' low-carbon preferences and the degree of retailers' fairness concerns. They explore the optimal pricing for manufacturers

Fig. 12 Effect of γ on π_m and π_r



and retailers under three scenarios: centralised decision-making under retailer fairness neutrality, decentralised decision-making, and decentralised decision-making under retailer fairness concern. It also analyses the impact of the degree of consumer low-carbon preference, offline market share and retailer fairness concerns on optimal pricing and maximum profitability, providing an essential reference for manufacturers' and retailers' decisions.

The main conclusions of this paper are as follows: When retailers behave with fairness concerns, increased fairness concerns lead to lower optimal pricing online, lower wholesale prices in traditional channels, lower maximum profits for manufacturers, and makes retailers' own offline sales prices lower. However, the reduction in sales prices in the retailer's offline channel does not result in a loss of profit for the retailer; on the contrary, it increases the retailer's maximum profit. (2) Optimal pricing for both manufacturers and retailers increases when consumers' low-carbon preferences increase, and the increase in consumers' low-carbon preferences helps manufacturers and retailers to maximise their revenue. (3) When the offline market share increases, the manufacturer's optimal selling price and maximum profit decrease, while the manufacturer's optimal wholesale price, the retailer's optimal selling price and maximum profit tend to increase.

The recommendations arising from the above conclusions are as follows. (1) For manufacturers, the extent of consumers' low-carbon preferences contributes to their profitability, so manufacturers should grasp the market demand, grasp consumers' pain points and produce green products that better meet consumers' low-carbon preferences. Increased retailer fairness concerns can result in lost profits for manufacturers, primarily because manufacturers take this behaviour of retailers fully into account and reduce their wholesale prices to meet retailers' needs for fairness in profit distribution. Therefore, to avoid diminishing returns, manufacturers may consider ignoring the fairness concerns of retailers to a certain extent. At the same time, it should also pay more attention to online channels. And they should be more active to use social software, video platforms and other new forms of media integration. It will help them occupy a larger market share and avoid the reduction of its maximum profit due to the squeezed market share. (2) For retailers, the degree of consumers' low-carbon preferences also affects their maximum profits. Retailers should regularly conduct market research, fully understand and consider consumers' preferences, and put forward their requirements on the greenness of manufacturers' products based on market research results. Force manufacturers to produce products that better meet consumers' low-carbon preferences to meet market demand. The increase in the share of offline sales channels will enhance the maximum profit of retailers. Manufacturers will seize market share to ensure their interests resulting in increased competition between channels. At the same time, the development of the Internet makes online channels more competitive. To cope with the pressure of channel competition, retailers can dig deeper into the advantages of offline media and stabilise the market share of offline channels from the perspective of providing diversified offline services. At the same time, they developed their own online sales channels and built a dual-channel sales approach to compensate for their disadvantages in terms of channel competition. Increased fairness concerns help retailers maximise their profits, so in subsequent transactions, retailers should make every effort to compensate for their lack of access to information. At the same time, retailers should improve their bargaining power to ensure that manufacturers pay sufficient attention to fairness concerns and that their earnings are not lost due to manufacturers' neglect of fairness concerns.

There are still shortcomings in this paper, such as the assumption that market information is transparent and that manufacturers are sufficiently willing to value retailers' fairness concern behaviour. Manufacturers can not accurately capture or predict the retailer's fairness concern factor. And even if they could, they may not give total weight to this retailer's behaviour. At the same time, there is a cost to manufacturers for green product development. There are also equity concerns for manufacturers, which are not considered in this paper. Therefore, in the subsequent research, the model constructed in the previous section needs to be further refined to make it more relevant to the actual operational situation.

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Research on Online Decision-Making Method for Oil Wells Shutting Down or Resetting Based on Dynamic Data-Driven

Cong Niu

Abstract In the unstable and uncertain international situation, how to balance the scale growth and efficiency improvement of oil production is a key issue to ensure national energy security and sustainable development of enterprises. In view of the dual problem of declining oil production and rising production cost in the middle and late stage of oilfield development, this paper focuses on oil well, the smallest unit of oilfield, to improve the economic benefit of single well and optimize the allocation of single well resources. This paper introduces the idea of data-driven decision making and machine learning method, proposes a prediction method of single well economic benefit using long and short-term memory neural network to mine complex structure and potential pattern of massive data, and develops an online decision system based on dynamic data driving to solve the problem that the model method is difficult for managers to use. Numerical example results show that both short-term and long-term memory neural network prediction model of single well economic benefit of short-term forecasting results are good and give full consideration to the well historical data value, break traditional management decision problems, strong paradigm it into the process of petroleum enterprise benefit stable data interactive collaborative decision-making process of learning and resources optimization, assist oil enterprises to avoid low and inefficient investment at source.

Keywords Intelligent oilfield · Grass well benefit · Data-driven · Machine learning · Online decision

1 Introduction

Affected by the impact of the COVID-19, the global demand for crude oil has decreased for the first time in a decade, and the international oil price has also fluctuated at a low level. In particular, in the first half of 2020, the spot price of

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WTI crude oil fell to a negative value for the first time, reaching a minimum of $−37.63/barrel, and rising to a maximum of $75.37/barrel after a year of fluctuating growth. Such fluctuations in the external environment of the petroleum industry have a great impact on the overall economic benefits of the oilfield. As the smallest unit of oilfield development, the level of economic benefits of a single well also affects the overall benefits of the oilfield to a certain extent. In the middle and late stages of oil well production, with the decline of oil well production and the continuous rise of production costs, the decision-making mode of pursuing high and stable production has gradually shifted to focusing on the economic benefits of oil wells. Starting from the economic benefits of oil well, whether to "continue production", when to "shut down" and when to "restart" a single well has become an important decision-making issue in oilfield development.

In recent years, the research on Oilfield decision-making can be roughly divided into production prediction, productivity prediction, benefit evaluation, oil price prediction, etc., but most of them are based on offline calculation and physical model driven decision-making, while the online decision-making model based on dynamic data input has not been applied in the external uncertainty environment. Taking oil well production forecasting as an example, traditional mathematical models and artificial intelligence algorithms are mainly used. Commonly used methods include production decline model [1–5], grey theory [6–11], BP neural network [12–14], long short-term memory Network [15] and various improved algorithms, etc., the decision results tend to be static and have a certain hysteresis.

In the big data environment, the traditional decision-making paradigm driven by physical models has encountered many challenges, and the decision-making elements such as information situation, decision-making subjects, concept assumptions, method processes have shown significant changes. Under the emerging information technology, the new paradigm of data-driven decision-making can fully tap the value of data, give full play to the utility of data, and solve the problem of strong assumptions under the traditional management decision-making paradigm [16]. In the process of oilfield development, the production and operation of each oil well has produced a large amount of data, and the laws and trends hidden in its historical data are difficult to be fully displayed through manual analysis and physical model driven methods. The dynamic data-driven decision-making method is no longer limited to the assumptions of the mathematical model. The hidden rules of the actual production data are discovered in the machine learning environment to predict the economic benefits of oil wells, so as to provide an objective basis for the phased on-line decision-making of single well production.

Dynamic Data Driven Application Systems (DDDAS), as a new simulation application system model in the era of emerging information technology, is gradually applied in the environment [17, 18], traffic [19–21], emergency warning [22], military [23] and many other fields. In the above research, the actual operation of DDDAS is that the simulation system obtains data from the actual system and outputs simulation results dynamically to guide the operation of the actual system, forming a dynamic feedback mechanism. The above model can also be applied to the production decision-making process of oil wells to solve the actual decision-making problems for the oilfield management.

This paper presents a dynamic data-driven online decision-making paradigm to solve the double problems of declining oil production and rising production costs in the middle and late stages of oilfield development. And by constructing the DDDAS of single-well economic benefit, using the daily historical data and dynamic measured data of a single well with time series as input, the oil well benefit prediction state model based on long-short term memory (LSTM) neural network is used for online calculation to provide visual prediction results, and the historical database is used to correct the model parameters to improve the accuracy of the state model. It provides a scientific basis for the phased decision-making of shutting down, restarting and continuing production of single wells, and assists oil enterprises to avoid inefficient and ineffective investment from the root.

2 Construction of Dynamic Data-Driven Application System

2.1 Construction of System Framework

The essence of constructing a complete DDDAS is to input the state information of the real system into the running results of the simulation system, and continuously feedback the simulation system to correct the system state model and improve the prediction effect and efficiency of the simulation system. In the online decision-making process of single-well production in oilfields, the decision-making department, the actual production system and the online decision-making system of single well jointly form a closed-loop feedback chain, as shown in Fig. 1.

The online decision-making system calculates and predicts the short-term economic benefit value of a single well through the simulation system, evaluates the feasible production scheme online, and outputs the visualized results to the decision-making department. The decision-making department makes production decisions

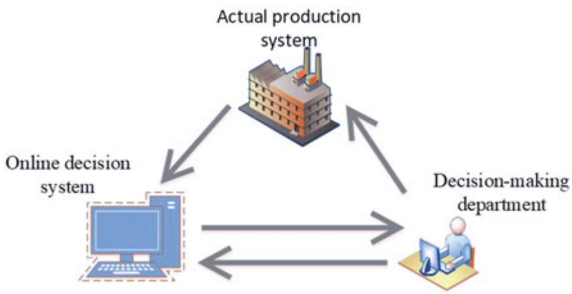


Fig. 1 Closed loop feedback chain for online decision-making

based on the comprehensive analysis of the forecast results. The actual production system produces according to the decision-making instructions and outputs the actual production data to the online decision-making system to correct the system parameters and the state prediction model.

According to the structural characteristics and functional requirements of the single well online decision system based on DDDAS, it is mainly divided into three levels, as shown in Fig. 2. The data layer takes historical data, model data and real-time data as the overall input of the system. The algorithm layer mainly includes data preprocessing (screening variables, filling missing values and normalization), grid optimization algorithm adjusting parameters, long-short term memory network for state prediction, and the algorithms are progressive and interrelated. The application layer transmits the system visualization results to the decision-making and production application platforms for oil well decision-making and production, and transmits the actual production data to the algorithm layer and the data layer.

The single well online decision-making system adopts the mode of combining online and offline calculation. It operates through the input of historical data and dynamic real-time data, and jointly corrects the system to realize its dynamic integration of production real-time data to form a closed-loop feedback chain. The overall framework of the system is shown in Fig. 3.

The system is mainly composed of four modules: (1) Data module. After collecting historical and real-time sequential production data, the standardized data will be input into the time series model database. (2) System state prediction module. The state prediction is carried out through the input of preliminary parameters and data sets, and then the state model is adjusted through network training and online correction to output accurate prediction data. (3) Decision-making and production module. The next production decision of single well production is judged online through the visual prediction results. The production department outputs the real-time production status and data to the offline database, and makes a comparative analysis with the prediction results online to facilitate the decision-making in the next stage. (4) Online correction module. Through the network training of the preliminary model and the error analysis of real-time production data and prediction data, the parameter

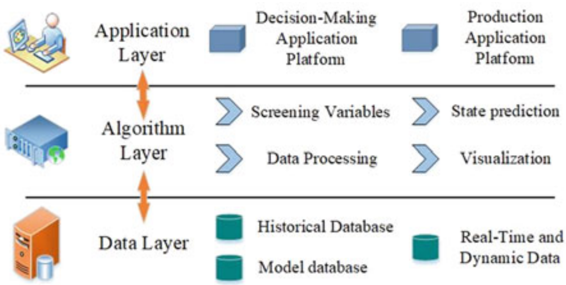


Fig. 2 System hierarchical structure diagram

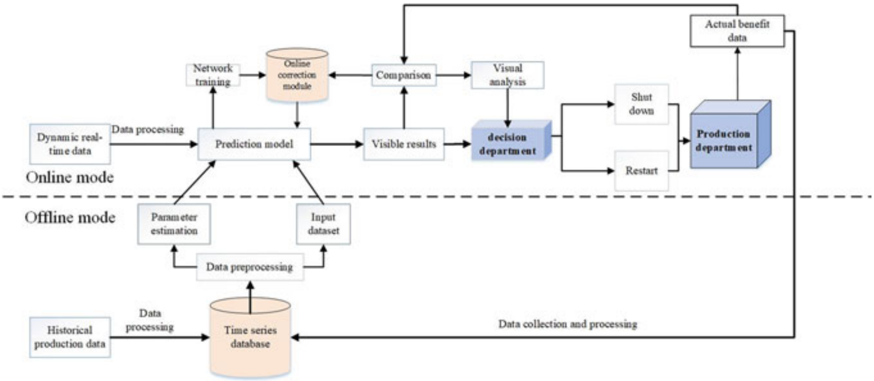


Fig. 3 Overall system framework diagram

adjustment and variable screening of the state model are carried out to realize the dynamic feedback mechanism of the system.

2.2 LSTM Network Prediction Model

LSTM neural network is a special recurrent neural network (RNN), which has been improved and applied since it was proposed in 1997. Although RNN can process sequence data, it cannot process long-term sequence data because the circular connection in its network structure only has the function of short-term memory. Compared with RNN, LSTM neural network adds forgetting gate, which solves this problem and is widely used in practical production. Therefore, this paper uses it to solve the problem of oil well economic benefit prediction with long time series and large amount of production data.

The LSTM network structure is shown in Fig. 4. The model is composed of several graphical modules, and the input h_{t-1} of each module is the state output of the previous module. The external input is x_t, the activation function is tanh, and the tanh layer is used to update the status value. The sigmod function is σ, corresponding to the forget gate, input gate and output gate respectively. The forget gate f_t selectively removes certain data information, input gates y_{t-1} and h_{t-1} update network module status information, output gate h_t and y_t output module calculation status.

2.3 Online Decision Process

When the economic benefit value of a single well is output from the system state prediction model, the on-line benefit evaluation of the well is carried out and the benefit type of the oil well is determined. It makes different oil well decision-making schemes according to different benefit categories, especially inefficient oil wells, to avoid invalid investment. The system determines the decision-making scheme of shutdown, measure production or no measure production based on the economic benefit limit of a single well, so as to further implement the management of "one well with multiple policies". The online decision-making process is shown in Fig. 5.

3 Example Analysis

Taking a single well production in DB oilfield as an example, this paper establishes a single well online decision system based on dynamic data driven. It takes the daily production data of the single well as the input, and presents the visual results through the short-term prediction of its economic benefits, so as to realize the dynamic production decision-making function of the system.

3.1 Selection of Input Variables

According to the actual production data, all possible indicators related to the model input are preliminarily selected. In order to prevent the long training cycle and slow convergence speed of the model caused by too large data magnitude, it uses Pearson correlation analysis to calculate the linear correlation between the input index data and the economic benefits of a single well, to reduce the input variables.

$$\mathrm{r} = \frac{N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{\sqrt{N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}\sqrt{N\sum_{i=1}^{N} y_i^2 b^2 - \left(\sum_{i=1}^{N} y_i\right)^2}} \tag{1}$$

The correlation coefficient r between the two indexes is calculated by Formula (1) to eliminate the variables with low correlation. Finally, six variables such as daily economic benefit value, daily oil production, daily oil price, daily cost (including

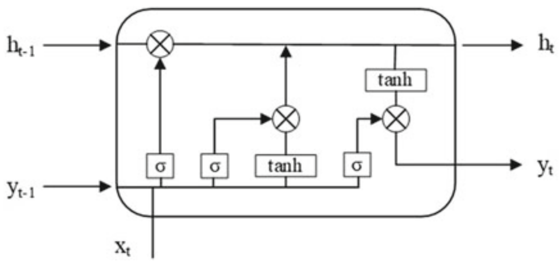


Fig. 4 LSTM network structure

operating cost, equally shared cost and other costs), daily water production and well water content are selected as inputs, with a total of 1525 time series data.

3.2 Data Preprocessing

Due to various reasons such as excessive water content, low pressure and low production, there is a phenomenon that the daily production data of some single wells are missing, which is common in the prediction of multivariate time series models, in the process of oil well production. The system adopts the filling method based on K-means clustering to supplement the missing data. According to the 8:2 division principle of neural network data set and the time node division, the production data from January 27, 2017 to June 30, 2020 are used as the training set to fit the model,

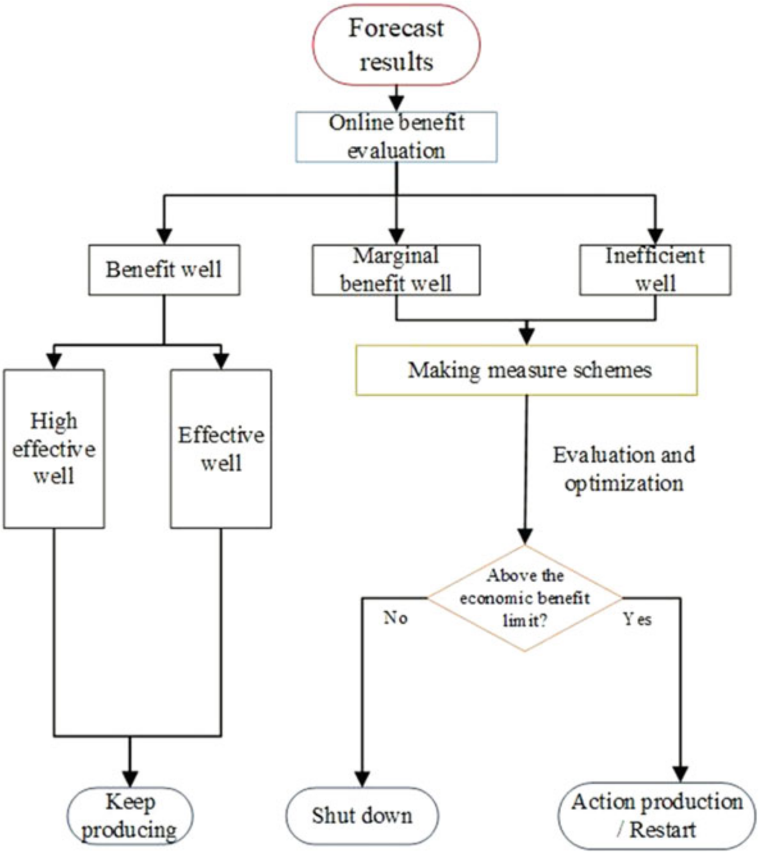


Fig. 5 Online decision process

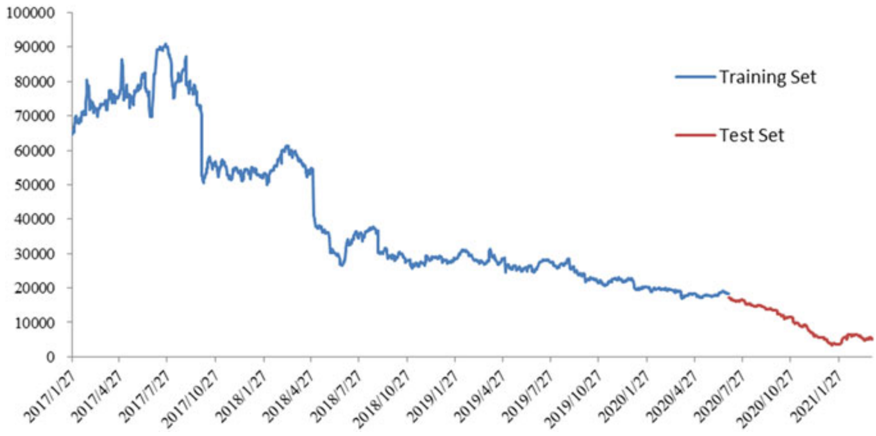


Fig. 6 Partition of data sets

and the data from July 1, 2020 to March 3, 2021 are used as the test set to determine the network structure and model parameters. The output variable of the model is the daily economic benefit of a single well, and the division of the data set is shown in Fig. 6.

Since there are many input factors in the state prediction model of oil well economic benefit, it uses the Min–Max normalization method to regularize the input data to prevent the abnormal operation results of the model caused by the different unit dimensions between the input data. According to Formula (2), it maps the data to the (0, 1) interval.

$$x_{ij} = \frac{x_{ij} - \min_{1 \le i \le N} x_{ij}}{\max_{1 \le i \le N} x_{ij} - \min_{1 \le i \le N} x_{ij}}. \tag{2}$$

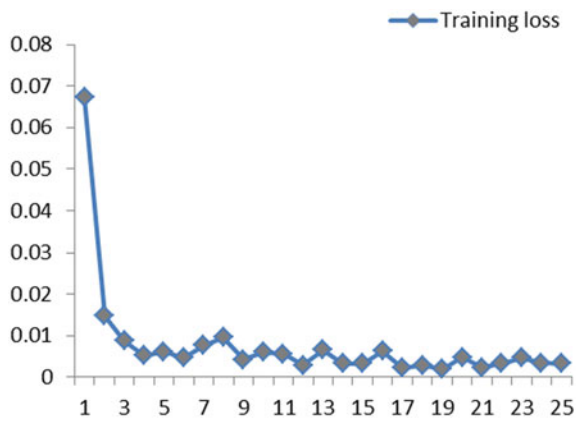
3.3 Prediction of Economic Benefits

The system takes Keras as the learning framework and Tensorflow as the background environment to build a single well economic benefit state prediction model based on LSTM neural network.

3.3.1 Network Training

In order to prevent the number of iterations and hidden neurons in the prediction module from being too large to reduce the prediction accuracy of the model, the grid search algorithm is used to find better parameters. It adopts a three-layer LSTM

Fig. 7 Training loss results



neural network model, that the mean square error function is used as the training function of the system state prediction model, and the Adam algorithm is used as the model optimizer, to predict the daily economic benefit of a single well. Before the variables inputting into the model, the time step is determined to be 120, in practice, considering the influence of multiple lag periods and the magnitude of the overall data set. After the grid search algorithm for parameter optimization, it is finally determined that there are 128 neuron units in each of the three layers of the model, the training rounds are 25, and the batch size is 100 to ensure the convergence of model.

The dropout method is adopted to prevent over fitting caused by large parameter magnitude, since three network layers are set, that the dropout scale is set to 0.2. In the process of network training, the loss function of the model on the training set continues to decline and finally approaches 0, as shown in Fig. 7, reaching a minimum of 0.0019. The results show that the final model parameters are the better combination of parameters under the structure.

3.3.2 Model Validation and Prediction Result Analysis

Through the training of the model, the pre-processed data set is input into the model for prediction. The final prediction result and the actual production result curve are shown in Fig. 8.

It can be seen from the curve in the figure that the prediction curve obtained by the prediction model shows the same trend as the actual production curve of a single well. Although there is a certain lag in the prediction results, the overall curve fitting effect is in a good state, and the performance is the best in the early stage, and the error fluctuates greatly in the later stage. The results show that the prediction model of the system has a good short-term prediction effect.

Based on the principle of short-term and dynamic prediction, it calculates and analyzes the relative error range and fitting degree of the data in the initial stage of

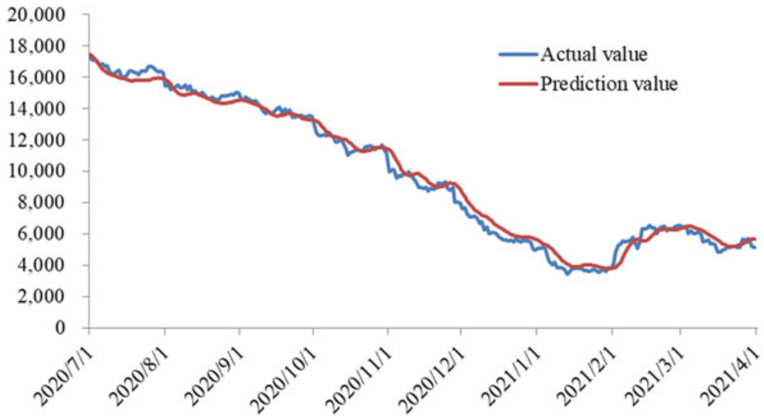


Fig. 8 Comparison of prediction results

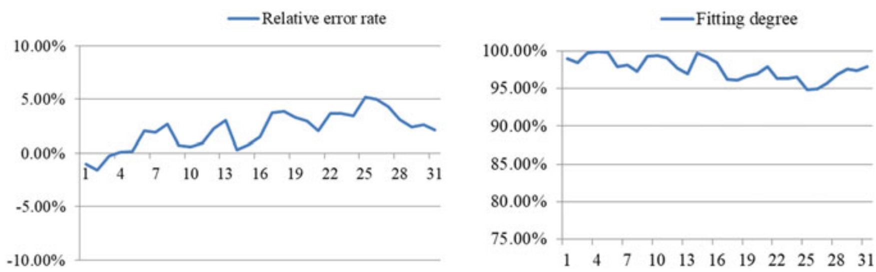


Fig. 9 Comparative analysis of results

the test set (i.e. the 31 day prediction result data in July 2020) from the perspective of error. As shown in Fig. 9, the relative error rate is basically within 5%, the curve fitting degree is basically above 95%, and the average fitting degree of the two curves is 97.70%. It can be seen that the state prediction module based on LSTM can achieve good short-term prediction results.

3.4 Online Decision Making

Different benefit limits proposed by oilfield companies for different single wells are used for production decision-making reference. It assumes that the oil production plant has set three economic benefit boundaries for this single well. As shown in Fig. 10, region I and region II are within the range of benefit wells, region III is within the range of inefficient wells, and Region IV is within the range of invalid wells.

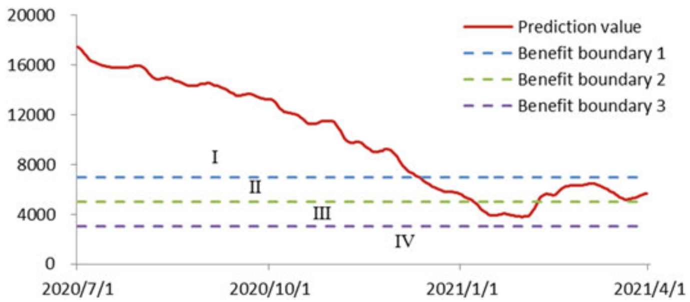


Fig. 10 Economic benefit limit of single well

It formulates relevant decision-making schemes from the relationship between the prediction curve and the three economic benefit boundaries:

(1) The stage in July 2020, as the main decision-making stage, is in the benefit well stage of region I. It is mainly to maintain the original production decision-making plan of the well, and the optimization of measures and schemes can be considered to expand the overall benefit in July.
(2) The period from August 2020 to the end of this year, as an auxiliary decision-making stage, is in the benefit well stage of region I and region II, but the economic benefit value shows an overall decline. The oil field needs to prepare measures and schemes based on the original production plan, and then make online adjustment and optimization according to the later dynamic prediction results, to slow down the decline of economic benefits of oil wells
(3) Since 2021, the economic benefit value of oil wells under the current prediction state fluctuates in the low efficiency and effective areas. The specific trend needs to be observed according to the later performance prediction, and the oil well may be inefficient or ineffective for a long time at this stage. When the effect of the optimized measures still cannot reach the economic benefit limit, it is necessary to consider shutting down the oil well. When the external environment changes, such as the oil price rises and the schemes effectively reach the production start-up limit, the restart decision of the oil well is made after the system online evaluation.

4 Conclusion

The production environment of oil well is complex and changeable, which is easily disturbed by external environmental factors and the production factors of oil well itself. Especially in the external uncertainty environment, oil production declines and production costs continue to rise in the middle and late stages of oilfield development. The data-driven decision paradigm combined with machine learning algorithm has become an effective means of oil well dynamic decision-making in the big data environment. In this paper, a dynamic data-driven online decision-making paradigm for oil wells is proposed. The long-short term memory network prediction model is used to explore the economic benefit trend of oil wells from massive production data, which provides a scientific basis for the decision-making of "shut down restart" of oil wells.

The results show that the prediction model based on long-short term memory network is effective under the dynamic data-driven decision paradigm. And the fitting degree of the short-term prediction results of the economic benefits of a single well has reached more than 95%, fully realizing the utility of the historical data value of the oil field. It solves the problem of strong assumptions under the traditional management decision paradigm, and provides a new idea for improving the economic benefits of single wells and the stable production process of oil enterprises in the middle and late stage of oilfield development into a collaborative decision-making process of data learning and optimal allocation of resources.

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Research on Risk Assessment of Natural Gas Supply in China Based on PSR

Liu Hui and Wang Zhao Qi

Abstract Natural gas is the cleanest kind of fossil energy that human beings have at present, and plays a very important role in human life. However, China's natural gas reserves are relatively insufficient. At this stage, the biggest challenge facing China is that the growth of natural gas production can not catch up with the growth of natural gas consumption. This forced China to import a large amount of natural gas to ease the domestic demand tension, but it also led to a new high of China's dependence on foreign natural gas. However, natural gas is one of the important strategic energy. It is closely related to people's lives and even enough to affect national security. The risk of natural gas supply is very important. In this paper, the risk of natural gas supply from 2017 to 2021 is analyzed by constructing the PSR model and using the fuzzy comprehensive analysis method. Find out the problems in the current natural gas supply and put forward reasonable solutions.

Keywords PSR model · Natural gas supply safety · Fuzzy comprehensive analysis method

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1 Introduction

Natural gas is the most clean and mature fossil energy in the world. Although the largest energy source in China is coal, with the urbanization process and the implementation of various policies of "coal to gas" in rural areas, the proportion of natural gas in China's energy share is rising. From 3.4% in 2008 to 7.8% in 2018, it increased by 129.41% [1].

Nowadays, China strives for progress while maintaining stable development. Compared with the previous years, the people's living standards have undergone earth shaking changes, and the quality of life has been continuously improved. In daily life, the use of natural gas is becoming more and more common [2]. China has a total population of 1.4 billion. Under the huge population base, China's total natural gas consumption ranks third in the world, accounting for 7.4% of the global market share, reaching a staggering $28 \times 108\ m^3$.

China's proved remaining recoverable reserves of natural gas rank seventh in the world, only $6.1 \times 1012\ m^3$. China's natural gas reserves account for only 3.1% of the world's proved remaining recoverable reserves. If divided by the population base, China's per capita proved remaining natural gas reserves are much lower than the international average, 0.44 per person $\times 108\ m^3$, ranking 38th in the world [3].

In addition to the shortage of natural gas reserves, the biggest challenge facing China is that the growth of natural gas production can not catch up with the growth of natural gas consumption, and the growth of total natural gas consumption is far greater than that of natural gas production. In 2018, there was a gap of about 154.75 million tons of standard coal in natural gas consumption compared with the total production [4].

In 2017, the problem of "gas shortage" faced by North China is one of the most direct manifestations that China's natural gas demand is far greater than supply. The most direct and effective measure to solve this problem is to import natural gas.

Today, China has become the largest natural gas importer, and the amount of natural gas that China needs to import every year is about $1254 \times 108\ m^3$, an increase of 31.7% compared with 2017. The degree of external dependence reached 45.3%, an increase of 6.2% points compared with 39.1% in 2017. Pipeline import and offshore LNG import are the main methods used to import natural gas in China. The natural gas volume imported through the natural gas pipeline is $479 \times 108\ m^3$, and the sources are relatively concentrated. 28.59% of the imported natural gas comes from Turkmenistan. The imported LNG volume transported by offshore LNG ship is $735 \times 108\ m^3$, and 33.96% of the imported LNG comes from Australia and Qatar [5].

At present, the importance of natural gas is self-evident. However, the per capita reserves of natural gas resources in China are not only far lower than those in developed countries in Europe and the United States, but also lower than the world average. Due to the huge population base, China's domestic natural gas resources security capacity is relatively weak. More importantly, as China has paid more and more attention to environmental protection in recent years, the implementation and implementation of policies such as "changing coal to gas" and "overcoming poverty" have continuously increased China's natural gas demand, which has greatly increased in a short period of time. This forced China to import a large amount of natural gas to ease domestic demand tension. This measure has led to China's high dependence on foreign natural gas in recent years.

Ji and Dengding made an overall evaluation on the supply risk of China's natural gas resources by forming a radar chart [6].

Guo, a scholar, studied the natural gas supply risk in China [7], systematically evaluated the natural gas security in China by using the PSR analysis model and the index weighting method, predicted the evolution of natural gas security in combination with the GM (1, 1) model, and diagnosed the obstacles impeding the optimization of natural gas security in China by using the obstacle degree model.

The scholar Chengzhu Gong proposed a comprehensive index for assessing the risk of natural gas supply in the Asia Pacific region to identify challenges and provide a benchmark for policy analysis in Asia Pacific countries [8].

Biresselioglu me evaluated the natural gas supply risk of 23 importing countries in different regions of the world from 2001 to 2013 [9]. The indicators used in the study are the quantity of imported natural gas and the number of natural gas suppliers.

During the safety evaluation of China's mineral resources, the author Yan Xiao carefully distinguished the nature of each influencing factor [10]. According to the logic of "cause effect response", each influencing factor is divided into three categories: pressure, state and response. Based on the PSR model, the safety evaluation index system of China's mineral resources is constructed.

Si Lin Bo, a foreign scholar, also used the PSR model [11] to evaluate the environment of Beijing, Tianjin and Hebei. According to the PSR model of international environmental governance, he established an evaluation system applicable to the results of environmental governance in Beijing, Tianjin and Hebei, and made an empirical analysis on the environmental governance data of 13 major cities in Beijing, Tianjin and Hebei from 2014 to 2016.

2 Risk Evaluation Index System of Natural Gas Supply in China

2.1 Evaluation Index System Model

In the natural gas supply risk assessment, considering the basic characteristics of China's natural gas supply situation, a PSR model index system for natural gas supply risk assessment is formed. Select appropriate and scientific evaluation methods and analyze various indicators in the evaluation system. The pressure index reflects the influencing factors of the current situation of natural gas supply risk, the status index reflects the current situation of natural gas supply risk, and the response index reflects the impact of changing the natural gas pressure index through some methods. Selecting PSR model to evaluate the security of natural gas supply and establishing an index system suitable for the conditions can better reflect the complex relationship among natural gas supply, economy and international situation.

2.2 Principles for Establishing Evaluation System and Index System

In order to get correct results, we must follow some principles when establishing the natural gas supply risk evaluation index system. However, due to different research problems, different PSR models, different indicators and different research indicators, there is no unified indicator set. However, after consulting the literature, I got a reasonable and applicable index establishment principle [12]. After summary, I have decided to abide by the following principles:

(1) Scientific principle [13]. In the process of evaluating the natural gas supply risk in China, the index system should directly and clearly reflect the real situation of the natural gas supply risk in China. The selected indicators should be objective, correctly reflect and reflect the deficiencies and risks of China's natural gas in the aspects of natural gas supply and demand, price, source and import dependence.
(2) Systematic principle [14]. The determination of the index system should meet the requirements of taking into account all aspects, and carefully consider the supply and demand relationship of natural gas, the price of natural gas, the risks that various industries related to natural gas will face, and the impact of natural gas supply on the daily life of our people.
(3) Feasibility principle. The selected indicators should be concise and clear enough, and the subsequent data analysis should be operable. The selected indicators must follow the existing statistical investigation system and be established within a scientific and reasonable range. In this way, the selected indicators are not only easy to collect data, but also more convincing.
(4) Real time principle. Natural gas supply is very vulnerable to the economic, military and current politics of the supplier country. Diplomatic events, historical and cultural differences and social events between countries will have a great impact on the security of natural gas supply. Therefore, when establishing the evaluation system, we should pay attention to the real-time nature of each data.
(5) Dominant principle. There are many factors and indicators that affect the risk of natural gas supply. If all of them are selected for evaluation, it is very difficult, not only the operation is complex, but also the relationship between the indicators cannot be analyzed clearly. Therefore, the indicators that have little impact on the system and no significant effect should be discarded, and the indicators with dominant factors and obvious impact on the system should be selected.

2.3 Selection of Evaluation Indicators

After analyzing the existing models of natural gas supply risk analysis, combined with the previous literature [15], this paper supplements and perfects the contents contained in the PSR index; In terms of pressure, in addition to economy, infrastructure and other basic aspects, possible factors such as natural gas transportation, policy adjustment and international trade friction are considered. In terms of response, it analyzes the response from three aspects: the government, the enterprise and the people. Comprehensively consider the scientificity, systematization, feasibility, real-time and dominance of each indicator data, and try to make the selected indicators reflect the current situation and risks of China's natural gas supply as much as possible, while minimizing the correlation between indicators. In the three directions of pressure, state and response, the following analysis is carried out.

(1) Pressure indicators. Under economic pressure, natural gas is not only one of the most important energy resources in China, but also the economic pillar for many enterprises to survive. For some companies such as ENN gas and China Resources gas, the risk of natural gas supply is closely related to the fate of these companies. The fluctuation of natural gas supply will greatly affect the benefits of these companies and China's economy. Social pressure, the accelerating urbanization process in China, and the per capita use of natural gas by Chinese people are soaring. Combined with China's huge population base, the demand for natural gas is soaring rapidly. Production pressure, transportation pressure and technological pressure refer to the defects, problems and costs of natural gas in production, transportation and technology. Political and international trade pressure means that when the import concentration and external dependence of China's natural gas supply are too high, China's natural gas security is vulnerable to the impact of international politics and trade.
(2) Status indicators. In terms of supply and demand, the growth rate of China's total natural gas consumption is far greater than that of natural gas production. In 2018, the gap between natural gas consumption and total production is about 154.75 million tons of standard coal. The state of natural gas resources, China's current lack of natural gas resources, natural gas production is far from meeting the demand. In terms of international trade, China's natural gas imports mainly import pipeline gas from Turkmenistan and LNG from Australia, which leads to high import concentration and high dependence on foreign countries.
(3) Response indicators. Policy response: every macro policy of the country has various impacts on China's natural gas supply. For example, after the "gas shortage" in 2017, the state introduced various policies to ensure the natural gas demand of residents. For example, various policies such as "pressure non residents to protect the people" should be adjusted to balance China's natural gas supply. Science and technology respond, science and technology is the primary productive force. Just like the "shale gas revolution" of the United States, the United States has become one of the world's top natural gas exporters from the former natural gas importer. The main reason is that the progress of shale

gas exploitation technology has greatly increased the shale gas production of the United States. Industry response: China's three major oil companies are the leaders in China's natural gas industry. Their every move is closely related to people's lives. Their business adjustment is of great significance to China's natural gas supply risk.

Finally, the method based on PSR was determined. After referring to the previous research results [16], combined with personal understanding, the selection of indicators was completed. See Table 1 for specific indicators, their meanings and units.

3 Risk Assessment of Natural Gas Supply in China

3.1 Evaluation and Analysis Ideas of Natural Gas Supply Risk in China

Selecting PSR model to evaluate the security of natural gas supply and establishing an index system suitable for the conditions can better reflect the complex relationship among natural gas supply, economy and international situation.

3.2 Sample Selection and Data Source

After selecting the indicators, select the samples. Considering that the natural gas supply is easily affected by the national situation and current affairs and politics, the five-year values from 2017 to 2021 are selected as the samples after fully considering the timeliness and feasibility. The basic data are mainly from the 2021 national statistical years and the 2012 edition of BP statistical yearbook of world energy. The specific data of each indicator from 2017 to 2021 are calculated, as shown in Table 2.

3.3 Evaluation Index Weighting

(1) Primary index weighting based on Analytic Hierarchy Process Compare the importance of P, S, R. This forms the matrix (see Table 3).

Consistency test: $\mathrm{CR} = \frac{\sum_{i=1}^{n} a_i CI_i}{\sum_{i=1}^{n} a_i RI_i}$, the calculated $\mathrm{cr} = 0.0193 < 0.10$, then the total hierarchy sorting is consistent. The calculation results are shown in Table 4.

(2) Two level index weighting based on entropy method.

Table 1 Meanings of indicators

First level criterion layer	Secondary index	Specific meaning of indicators	Indicator unit
Pressure			
	Population density P1	Total population/total area	10,000 people/km^2
	Natural gas resources per capita P2	Total natural gas reserves/total population	Ten thousand tons of standard coal/ten thousand people
	Population growth rate P3	(number at the end of the year—number at the beginning of the year)/annual average number	‰
	Market concentration of natural gas P4	Natural gas imports from the top 3 countries/total natural gas imports	%
Status			
	Engel's coefficient S1	Total food expenditure/total consumption expenditure	%
	Urbanization rate S2	Urban population/total population	%
	Natural gas supply and demand rate S3	Natural gas production/natural gas demand	%
	Natural gas reserve production ratio S4	Remaining recoverable reserves of natural gas at the end of the year/produced volume of natural gas in the year	%
	Natural gas import dependency S5	Net natural gas imports/total national energy consumption	%
Response			
	Natural gas consumption ratio R1	Total natural gas consumption/total national energy consumption	%
	Gas consumption population growth rate R2	(population using natural gas in the current year/population using natural gas in the previous year) − 1	%
	Natural gas consumption R3 required for 100 million yuan GDP	Ratio of natural gas consumption to regional GDP	%

(continued)

Table 1 (continued)

First level criterion layer	Secondary index	Specific meaning of indicators	Indicator unit
	Natural gas consumption intensity R4	Ratio of total national natural gas consumption to total GDP	%

Table 2 2017–2021 indicators

Index year	2017	2018	2019	2020	2021
Population density P1 (person/[km]^2)	142.4	143.1	144.0	144.8	145.3
Per capita natural gas resource P2 (10,000 tons of standard coal/10,000 people)	0.124342	0.126223	0.130135	0.139265	0.148598
Population growth rate P3 (%)	0.005191	0.004947	0.005851	0.005302	0.003798
Natural gas market concentration P4 (%)	68.571	72.464	79.463	74.143	69.341
Engel's coefficient S1 (%)	28.1434	28.4701	28.1697	29.4593	29.6688
Urbanization rate S2 (%)	54.77	56.1	57.35	58.52	59.58
Natural gas supply and demand ratio S3 (%)	70.0743	68.4063	66.5929	61.6587	57.2917
Natural gas reserve production ratio S4 (%)	28.8875946	38.9153	39.27723	37.08213	34.62132
Natural gas import dependency S5 (%)	15.312	21.558	28.894	31.600	32.200
Natural gas consumption ratio R1 (%)	5.7	5.9	6.2	7.0	7.8
Gas consumption population growth rate R2 (‰)	0.18988	0.23708	0.21796	0.19993	0.17791
Natural gas consumption of RMB 100 million GDP R3 (RMB 100 million/ten thousand tons of standard coal)	26.45540499	26.94291	27.27805	26.12029	24.78215
Natural gas consumption intensity R4 (%)	0.024	0.025	0.025	0.026	0.025

Table 3 Relative importance of PSR

A	P	S	R
P	1	3	5
S	1/3	1	3
R	1/5	1/3	1

Table 4 Consistency inspection

A	P	S	R	W
P	1	3	5	0.2583
S	1/3	1	3	0.1047
R	1/5	1/3	1	0.6370

The maximum characteristic root t = 3.0385, ci = 0.0193, cr = 0.0371, the consistency of this matrix is acceptable

The entropy method is used to calculate the weight of China's natural gas supply risk utilization safety subsystem and the total weight. The results are shown in Table 5.

Table 5 Weight of risk subsystem of natural gas supply in China

First level criterion layer	Secondary index	Subweight
Pressure		
	Population density P1	0.26724
	Natural gas resources per capita P2	0.21921
	Population growth rate P3	0.26724
	Market concentration of natural gas P4	0.24630
Status		
	Engel's coefficient S1	0.0558
	Urbanization rate S2	0.6528
	Natural gas supply and demand rate S3	0.1283
	Natural gas reserve production ratio S4	0.0644
	Natural gas import dependency S5	0.0987
Response		
	Natural gas consumption ratio R1	
	Gas consumption population growth rate R2	0.2155
	Natural gas consumption R3 required for 100 million yuan GDP	0.2415
	Natural gas consumption intensity R4	0.2992

3.4 Evaluate the Risk of Natural Gas Supply in China

In order to evaluate the risk of natural gas supply, the main problem is that the risk of natural gas supply is complex and fuzzy, so it is difficult to describe it with an accurate mathematical model. A comprehensive application of fuzzy mathematics is fuzzy comprehensive evaluation, which is suitable for the study of this complex and fuzzy object.

(1) Classification of evaluation index classification standards

Here, a fuzzy comprehensive evaluation is made on the risk of natural gas supply in China. We should first determine the evaluation grade [17] and see Table 6 for the classification of grades.

The specific classification basis is shown in Table 7.

(2) Establishment of membership function and single factor evaluation

Set c_i is the minimum value of index u in the index sample, d_i is the maximum value of index u, m_i is the average value of index u. The membership function of positive indicators is as follows:

$$v_{1ij}(u) = \begin{cases} 1, & u \geq d_i \\ (u - m_i)/(d_i - m_i), & u \in [m_i, d_i] \\ 0, & others \end{cases} \tag{1}$$

$$v_{2ij}(u) = \begin{cases} (u - c_i)/(m_i - c_i), & u \in [c_i, m_i] \\ (u - d_i)/(m_i - d_i), & u \in [m_i, d_i] \\ 0, & others \end{cases} \tag{2}$$

$$v_{3ij}(u) = \begin{cases} 1, & u \geq c_i \\ (u - m_i)/(c_i - m_i), & u \in [c_i, m_i] \\ 0, & others \end{cases} \tag{3}$$

The membership function of the reverse index is constructed as follows:

Table 6 Risk level of natural gas supply in China

Level	Meaning
1	Security
2	Basic safety
3	Unsafe
4	Seriously unsafe
5	Crisis is coming

Table 7 Basis for risk classification of natural gas supply in China

Index	Safety level				
	Crisis is coming	Seriously unsafe	Unsafe	Basic safety	Security
Population density P1	>300	150–300	50–150	15–50	<15
Natural gas resources per capita P2	<0.1	0.1–0.3	0.3–0.5	0.5–0.7	>0.7
Population growth rate P3	>15	12–15	10–12	8–10	<8
Market concentration of natural gas P4	>90	80–90	70–80	60–70	<60
Engel's coefficient S1	<10	10–20	20–30	30–40	<40
Urbanization rate S2	<20	20–35	35–50	50–70	>70
Natural gas supply and demand rate S3	<50	50–70	70–100	100–130	>130
Natural gas reserve production ratio S4	<30	30–40	40–50	50–60	>60
Natural gas import dependency S5	>50	40–50	30–40	20–10	<10
Natural gas consumption ratio R1	>20	15–20	10–15	5–10	<5
Gas consumption population growth rate R2	>1	0.75–1	0.5–0.75	0.25–0.5	<0.5
Natural gas consumption R3 required for 100 million yuan GDP	>40	30–40	20–30	10–20	<10
Natural gas consumption intensity R4	>0.5	0.1–0.5	0.05–0.1	0.02–0.1	<0.02

$$v_{1ij}(u) = \begin{cases} 1, & u \le c_i \\ (u - m_i)/(c_i - m_i), & u \in [c_i, m_i] \\ 0, & others \end{cases} \tag{4}$$

$$v_{2ij}(u) = \begin{cases} (u - c_i)/(m_i - c_i), & u \in [c_i, m_i] \\ (u - d_i)/(m_i - d_i), & u \in [m_i, d_i] \\ 0, & others \end{cases} \tag{5}$$

$$v_{3ij}(u) = \begin{cases} 1, & u \le d_i \\ (u - m_i)/(d_i - m_i), & u \in [m_i, d_i] \\ 0, & others \end{cases} \tag{6}$$

(3) Combined with the data of each indicator from 2017 to 2021, the annual single factor evaluation membership table is obtained through calculation. See Tables 8, 9, 10, 11, 12, 13 and 14.

(4) Comprehensive evaluation index

Combining the membership degree of single factor evaluation with its weight, the calculation results of P, s and R are as follows (Tables 15, 16 and 17):

Score each grade from 1 to 5, taking $u_1 = 1$, $u_2 = 2$, $u_3 = 3$, $u_4 = 4$, $u_5 = 5$, the comprehensive evaluation formula is as follows (Table 18)

Table 8 Membership table of single factor evaluation in 2017

Evaluating indicator	u_1	u_2	u_3	u_4	u_5
Population density P1	0	0.038	0.962	0	0
Natural gas resources per capita P2	0.439145	0.560855	0	0	0
Population growth rate P3	0	0	0	0.0667	0.9333
Market concentration of natural gas P4	0	0	0	0.92855	0.07145
Engel's coefficient S1	0	0	0.635723	0.364277	0
Urbanization rate S2	0	0	0.465929	0.534071	0
Natural gas supply and demand rate S3	0	0.498762	0.501238	0	0
Natural gas reserve production ratio S4	0.98145	0.01855	0	0	0
Natural gas import dependency S5	0	0	0	0.1172	0.8828
Natural gas consumption ratio R1	0	0	0	0.57	0.43
Gas consumption population growth rate R2	0	0	0	0.12024	0.87976
Natural gas consumption R3 required for 100 million yuan GDP	0	0.17723	0.82277	0	0
Natural gas consumption intensity R4	0	0	0	0.525	0.475

Table 9 Membership table of single factor evaluation in 2018

Evaluating indicator	u_1	u_2	u_3	u_4	u_5
Population density P1	0	0.0345	0.9655	0	0
Natural gas resources per capita P2	0.434443	0.565558	0	0	0
Population growth rate P3	0	0	0	0.0667	0.9333
Market concentration of natural gas P4	0	0	0.6232	0.3768	0
Engel's coefficient S1	0	0	0.641168	0.358832	0
Urbanization rate S2	0	0	0.456429	0.543571	0
Natural gas supply and demand rate S3	0	0.960158	0.039843	0	0
Natural gas reserve production ratio S4	0	0.945765	0.054235	0	0
Natural gas import dependency S5	0	0	0	0.5779	0.4221
Natural gas consumption ratio R1	0	0	0	0.59	0.41
Gas consumption population growth rate R2	0	0	0	0.02584	0.97416
Natural gas consumption R3 required for 100 million yuan GDP	0	0.152855	0.847146	0	0
Natural gas consumption intensity R4	0	0	0	0.53125	0.46875

Table 10 Membership table of single factor evaluation in 2019

Evaluating indicator	u_1	u_2	u_3	u_4	u_5
Population density P1	0	0.03	0.97	0	0
Natural gas resources per capita P2	0.424663	0.575338	0	0	0
Population growth rate P3	0	0	0	0.0667	0.9333
Market concentration of natural gas P4	0	0.02685	0.97315	0	0
Engel's coefficient S1	0	0	0.636162	0.363838	0
Urbanization rate S2	0	0	0.4475	0.5525	0
Natural gas supply and demand rate S3	0	0.914823	0.085178	0	0
Natural gas reserve production ratio S4	0	0.963862	0.036138	0	0
Natural gas import dependency S5	0	0	0.0553	0.9447	0
Natural gas consumption ratio R1	0	0	0	0.62	0.38
Gas consumption population growth rate R2	0	0	0	0.06408	0.93592
Natural gas consumption R3 required for 100 million yuan GDP	0	0.136098	0.863903	0	0
Natural gas consumption intensity R4	0	0	0	0.53125	0.46875

Table 11 Membership table of single factor evaluation in 2020

Evaluating indicator	u_1	u_2	u_3	u_4	u_5
Population density P1	0	0.026	0.974	0	0
Natural gas resources per capita P2	0.401838	0.598163	0	0	0
Population growth rate P3	0	0	0	0.0667	0.9333
Market concentration of natural gas P4	0	0	0.70715	0.29285	0
Engel's coefficient S1	0	0	0.657655	0.342345	0
Urbanization rate S2	0	0	0.439143	0.560857	0
Natural gas supply and demand rate S3	0	0.791468	0.208533	0	0
Natural gas reserve production ratio S4	0	0.854107	0.145894	0	0
Natural gas import dependency S5	0	0	0.58000	0.42000	0
Natural gas consumption ratio R1	0	0	0	0.7	0.3
Gas consumption population growth rate R2	0	0	0	0.10014	0.89986
Natural gas consumption R3 required for 100 million yuan GDP	0	0.193986	0.806015	0	0
Natural gas consumption intensity R4	0	0	0	0.5375	0.4625

Table 12 Membership table of single factor evaluation in 2021

Evaluating indicator	u_1	u_2	u_3	u_4	u_5
Population density P1	0	0.02350	0.97650	0	0
Natural gas resources per capita P2	0.378505	0.621495	0	0	0
Population growth rate P3	0	0	0	0.0667	0.9333
Market concentration of natural gas P4	0	0	0.03295	0.96705	0
Engel's coefficient S1	0	0	0.661147	0.338853	0
Urbanization rate S2	0	0	0.431571	0.568429	0
Natural gas supply and demand rate S3	0	0.682293	0.317708	0	0
Natural gas reserve production ratio S4	0	0.731066	0.268934	0	0
Natural gas import dependency S5	0	0	0.61000	0.39000	0
Natural gas consumption ratio R1	0	0	0.22	0.78	0
Gas consumption population growth rate R2	0	0	0	0.14418	0.85582
Natural gas consumption R3 required for 100 million yuan GDP	0	0.260893	0.739108	0	0
Natural gas consumption intensity R4	0	0	0	0.53125	0.46875

Table 13 Membership of P, s and R systems to evaluation grades in 2017

System	u_1	u_2	u_3	u_4	u_5
Pressure subsystem p	0.109786	0.149714	0.2405	0.248813	0.251188
Status subsystem s	0.19629	0.103462	0.320578	0.20311	0.17656
Response subsystem R	0.00000	0.044308	0.205693	0.30381	0.44619
Total system	0.102025	0.099161	0.25559	0.251911	0.291313

Table 14 Membership of P, s and R systems to evaluation grades in 2018

System	u_1	u_2	u_3	u_4	u_5
Pressure subsystem p	0.108611	0.150015	0.397175	0.110875	0.233325
Status subsystem s	0.000000	0.381186	0.238336	0.296060	0.084410
Response subsystem R	0.000000	0.038214	0.211787	0.286773	0.463228
Total system	0.036204	0.189805	0.282432	0.231236	0.260324

Table 15 Membership of P, s and R systems to evaluation grades in 2019

System	u_1	u_2	u_3	u_4	u_5
Pressure subsystem p	0.106176	0.158037	0.485778	0.016665	0.233345
Status subsystem s	0.000000	0.375737	0.252056	0.372208	0.000000
Response subsystem R	0.000000	0.034025	0.215976	0.303833	0.446168
Total system	0.035389	0.18927	0.31794	0.230905	0.226498

Table 16 Membership of P, s and R systems to evaluation grades in 2020

System	u_1	u_2	u_3	u_4	u_5
Pressure subsystem p	0.10046	0.156041	0.420288	0.089888	0.233325
Status subsystem s	0.00000	0.329115	0.406245	0.26464	0.000000
Response subsystem R	0.00000	0.048497	0.201504	0.33441	0.41559
Total system	0.033487	0.177884	0.342679	0.229646	0.216305

Table 17 Membership of P, s and R systems to evaluation grades in 2021

System	u_1	u_2	u_3	u_4	u_5
Pressure subsystem p	0.094626	0.161249	0.252363	0.258438	0.233325
Status subsystem s	0.000000	0.282672	0.457872	0.259456	0.000000
Response subsystem R	0.000000	0.065223	0.239777	0.363858	0.331143
Total system	0.031542	0.169715	0.316671	0.293917	0.188156

Table 18 Scoring table for comprehensive assessment of natural gas supply risk in China

System	2017	2018	2019	2020	2021
Pressure subsystem p	3.381906	3.210291	3.112949	3.199583	3.37459
Status subsystem s	3.060188	3.083719	2.996474	2.935525	2.976784
Response subsystem R	4.151885	4.175021	4.16215	4.117096	3.960924
Total system	3.531326	3.489674	3.423859	3.417401	3.437433

$$\mathrm{a} = \frac{\sum_{j=1}^{5} a_i b_j^k}{\sum_{j=1}^{5} b_j^k} \quad (7)$$

where, the greater the value of a, the greater the risk of natural gas supply.

(5) Analysis of evaluation results

Process the data in to form the following two line charts 1 and 1. We can clearly see the trend of China's natural gas supply risk in recent five years from the line chart (Fig. 1).

Analysis of pressure subsystem P evaluation results. In the assessment of natural gas supply risk in China, the comprehensive scores of pressure subsystem P from 2017 to 2021 are 3.381906, 3.210291, 3.112949, 3.19983 and 3.37459 respectively. It can be seen that there is a downward trend from 2017 to 2019, but there is an upward trend from 2017 to 2018.

State subsystem s evaluation result analysis. In the assessment of natural gas supply risk in China, the comprehensive scores of state subsystem s from 2017 to 2021 are 3.060188, 3.083719, 2.996474, 2.935525 and 2.976784 respectively. It shows an upward trend from 2017 to 2018 and a downward trend from 2019 to 2021.

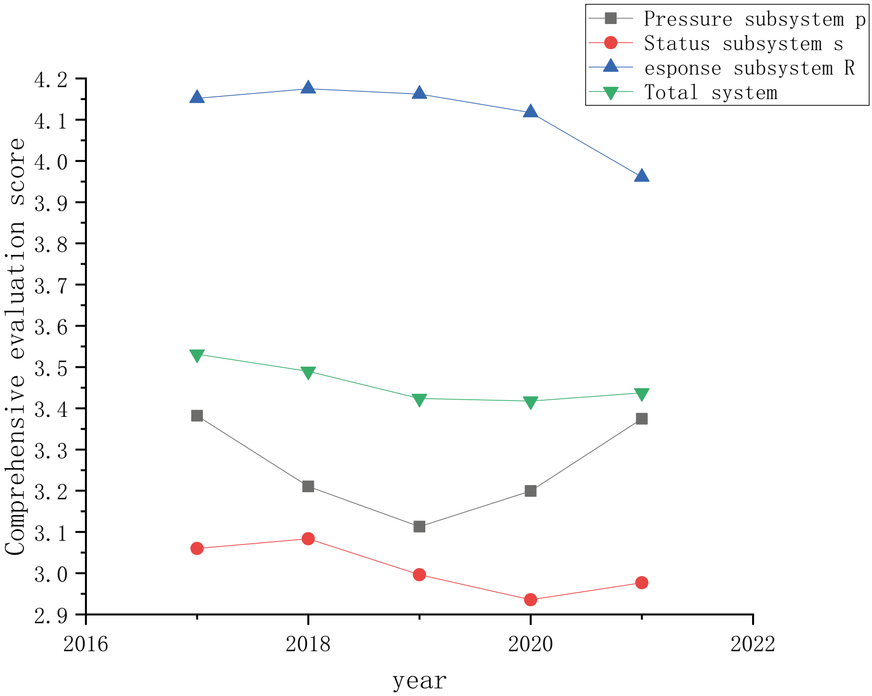

Fig. 1 Comprehensive evaluation scores of the overall system

Response subsystem r evaluation result analysis. In the assessment of natural gas supply risk in China, the comprehensive scores of response subsystem r from 2017 to 2021 are 4.151885, 4.175021, 4.16215, 4.117096 and 3.960924 respectively. It can be seen that there is a downward trend from 2017 to 2018, but it will not decline but rise from 2019 to 2021.

Overall system evaluation results. In the assessment of natural gas supply risk in China, the comprehensive scores of the overall system assessment results from 2017 to 2021 are 3.531326, 3.489674, 3.423859, 3.417401 and 3.437433 respectively. It can be seen that from 2017 to 2020, the overall decline has been continuous, but in 2021, compared with 2017, it has not decreased, but increased.

4 Countermeasures

4.1 Enhance LNG Reserve Capacity and Relieve China's Natural Gas Supply Pressure

Considering the P (pressure) in PSR, accelerate the construction of LNG receiving facilities and enhance China's LNG strategic reserve capacity. After the national pipe network companies play a practical role, provinces and cities should accelerate the process of overall planning of natural gas pipelines, the distribution and construction of LNG terminals, liberalize the use and construction of these natural gas infrastructure, and actively encourage the influx of private capital. Liberalize the construction of underground gas storage and LNG terminal, vigorously build natural gas storage tanks inland, mobilize the enthusiasm of various regions, build natural gas pipeline network, and form a perfect gas storage system. This will greatly improve China's natural gas storage peak shaving and natural gas receiving and turnover capacity, and greatly reduce the receiving and storage turnover cost of each natural gas company. This will greatly improve China's LNG strategic reserve capacity, relieve China's natural gas supply pressure, and greatly protect China's natural gas supply risk.

4.2 Develop Renewable Energy and Change the Current Situation of China's Energy Pattern

Considering the S (state) in PSR, the state should strengthen the research investment in renewable resources and accelerate the development of renewable energy. Oil and natural gas are primary energy sources, which are not inexhaustible. They will always decline. China is a "poor oil and gas" country. The per capita oil and natural gas resources in China are insufficient to support the realization of the "Chinese dream" of our people. Excessive dependence on natural gas imports has always been a hidden danger for China's economic take-off and national review. If renewable energy such as wind energy and tidal energy are developed, they will improve China's energy structure, improve the security of China's natural gas supply, and help to ensure China's energy security [18].

4.3 Strengthen Investment in Pipe Network Construction and Interconnection, and Actively Respond

Consider from R (response) in PSR. Optimize the planning and layout of cross provincial long-distance pipelines, strengthen the exchange of information between cities and provinces, and increase investment in the construction of natural gas pipeline networks. In terms of the operation and scheduling relationship between the inter provincial pipeline network and the provincial long-distance transmission pipeline network, we should achieve overall coordination and advance and retreat at the same time. Realize the separation of natural gas transportation from sales in the region, prohibit the unified purchase and marketing of natural gas transportation enterprises, inject vitality into the market and avoid the formation of hidden monopoly. Further open infrastructure such as pipelines and LNG terminals to allow more enterprises to participate in production and operation activities. Strengthen the supervision of pipeline transportation links, ensure safe operation, improve operation efficiency, ensure that services are in place and ensure reasonable income [19].

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Prediction of Comprehensive Pollution Index in Shandong Province Based on LSTM Neural Network

Yu Yu

Abstract Economic growth is an important factor affecting environmental pollution. It is of great significance to effectively control and prevent environmental pollution by using a variety of economic factor indicators in a certain area to predict the local pollution level. In this paper, a comprehensive pollution index prediction model based on deep learning method is proposed and verified by using the relevant data of Shandong Province over the years. Firstly, the entropy weight method is used to construct the comprehensive pollution index, and the nonlinear processing ability of LSTM neural network to multivariable time series data is used to construct the prediction model to realize the prediction of the comprehensive pollution index. Compared with the traditional cyclic neural network model and BP neural network model, the results show that the LSTM neural network model has the best prediction effect, and with the passage of time, the LSTM model can effectively learn the time series information in the time series, reflecting the advantages of the model in predicting the comprehensive pollution index.

Keywords Economic growth · Composite pollution index · Deep learning · LSTM neural network · Prediction

1 Introduction

With the continuous progress of reform and opening up, China's economic development has made remarkable achievements in the world. A large number of foreign capital have poured in to promote the upgrading of industrial structure and the development of manufacturing industry. At the same time, the environmental problems caused by the rapid economic development are becoming increasingly serious. The 19th National Congress of the Communist Party of China proposed to speed up the reform of the ecological civilization system and build a beautiful China, requiring efforts to solve outstanding environmental problems and promote green development.

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Under the background of the current national efforts to build ecological civilization, coordinating the balanced development of economic growth and environmental pollution prevention and control has always been a continuous concern of China and all provinces. The existing literature has done a lot of research on related issues, including the relationship between economic growth and environmental pollution, how foreign direct investment affects environmental pollution, and the prediction of individual pollutants.

At first, Grossman and Krueger studied the relationship between economic growth and environmental pollution. Grossman and Krueger learned from Kuznets' view that there is an inverted "U" relationship between income distribution and economic growth, and called it the Environmental Kuznets curve [1]. Later, most domestic and foreign studies on the relationship between economic growth and environmental pollution were carried out around the verification of the Environmental Kuznets curve, and the conclusions were different [2–5]. With the introduction of a large number of foreign capital, its impact on the environment can not be ignored. Scholars began to introduce foreign direct investment (FDI) into the study of environmental pollution. On the one hand, the introduction of foreign capital exacerbated China's environmental pollution, and on the other hand, the resulting advanced technology is conducive to pollution control. Therefore, the academia has formed two popular hypotheses of "pollution paradise" and "pollution halo" [6–9]. Of course, the relationship between economic growth and environmental pollution, as well as the effect of foreign direct investment, will vary due to different factors such as regional characteristics, development stages, time span, spatial agglomeration, measurement methods and the selection of pollutant indicators [10, 11]. Therefore, there are a large number of different conclusions and even completely contradictory views in the study of such issues. In the existing literature, the most research on the prediction of environmental pollution is the prediction of the concentration of air pollutants such as PM2.5. At present, the research focus is mainly on improving the prediction method to improve the prediction accuracy[12–17]. In addition, there is little research on the prediction of the emission and concentration of other pollutants.

At present, many scholars mostly use the model driven method in the study of the impact of economic factors on environmental pollution, and the conclusions are different, and whether the model driven method can make full use of historical data remains to be discussed. And most of the studies focus on the nonlinear relationship between economic growth, FDI and environmental pollution, and rarely continue to the prediction and prevention of environmental pollution. In recent years, with the continuous application and development of deep learning, LSTM neural network model has been widely used, and has been successfully applied in the fields of natural language processing [18], traffic accident prediction [19], unit commitment intelligent decision-making [20] and load forecasting [21, 22]. However, in the field of economic management, the application of in-depth learning is still very limited, and the applied research on pollution prediction is even less.

In view of the above problems, this paper intends to adopt the idea of data-driven. Taking the relevant data of Shandong Province as an example, this paper proposes a comprehensive pollution index prediction model based on in-depth learning (LSTM), predicts the pollution situation by learning the time series relationship existing in the economic index data of Shandong Province over the years, and compares and verifies other machine learning models to highlight the advantages of LSTM model, so as to make further progress on the basis of previous studies, To provide a feasible solution to the problem of pollution prediction and prevention, and promote the application of in-depth learning method in economic management research.

2 Method

2.1 Recurrent Neural Network

Recurrent neural network (RNN) is very effective for data with sequence characteristics. It can mine time sequence information and semantic information in data [23]. Its structure is shown in Fig. 1. It is similar to ordinary fully connected neural network, including input layer, hidden layer and output layer. Different from the fully connected neural network, the hidden layer neurons of the RNN are connected, and the input of the hidden layer neurons includes the input of the input layer and the output of the hidden layer at the previous time. That is, the hidden layer at each time is determined not only by the input layer at the current time, but also by the hidden layer at the previous time. The forward propagation process can be expressed by formulas (1) and (2).

$$O_t = g(V \cdot S_t) \tag{1}$$

$$S_t = f(U \cdot X_t + W \cdot S_{t-1} + b) \tag{2}$$

where X_t represents the input of the input layer at time t, S_{t-1} represents the input of the hidden layer at time $t-1$, U, V and W represent each weight matrix respectively,

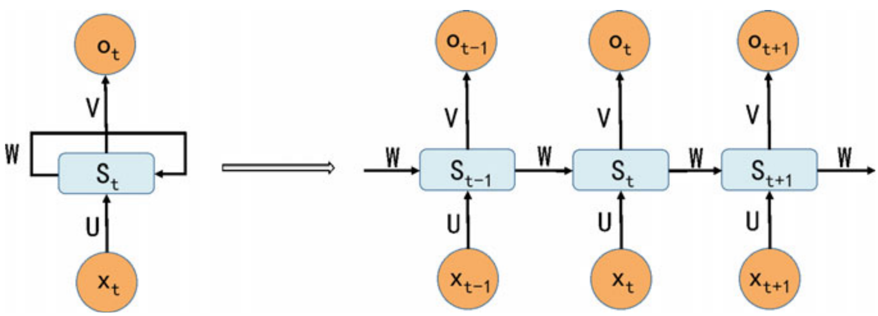

Fig. 1 Structure of the RNN

b represents the offset term, f is the activation function $sigmoid$, and O_t represents the output of the hidden layer at time t.

RNN can be regarded as a neural network propagating in the time dimension. In principle, RNN can store past inputs and produce current outputs. This feature can be used for the control of time series prediction process. There are many time steps between the relevant input and the expected output. In this case, the gradient descent learning method often takes a lot of time. However, with the passage of time, the ability of the later time nodes to perceive the information of the previous time nodes will be weakened, and the problem of "gradient disappearance" will occur [24].

2.2 *Long and Short Term Memory Neural Network*

Long short term memory (LSTM) neural network is an improved type based on RNN proposed by Hochreiter et al. [25]. It replaces hidden layer neurons with memory neurons, which can effectively solve the problem of gradient disappearance caused by long sequence. The structure of LSTM includes input gate, forgetting gate, output gate and a memory unit. Its internal structure is shown in Fig. 2.

Forgotten gate formula:

$$f_t = \sigma(\omega_{fx} x_t + \omega_{fh} h_{t-1} + b_f) \tag{3}$$

Input gate formula:

$$i_t = \sigma(\omega_{ix} x_t + \omega_{ih} h_{t-1} + b_i) \tag{4}$$

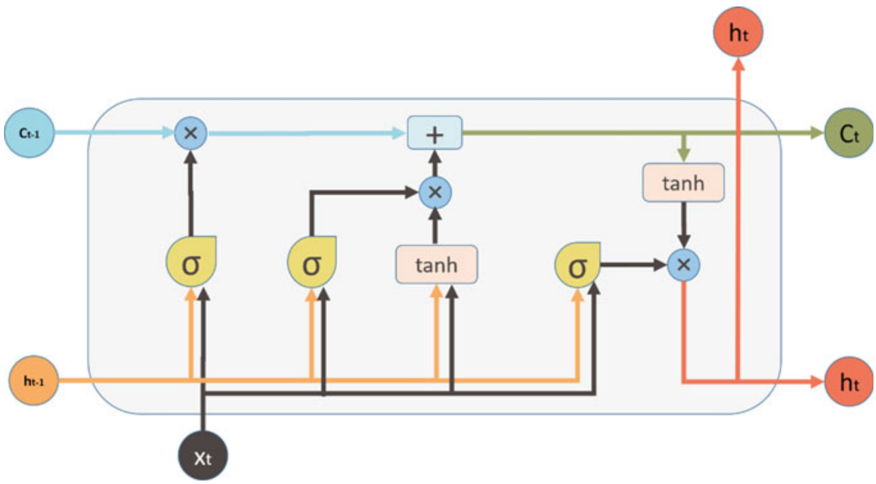

Fig. 2 Structure of LSTM

Memory unit temporary status:

$$c_t^{'} = tanh(\omega_{cx}x_t + \omega_{ch}h_{t-1} + b_c) \tag{5}$$

Update memory unit:

$$c_t = f_t \cdot c_{t-1} + i_t \cdot c_t^{'} \tag{6}$$

Output gate formula:

$$o_t = \sigma(\omega_{ox}x_t + \omega_{oh}h_{t-1} + b_o) \tag{7}$$

Hidden layer calculation formula:

$$h_t = o_t \cdot tanh(c_t) \tag{8}$$

where ω represents each weight matrix, x_t and h_{t-1} represent the input vector considering the time characteristics and the state of the hidden layer at the previous time, b represents the bias parameter, c_{t-1} represents the state of the $t-1$ time memory unit, σ is the activation function, and $tanh$ is the hyperbolic tangent activation function.

The three gates of LSTM jointly control the entry and exit of information. The input gate controls how much information is entered into the memory cells, the forgetting gate controls how much information is retained in the memory cells, and the input gate controls how much information is output by the memory cells. This special structure of LSTM can effectively solve the problem of gradient disappearance in the training process.

3 Indicator Selection and Data Source

3.1 Data Sources and Indicators

Considering the availability and integrity of the data, this paper selects the data of Shandong Province from 1999 to 2018 as the sample. The original data are from China Statistical Yearbook, Shandong statistical yearbook and China urban statistical yearbook. The relevant data indicators used in the experiment are selected as follows.

Output level (GDP): The output level is the most commonly used indicator to measure the economic growth of a country or region, and environmental pollution is closely related to the level of economic development. This paper uses the regional GDP of Shandong Province over the years to measure the output level.

Foreign direct investment (FDI): The foreign direct investment is an important factor affecting China's environmental pollution. Especially after the reform and opening up, a large number of foreign capital has entered China, which on the one hand intensifies the degree of environmental pollution, and on the other hand brings advanced technology to control pollution. This paper uses the actual amount of foreign capital to measure the level of investment.

Industrial structure (Sec): The industrial pollution emissions account for the majority of the total pollution emissions. The optimization and adjustment of industrial structure has reduced the proportion of the secondary industry and the pressure on resources and environment. Therefore, the industrial structure will also affect the degree of pollution. This paper uses the proportion of the output value of the secondary industry in the regional GDP to measure.

Population density (Pop): The more densely populated places tend to have more frequent economic activities and higher degree of industrialization, so the population density of an area will also affect the pollution level.

Technical level (K/L): the improvement of technical level can help enterprises improve resource utilization, use cleaner production technologies and reduce pollutant emissions. This paper uses the capital labor ratio to measure the technological level. The higher the capital labor ratio, the higher the technological level. The physical capital stock (K) is estimated using the perpetual inventory method used by Zhang Jun and others [26], and the depreciation rate is 9.6%. The labor force level (L) is measured by the number of employees at the end of each year.

Environmental awareness (Inv): the stronger the environmental awareness of residents and governments in a region, the more conducive it is to reduce the pollution level. This paper uses the investment in environmental pollution control to measure the environmental awareness.

Comprehensive index of environmental pollution (Pol): the comprehensive index of environmental pollution is calculated by selecting four pollutant emission indicators, namely, industrial wastewater emission, industrial sulfur dioxide emission, industrial smoke emission and industrial solid waste emission, and the entropy weight method, which can more truly express the comprehensive pollution level of Shandong Province than using a single pollutant emission.

In this study, the first six indicators will be used as the input variables of the model, the comprehensive index of environmental pollution will be used as the prediction indicators, and part of the data will be selected for the training and testing of the model.

3.2 Indicator Correlation Analysis

The correlation between the indicators will affect the experimental results. If the selected input variables are not related to the prediction variables or the information between the input variables, the prediction effect of the model will be affected. In this paper, Pearson correlation coefficient and Spearman correlation coefficient are used to judge the correlation between variables.

Pearson correlation coefficient calculation formula:

$$r_p = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \tag{9}$$

where $\overline{x}$ and $\overline{y}$ are the mean values of variables X and Y respectively, r_p is the correlation coefficient of the two variables, and the r_p is between -1 and 1. The closer r_p is to 1, the stronger the positive correlation is, and the closer r_p is to -1, the stronger the negative correlation is.

Spearman correlation coefficient [27] calculation formula:

$$\rho = \frac{\sum_{i=1}^{n}(R_i - \overline{R})(S_i - \overline{S})}{\sqrt{\sum_{i=1}^{n}(R_i - \overline{R})^2 \sum_{i=1}^{n}(S_i - \overline{S})^2}} \tag{10}$$

where R_i and S_i are respectively the order of the positions of variables R and S in their respective sequential arrangement samples, that is, the rank. $\overline{R}$ and $\overline{S}$ are the mean values of R and S respectively. Similar to Pearson correlation coefficient, the value of ρ is between -1 and 1. The closer ρ is to 1, the stronger the positive correlation is. The closer ρ is to -1, the stronger the negative correlation is.

The correlation between variables is calculated by using the correlation thermodynamic diagram. The calculation results are shown in Figs. 3 and 4. Except that the proportion of the secondary industry in GDP (Str) has a negative correlation with other indicators, other indicators have a strong positive correlation. Finally, it can be determined that the selected six independent variable indicators and one output indicator can be used as the sample data of this experiment.

4 Model Construction and Empirical Analysis

4.1 Data Preprocessing

In the six input indexes and one prediction index selected in this paper, the units and dimensions of each index are different, so they can not be directly used in the experiment. In order to eliminate the influence of dimension, it is necessary to standardize each index and transform the original data. The data standardization formula is:

$$X = \frac{x - min}{max - min} \tag{11}$$

where x is the original data, max is the maximum value of features in the sample data, min is the minimum value of features in the sample data, and X is the normalized data.

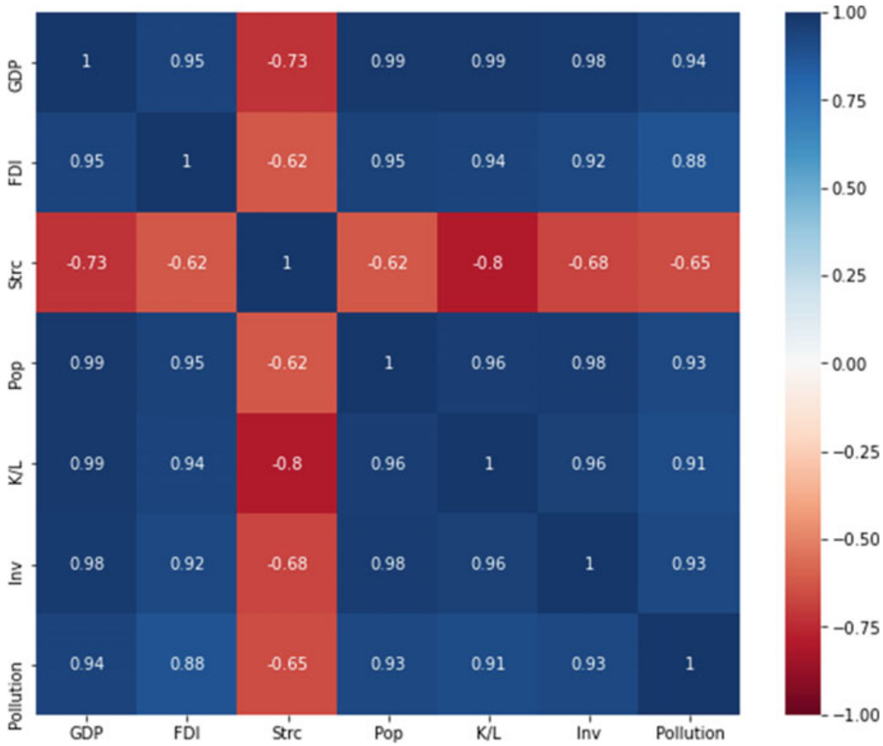

Fig. 3 Pearson correlation heatmap

4.2 Model Construction

There are two main parameters to determine the LSTM model, one is the number of hidden layer nodes, the other is the depth of the model, that is, the number of LSTM layers. The number of hidden layers and the number of nodes in each layer will affect the nonlinear processing ability and complexity of the network. The number of layers and nodes of each layer are too few, the learning ability of the network is insufficient, and the fitting effect of the data is not good; Too many layers and nodes in each layer will improve the analysis ability of the network, but it will increase the complexity of network training and easily lead to the problem of over fitting.

There is no clear theory to guide the determination of the number of hidden layer nodes. Generally, the following formula will be used in most literatures to determine the range of the number of hidden layer nodes:

$$N = \sqrt{n + m} + a \tag{12}$$

where N is the number of hidden layer nodes, n is the number of input layer nodes, m is the number of output layer nodes, a and is an integer from 1 to 10.

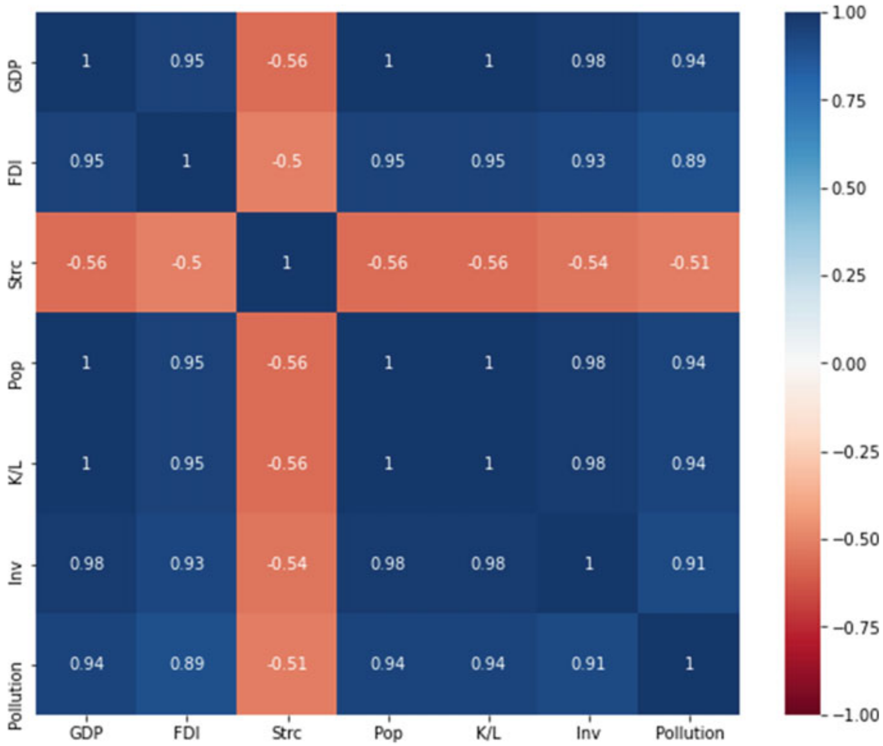

Fig. 4 Spearman correlation heatmap

The experimental model has 6 input layer nodes and 1 output layer node, so it can be determined that the number of hidden layer nodes ranges from 4 to 13. The model is set to contain one LSTM hidden layer, and the root mean square error (RMSE) is used as the performance evaluation index to determine the number of hidden layer nodes. The calculation formula of root mean square error is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y_p)^2}{n}} \tag{13}$$

During the experiment, the mean absolute error (MAE), mean square error (MSE) and root mean square error (RMSE) will be used to compare the deviation degree of the predicted values of different models. The average absolute error and mean square error are calculated as follows:

$$MAE = \frac{\sum_{i=1}^{n}|y_i - y_p|}{n} \tag{14}$$

$$MSE = \frac{\sum_{i=1}^{n} (y_i - y_p)^2}{n} \tag{15}$$

where y_i is the original value, y_p is the predicted value, and n is the number of samples.

According to the experimental results of the test set, the smaller the RMSE value is, the better the prediction effect of the model is. Table 1 shows the root mean square error of the test set with different node numbers of single-layer LSTM. Therefore, it can be determined that the prediction effect of the model is the best when the number of hidden layer nodes is 7.

For the determination of model depth, considering the small amount of data used in this experiment, it is not appropriate to set the model depth too high to avoid over fitting problems. During the experiment, the number of nodes in each hidden layer is set to 7, and the prediction effect of 1 –5 layer LSTM model is tested respectively. RMSE is still used as the model performance evaluation index. The experimental results show that different levels of LSTM have no obvious effect on the prediction effect of the test set, and there is no difference in the value of RMSE. According to the principle of simplifying neural network modeling as much as possible, the hidden layer of LSTM model is determined as one layer.

The network structure finally determined in this paper is that the LSTM model has one hidden layer, seven hidden layer nodes, six input layer nodes and one output layer node. The weight matrix W_1 between the input layer and the hidden layer, the weight matrix W_2 between the hidden layer and the output layer, and the offset vector b are all initialized randomly and updated iteratively through the training process. The training method of LSTM neural network adopts time-based back propagation (BPTT) algorithm, the loss function adopts mean absolute error (MAE), and the optimizer adopts Adam optimizer. Adam algorithm combines the advantages of momentum gradient descent method and root mean square back propagation algorithm, and has obvious advantages over other algorithms.

Table 1 RMSE of different number of nodes

Number of nodes	RMSE
4	0.084
5	0.083
6	0.083
7	0.082
8	0.083
9	0.086
10	0.087
11	0.087
12	0.090
13	0.093

4.3 Empirical Analysis

In order to test and compare the prediction performance of LSTM neural network model, another two groups of experiments are designed in the research process, namely, BP neural network model (BP) and general recurrent neural network model (RNN). BP neural network adopts the feedforward neural network structure of a single hidden layer, and RNN also adopts the network structure of a single hidden layer. The first 80% of the data is used as the training set, and the last 20% of the data is used as the test set, that is, 16 groups of data from 1999 to 2014 are used to train each model of the experiment, and 4 groups of data from 2015 to 2018 are used as the test set of the model.

Figure 5 shows the actual comprehensive pollution index of Shandong Province from 1999 to 2018 calculated by entropy weight method, which can clarify the trend of pollution in Shandong Province over the years.

The experimental results of the real value and the predicted value on the test set are compared, and Mae, MSE and RMSE are used as the performance evaluation indexes of each model. After experimental training, the prediction performance of each model and the prediction results of the test set are shown in Tables 2 and 3.

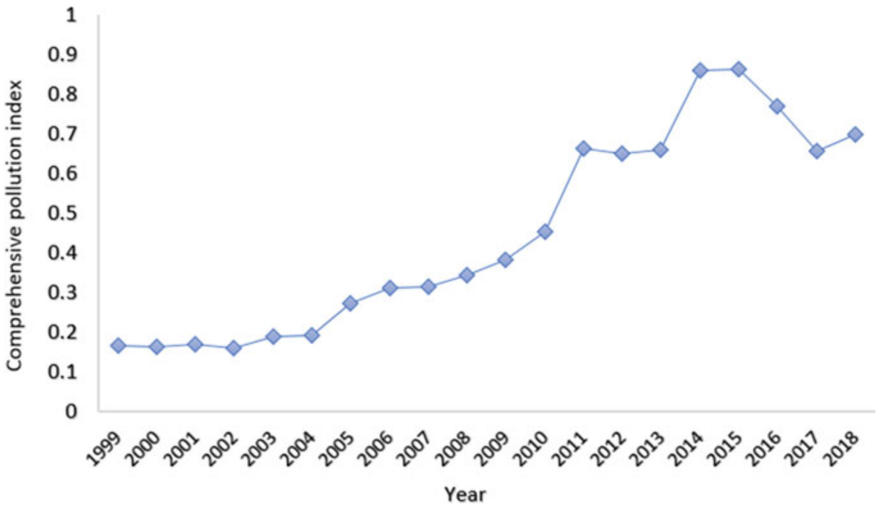

Fig. 5 The actual comprehensive pollution index of Shandong Province

Table 2 Performance indicators of each model

Model	MAE	MSE	RMSE
LSTM	0.048	0.003	0.058
RNN	0.058	0.005	0.071
BP	0.071	0.007	0.085

Table 3 Predicted results of each model

Year	Actual value	LSTM	RNN	BP
2015	0.8635	0.7859	0.8373	0.8740
2016	0.7693	0.7871	0.8381	0.8766
2017	0.6566	0.7412	0.7774	0.7818
2018	0.7000	0.6868	0.6826	0.6594

Whether MAE, MSE or RMSE, they all represent the deviation between the predicted value and the real value. The smaller the error value, the better the prediction performance of the model. According to the values of various performance indicators in Table 2, the values of the three indicators are the smallest in the LSTM network model, the second in the RNN model, and the largest in the BP neural network model. It can be easily determined that among the three models, the LSTM model has the best performance, the RNN model is the second, and the BP neural network model is the worst (Fig. 6).

Let's look at the comparison between the predicted results of the three models and the real values. According to the predicted results of the models in Table 3, the real value of the comprehensive pollution level in Shandong Province in 2015 was 0.8635. The BP neural network model was the closest model to the predicted value, but there was a large gap between the predicted results and the real values in the following three years, followed by the RNN model, and the LSTM model with the largest error. From 2016 to 2018, the least error between the real value of comprehensive pollution level in Shandong Province and the predicted value of each model is LSTM model, followed by RNN model, and the most error is BP neural

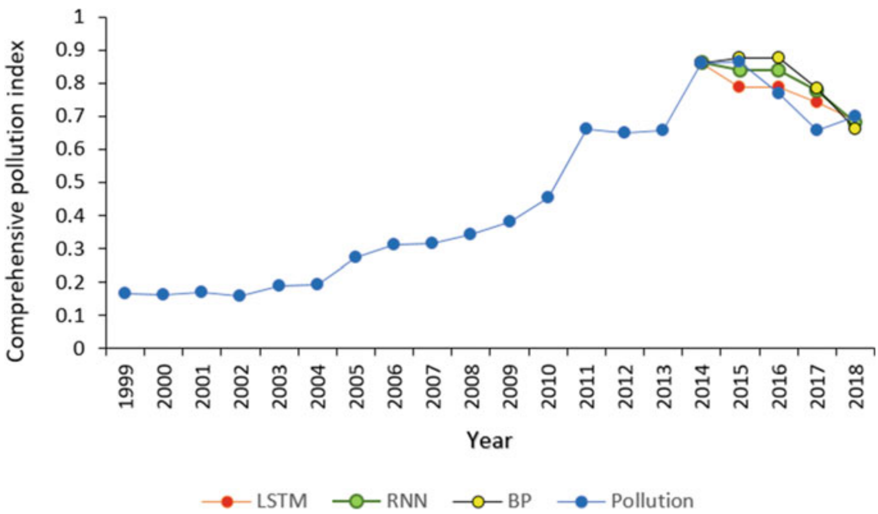

Fig. 6 Prediction effect diagram of each model

network model. This shows that although the prediction results of BP neural network model in the first year are good, the prediction error will become larger and larger with the passage of time. The overall prediction error of RNN model is smaller than that of BP model, but it is not as good as that of LSTM model, which indicates that the prediction performance of deep learning method is better than that of ordinary neural network. The prediction effect of LSTM model for the first year of the test set is not the best, but with the passage of time, its prediction effect will gradually become better. In general, it is the best of the three models, which also proves that LSTM neural network model can learn the time series information in the time series data.

5 Conclusion

This paper presents a comprehensive pollution index prediction model based on LSTM neural network. Firstly, based on Pearson correlation coefficient and Spearman correlation coefficient, the correlation between variables is analyzed to ensure the effect of model prediction. Then, the data are normalized, and the prediction model is constructed by using the nonlinear processing ability of LSTM neural network for multivariable time series data. Finally, the data of Shandong Province from 1999 to 2018 are used to train and test the model, and compared with RNN model and BP neural network model to achieve the prediction task. The results show that the comprehensive pollution index prediction model based on LSTM neural network can effectively learn the time series information in multivariable time series data. With the passage of time, the advantages of its model performance will be reflected, and it has higher prediction accuracy than RNN model and BP neural network model.

The model proposed in this paper can predict the local pollution situation according to the economic index data of a certain area over the years, can effectively help relevant departments to formulate more scientific pollution prevention and control measures, and has certain significance for the evaluation of the local pollution situation. Of course, the current research of this paper also has certain limitations. First, the amount of index data used in the available model prediction is limited, and the model training effect may have room to improve. With the accumulation of data over the years, this problem can be further solved; Second, the model has only used the data of Shandong Province for experiments. Whether the model has universality needs to be further verified. This experiment only predicts the comprehensive pollution index. Further research can be done on the prediction effect of single pollutants.

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Price Forecasting of Emission Rights Trading Based on Data Mining and Machine Learning

Qiwei Lu

Abstract The implementation of emission trading system effectively promotes pollution control and emission reduction. However, in the market-oriented mechanism, the behavior decision-making of emission trading subjects is full of complexity and uncertainty, resulting in the instability of emission trading market and decision-making risks of enterprises. In the process of emissions trading, emission trading is one of the external performance of emissions trading behavior, understand its principle and the law is very important, this paper assumes that the trading behavior of polluters and price some mechanisms, emission trading behavior and the market environment changes may affect the market price, By mining the behavior data of emission trading and other factors, we can predict the change of market price of emission trading. Neural network and support vector machine are selected to predict the price change trend of emission rights trading in Zhejiang Province, and the results are verified: using the data of emission rights trading can make the price forecast more authentic, and provide good reference value for the decision support of emission permits enterprises and government regulatory departments.

Keywords Emission trading · Forecasting · Machine learning

1 Introduction

After the strategic decision of "vigorously promoting the construction of ecological civilization" was made at the 18th National Congress of the Communist Party of China, China paid more attention to the balance between economic development and ecological environment. Government departments adopted a series of measures to promote energy conservation and emission reduction, such as direct control, implementation of emission tax, implementation of emission trading system, etc. The paid use and trading system of pollution discharge right is an economic measure

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that the government uses the market mechanism to control the emission of pollutants and encourage enterprises to control pollution and reduce emissions. Since Jiaxing, Zhejiang Province, established the first emission right trading center in China, the emission right trading system has basically covered the whole country so far. In November 2021, the “Opinions of the CPC Central Committee and The State Council on Deepening the Battle against Pollution” proposed to accelerate the market-oriented trading of emission rights, energy use rights and carbon emission rights. Compared with the primary market of emission right trading as the issuing market, the secondary market is the market where the emission index is transferred between the surplus enterprises and the enterprises lacking emission index, which is conducive to the transformation of passive emission reduction into spontaneous behavior of the enterprises. Establishing and perfecting the emission right trading market is the most important thing to improve the emission right trading mechanism. Although the preliminary basic work required for the implementation of emission rights trading in various regions has been basically completed, it is difficult for the secondary market to be active due to the small number of trading subjects, high transaction costs, inadequate supervision and other reasons. Many emission rights transactions are completed under the guidance and coordination of local government departments, and it is difficult to play the due function of market regulation and resource allocation. Zhejiang is one of the most developed provinces in China’s economy, is the domestic first set up in the province of emissions trading center in more than ten years of development has accumulated rich experience, and Zhejiang province ecological environment agency around the emissions of check and ratify, price formulation, implementation of trading, oversee several core link, continuous study of emissions trading policy and mechanism design, We will comprehensively advance reform of the emissions trading system. Since 2018, Zhejiang first enable “emissions trading index”, realize the era of big data emissions trading clinch a deal the price, volume, active index, such as changing trend of visualization, and emissions trading through the analysis of the data science and the correlation between industrial economic level and environment level, actively to achieve the scientific allocation of environmental resources [1]. Up to now, Zhejiang has reached a total of nearly 70 thousand transactions, the value of more than 12 billion yuan, accounting for about half of the national emission rights trading, for other provinces and cities of the emission rights trading policy to play a good lead. In this context, this article analysis pollutant discharging enterprises in Zhejiang province trading heterogeneity driver behavior and the market rules, predict the evolution of the emissions trading market price in Zhejiang province, and study the trading characteristics under the influence of the emission trading behavior, on polluters, trading platform and government departments to understand the internal mechanism of emissions trading, It is of great significance to make relevant decisions or perfect the market trading system.

2 Literature Review

Due to the diversification of emission trading products, the trading objects involve different roles such as government and enterprises, and are closely related to the investment, clean production and operation of emission enterprises, so the trading process is very complicated. Research on emission trading has been involved in many fields. It mainly includes the influence and implementation effect of emission right trading policy [2, 3], emission right trading market allocation and market power [4–6], emission right trading mechanism design and initial allocation [7–9], uncertain behavior under emission right trading [10–12], production decision-making under emission right trading [13–15], etc. This paper summarizes the research situation of emission rights trading at home and abroad, reviews the related research on trading behavior and price, and explores new research methods in this field.

In 1920, Pigou [16] first proposed the environmental policy of internalizing the cost of environmental pollution by using sewage charge and sewage tax as an economic means. In 1966, Crocker [17] proposed that the government set a cap on total emissions and let the market, rather than the government, determine the price and degree of emission reduction. Two years later, Dales[18] proposed emission trading and perfected this idea. To address SO_2 emissions and acid rain, the US Congress passed the Clean Air Act Amendments (CAAAs) in 1990 and successfully constructed and implemented an emissions Trading Scheme (ETS). Since then, the emission trading mechanism has been gradually implemented in The UK, Germany and other European countries [19], with remarkable results. After the gradual improvement of the theory of emission rights, a large number of foreign scholars focused on the practice and effect of emission trading mechanism. Montgomery [20], an economist, evaluated the economic impact of the carbon emission reduction plan proposed in accordance with the Kyoto Protocol and believed that the emission trading system was the lowest cost way to achieve emission reduction. Benkovic [21] discussed the results of SO_2 in the United States and argued that the emissions trading system was an extremely effective policy tool, with over 4 million tons less SO_2 per year in the regions participating in the EMISSIONS trading scheme than in the initial period. However, in practice, transaction cost will affect the implementation effect of emission right trading. Therefore, in the early stage of emission right trading, excessive government control and supervision will produce high transaction cost, resulting in low activity of emission right trading market. In order to further promote the smooth operation of the system, many experts believe that the initial allocation and mechanism design of emission rights trading are crucial. Compared with free allocation and paid sale, public auction of emission rights is more efficient. Hahn et al. [22] believe that the auction mechanism can prevent some polluters from monopolizing the trading of emission rights and make the trading price conform to the market law. In terms of the market power of emission rights, Tanaka et al. [23] tested the performance of the emissions trading market by using the bilateral oligopoly model and verified that the marginal emission reduction cost affects

Table 1 "Emission trading" high-frequency keywords

Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
Emission rights	82	Auction	8	Environmental pollution	6
Total control	25	Taihu Basin	8	Real options	5
Initial allocation	18	transactions	8	Coase theorem	5
The paid use	10	Oligopoly	8	Accounting treatment	5
Transaction cost	9	Market mechanism	7	Trading system	5
Environmental policy	9	Emission trading	7	Emission reduction	5
SO_2	8	Secondary market	6	Pigovian tax	4

the change of market power. In addition, many experts also discussed production decisions under emission trading.

In this paper, using "emission trading" as the key word in CNKI database, we searched literatures from SCI, CSSCI and EI from 2002 to 2012, and finally obtained 542 sample literatures after excluding news, reviews and irrelevant literatures. CiteSpace document metrology tool was used to study the hot frontier trends of domestic emission rights trading. In the early stage, domestic scholars mainly studied total pollutant control, paid use of emission rights, initial distribution mode, policy mechanism design, etc. With the passage of time, Market allocation, Porter effect, policy effect and behavior uncertainty of polluters have become the research trends in recent years (Table 1).

Si Lijuan and Cao Haoyu [24] studied the provincial panel data of China and found that excluding other emission reduction policies, pollutant emissions in areas where the emission trading system is implemented significantly decreased, indicating that the construction of China's emission trading system uses market means to control pollutant emissions and has achieved good results. It is encouraging the government to promote the perfection of emission trading market and encouraging enterprises to actively participate in emission trading. The complex behaviors of pollutant discharging enterprises under the influence of pollutant emission trading policies can be roughly divided into two categories: one is indirect behaviors of enterprises under the influence of pollutant emission trading, such as illegal relocation, pollution control and emission reduction, adjustment of production and investment; The other is the direct trading behavior such as the selection of index type and trading object, the determination of trading volume and trading price, the selection of trading mode, and the game with the government when the enterprises buy or sell pollution index in the process of emission right trading.

There have been a lot of research results on emission trading behavior in China. As for the indirect behavior of emission right trading, Hu Mingyi [25] analyzed the effect mechanism of emission permit system on environmental protection of enterprises from two aspects of enterprises' goals and output functions, and discussed the choice of enterprises' behaviors under the emission permit system. Wang Yi et al. [26], in the process of studying the emission right trading behavior of thermal power enterprises, constructed the pollution control cost and benefit model and put forward corresponding suggestions for improving the denitration price policy. As for direct behavior, Sun Dongying et al. [6] constructed a three-party evolutionary game model for the secondary market trading of emission rights based on the different demands of the government and polluters, and put forward some suggestions.

For the study of transaction price, Wu Fengping et al. [27] discussed the formation model of emission right transaction price in an imperfect competition market, and they believed that transaction price preference and transaction cost are all factors in the formation of emission right transaction price. Song Fuzhong et al. [28] established a practical fuzzy mathematical evaluation system for the benchmark price of emission right trading, which provided reference for the pricing of emission right.

Early scholars' research on the behavior and price of emission right trading mostly focused on mathematical modeling and analysis, using game method to analyze and predict the behavior strategy of emission right trading objects. Many scholars also built system dynamics model and predicted the efficiency and price of emission right trading system through experimental methods. However, Due to the complexity of the real system, the predicted result of the model deviates from the real value, and the emission trading can not be predicted from the actual situation. With the rise of data mining and machine learning, more and more scholars are involved in machine learning methods. For example, Zhou et al. [29] constructed multiple single-step forward prediction models to analyze and predict carbon price based on fully integrated empirical mode decomposition of adaptive noise and long-term and short-term memory recursive neural network.

3 Prediction of Emission Rights Trading Based on Machine Learning

3.1 Analysis of Trading Characteristics

This paper carries out statistical analysis on the data obtained from Zhejiang emission right trading website, and selects the transaction data of electronic bidding platform published from 2017 to the end of 2021. At present, the emission right bidding in Zhejiang province is mainly between the government and enterprises, and a total of 2347 auctions are held. The statistical data of the four pollutant indicators are shown in Table 2. AB, AT, 50%, 75%, VOL, AE and AP respectively represent average bidding price (unit: YUAN/year), average transaction price (unit: Yuan/year), median transaction price (unit: Yuan/year), and upper quartile of transaction price (unit: Yuan/year), the proportion of trading volume, the average number of enterprises

Table 2 Trade statistics of four pollutant indexes in Zhejiang Province

	AB	AT	50%	75%	VOL (%)	AE	AP
COD	18,396.73	21,344.63	17,800	22,000	21.55	14.00	1.47
NH_3-N	35,893.52	39,714.52	27,000	40,000	2.47	13.82	1.45
SO_2	13,911.31	15,489.53	7100	14,500	23.9	11.48	1.54
NO_X	8032.45	11,555.35	4900	8000	52.08	12.09	1.53

participating in each bidding and the average transaction times of each enterprise (unit: times).

As can be seen from the transaction price, the average transaction price is driven up by less than a quarter of the partial companies. Parts analysis found that the reasons due to the environmental quality level, industrial production level and the differences of bidding mechanism, enterprise bidding is very fierce, such as 2020 years ago Jinhua faster in order to realize the environmental effect of emission trading, in the bidding transaction set the bid-winning rate is only 50% other parts to the (70%), in the meantime, Bidding in Jinhua has averaged about 30 times the base price. Another reason is that their own bid, in the fierce competitive bidding, some enterprises in the first time to participate in the bid deal after many times to participate in trading, prices are pushing up until the bidding and bid is successful, in order to ensure success for the emission index, companies offer price is a little bit higher, raising the overall bid price. Therefore, it can be inferred that regional ecological environment, industrial production level, trading times of enterprises and other reasons may have an impact on the trading price of emission rights.

From the analysis of trading volume, enterprises' demand for SO_2 and nitrogen oxide is large, accounting for nearly 80% of the total trading volume, and is inversely proportional to the transaction price. The higher the trading volume, the lower the price. Therefore, it can be inferred that the volume of pollutant indicators may also be one of the factors affecting the price fluctuation of emission rights trading.

3.2 Price Forecasting

At present, it is difficult to predict the market price of pollutant index of emission right trading. The fundamental reason is that the emission right trading mechanism is a complex system, and the price fluctuation is not only affected by the relationship between market supply and demand and enterprises' emission decision, but also related to the characteristics of emission right trading behavior. As can be seen from the above analysis, the trading price of emission rights is generated under the regular trading behavior of enterprises. Based on the effectiveness of the market, data with similar distribution of historical trading data can be generated to predict the trading price trend of emission rights. Taking SO_2 as an example, this paper uses the method of combining Principal Component Analysis (PCA) with BP neural network and Support Vector Machine (SVM) to design the price prediction model, which improves the prediction accuracy. It can be used to help pollutant discharging enterprises choose appropriate purchasing strategy and reduce the purchasing cost of SO_2.

3.2.1 Select the Variable

For hybrid deep learning model, selecting appropriate input variables can improve the accuracy of prediction. In this paper, on the basis of the previous literature research and the above analysis and summary, select the factors that affect the price of emission rights. They are emission trading market, upstream and downstream product output, related price index, industrial added value growth, air quality and network search index.

Due to the influence of different trading policies and economic development level in the pilot regions of China's emission trading market, the development degree of emission trading is dissimilar. Moreover, the inter-regional emission right transfer policy is not yet perfect. Even in different regions of the same province, the trading price level is different before discharging, and the fluctuation is greatly different in space. The change of emission right trading policy in different time makes the price fluctuation greatly different in time. For example, shaoxing has a high level of emission right price, while Wenzhou and Jiaxing have a relatively low level of emission right price, Jinhua has a large fluctuation of emission right price, while Huzhou has a relatively stable price. At the same time, according to the analysis results, the price of emission trading market may be affected by the mutual trading behavior of enterprises. Therefore, the historical price of SO_2 and the other three pollutant indexes, the number of enterprises and the historical purchase amount are selected as the input variables of the model considering the factors of emission trading market.

The level of economic development is also one of the factors affecting the fluctuation of emission trading price [30]. Theoretically, with the increasing prosperity of macroeconomic environment, the output of industrial products will increase, and the demand of pollutant discharging enterprises or departments for pollutant discharging rights will increase faster, leading to the rise of pollutant discharging rights price. Meanwhile, the related prices of products and consumption may also affect the price of pollutant discharging rights. So far, industrial enterprises are the main consumers of various pollution indicators in the emission right trading. The quarterly fluctuation trend of industrial added value in Zhejiang province is highly consistent with the activity of emission right trading, and the activity of emission right trading greatly affects the price of emission right. Therefore, the output of upstream and downstream products required by the production and operation of pollution-discharging enterprises, relevant price indices and the growth rate of industrial added value that can reflect the total local production results within the reporting period are selected as input variables in this paper.

With the increase of production activities of pollutant discharging enterprises, air pollutants and water pollutants are also increasing, and the demand for pollutant discharge indicators is also increasing. From the perspective of environmental improvement, the volume of air pollutants is highly negatively correlated with PM2.5 index. In addition, the pollution levels in different regions are different, and the difficulty of treatment is different, which ultimately affects the market price of emission rights. Therefore, this study selects this factor as the input variable.

At present, some progress has been made in forecasting macroeconomic and market conditions by using online big data. On the basis of making full use of existing emission rights trading and other macro data, the prediction accuracy of the model can be improved by adding Internet search data [31]. Therefore, this paper adds the search index of the predicted region into the input variable of the model.

To sum up, this study selects 37 variables in six categories, including emission trading market, output of upstream and downstream products, related price index, industrial added value, air quality and network search index, among which data of emission trading market and network search index are obtained through data mining. In order to study the latest emission trading situation, we set the sample period as January 2019 to December 2021. A total of 33 months of data were available from the valid sample obtained through data cleansing and outlier screening. Table 3 shows the selected input variables. All data come from national data and Zhejiang Emission trading network.

Table 3 The category and name of input variables

Category	Name	Interpretation of variables
Emission trading market	COD Price −1	−1 represents the historical price of the previous two months, and −0 represents the historical price of the previous month
	COD Price −0	
	NH_3-N Price −1	
	NH_3-N Price −0	
	SO_2 Price −1	
	SO_2 Price −0	
	NO_X Price −1	
	NO_X Price −0	
	Companies of COD	The number of enterprises participating in purchasing the corresponding pollution index each month
	Companies of NH_3-N	
	Companies of SO_2	
	Companies of NO_X	
	The purchase of COD	Purchase quantity of corresponding pollution index monthly
	The purchase of NH_3-N	
	The purchase of SO_2	
	The purchase of NO_X	

(continued)

Table 3 (continued)

Category	Name	Interpretation of variables
Upstream and downstream product output	Production of primary plastic	
	Production of plastic products	
	Cement output	
	Pig iron production	
	Steel output	
	Copper production	
	Aluminum production	
	Regional power generation	
	Total consumer price index	
Related price index	Consumer price index for clothing	These price indices measure the trend and degree of change in prices compared with the same month in the previous year
	Consumer price index for textile	
	Retail price index for goods	
	Retail Price Index of Building Materials and Hardware electrical goods	
	Industrial producer purchasing price index	
	The producer price index	
Industrial added value	Industrial added value	
AQI	Air quality composite index	
	The monthly average concentration of PM2.5	
	The monthly average concentration of SO_2	
	The monthly average concentration of NO_2	
Web Search Index	Baidu index	

3.2.2 Process the Data

Move the price data up as a whole (because the features of the last month are combined to predict the price of the next month, so it needs to move up as a whole one bit, that is, to get the target value of each row of data). Determine the coefficient N when preparing the training data, where N represents the target value predicted by the data of the previous days, for example, set it to 2. Is used to predict the price of the next month using the data of the previous two months. Because there are many meaningless 0 values and NULL values in the data, the four data with the price of 0 are deleted according to the actual situation to avoid affecting the subsequent calculation.

Using Z-Score standardization to eliminate dimensionality from raw data, that is, all input variables are at the same quantity level to improve data comparability. The input variables are processed as follows, μ is the mean value of each input variable, σ is the standard deviation of each variable, and the normalized value fluctuates around 0.

$$z = \frac{x - \mu}{\sigma} \tag{1}$$

3.2.3 Feature Extraction

The selected feature variables need to further remove redundant data and extract key features. Feature extraction is an important processing step in machine learning, which can increase the efficiency and effect of machine learning and improve the accuracy of the algorithm. In this paper, we input the data set of feature variables, select the features of 37 attributes in the data set, use a trained XGBoost model to automatically calculate the importance of features, and output the ranking of influence degree, namely the ranking of importance of features. The ranking results are shown in Fig. 1. According to the figure, the purchase quantity of SO_2, nitrogen oxide price −0 (the previous month), nitrogen oxide price −0 (the previous two months), average

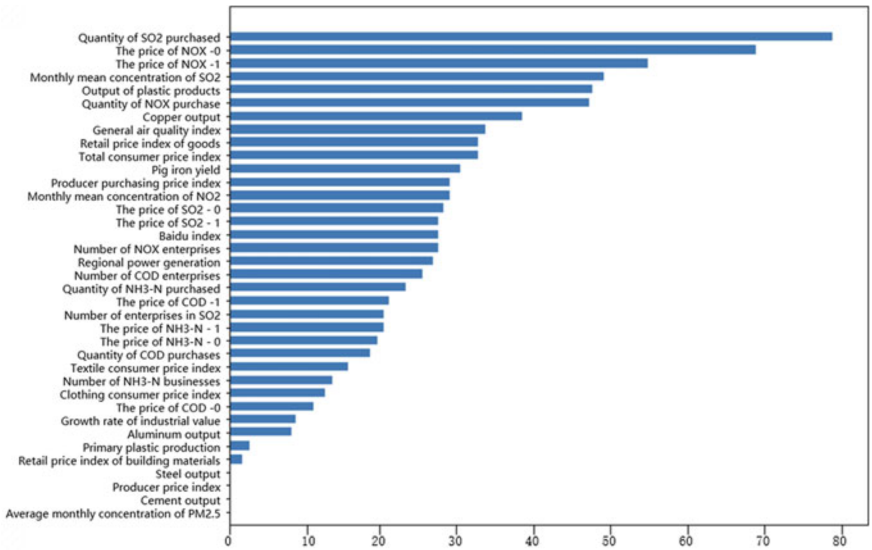

Fig. 1 Ranking the degree of influence of characteristics

concentration of SO2, production of plastic products, purchase quantity of nitrogen oxide and other characteristics have a decreasing influence on the prediction results.

3.2.4 Model and Parameters

Taking SO_2 price in Huzhou city, Zhejiang Province as the research object, factors affecting the price of SO_2 are selected for analysis. Since each indicator has a certain correlation, PCA dimension reduction is carried out to eliminate the correlation and reduce the number of variables in the input layer, in order to improve the prediction efficiency. SVM and BP neural network usually have good performance in the processing of complex nonlinear problems. In order to verify whether they still perform well in the price prediction of emission rights trading, xgboost model of machine learning is taken as the control. Therefore, scholars take the price of SO_2 as the output variable. The PCA-BP prediction model, PCA-SVM prediction model and PCA-xgboost prediction model were used as input variables. At the same time, the unreduced dimension data is retained for comparison.

When constructing the PCA-BP neural network model, the extracted principal component was taken as the influencing factor of SO_2 price, and it was taken as the input layer of BP neural network. The network layer is set as 3 layers, the number of input nodes is 6, the number of output nodes is 1, the initial learning rate is set as 0.01, and the optimizer is Adam. After several experiments, the fitting effect is optimal when the number of neurons is determined to be 10. The penalty factor C was set as 0.6 when constructing the PCA-SVM model, because the number of samples was small, linear kernel function was selected as the kernel function type. In the PCA-xgboost model, the maximum depth of the tree is set as 8, and the sum of the minimum sample weight is set as 0.1.

3.2.5 Prediction Results and Error Analysis

70% of the samples were selected as the training set samples, and the remaining 30% as the test set samples. After the three prediction models were established, the three basic prediction models without principal component analysis were compared. There were six models in total, and the R fitting degree ranged from 0.3 to 0.8. Among them, the PCA-SVM model had the best training effect, with the R fitting degree reaching 0.80503, and the training set optimization effect was good. Indicates that the optimization parameters are valid and the next prediction can be made.

Since the formation of emission trading price has nothing to do with time variable, SO_2 prices at 10 points are predicted randomly. Input variables are selected as part of characteristic data, and there is a certain degree of error between the final predicted SO_2 trading price and the actual price. The prediction results are shown in Fig. 2.

We will get the sulfur dioxide prices compare the predicted values and the real value of validation, the relative error of calculation of six kinds of prediction model, as shown in Table 4, visible PCA-the SVM prediction model, the average relative

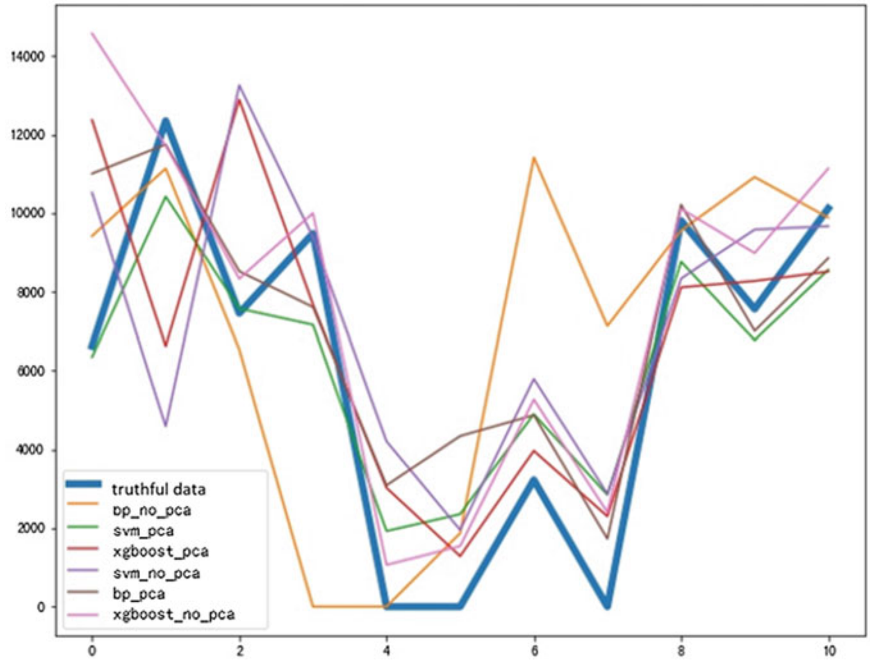

Fig. 2 Six models predict results

Table 4 The error analysis

Model	Mean relative error (%)
PCA-SVM	16.5522
PCA-BP	27.1723
SVM	32.1996
xgboost	33.1269
PCA-xgboost	38.6031
BP	48.6021

error of the minimum average relative error of BP neural network prediction model is the biggest, deep learning model as a whole is better than machine learning model prediction effect, After processing data by PCA dimensionality reduction method, the prediction accuracy is improved.

4 Conclusion

In order to better understand the emissions trading market, and for the tradable permits companies and government regulatory decision support provides a good reference value, to price of tradable permits to tradable permits companies can according to the price of emissions trading and combined with factors influencing the fluctuations in the price of reasonably adjust strategy to obtain greater benefits. This paper takes sulfur dioxide in Huzhou city, Zhejiang Province as an example, and uses six models to predict the price of sulfur dioxide. The results show that the PCA-SVM model has smaller fitting error and higher accuracy.

Emissions trading price changes not only affected by the current market environment and enterprise external transaction behavior, the influence of polluters expectations of future market price, and the adjustment of the production decision can produce complex effects on emissions trading prices, although using machine learning method, this paper through the historical data is relatively objective and rational forecast emissions trading price, But the ideal goal has not been reached, and some complicated factors have not been taken into account. We will further study the behavior of emission trading, including the complex behavior of bidding and transfer under irrational conditions, so as to improve the accuracy of emission trading prediction and provide a strong reference for enterprises to choose in the process of emission trading.

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Research on the Driving Factors of Carbon Emissions Inequality of Logistics in China

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Abstract Logistics industry is one of the main sources of carbon emission in China, and the realization of low-carbon logistics is of great significance to promote environmental governance in China. Due to the regional inequality in the development of China's logistics industry, it is urgent to break through the barriers brought by regional inequality in the construction of a low-carbon logistics system, so as to promote the coordinated development of low-carbon logistics. Based on the carbon emission accounting of three regions in China from 2007 to 2019, Theil index was used to measure the regional inequality of China's logistics industry based on per capita carbon emission index, and LMDI method was used to decompose and analyze the driving factors of inequality in China's regional logistics industry.The empirical results show that: (1) The level of inequality in China's region is obviously higher than the level of inequality between regions; (2) Each driving factor has a big difference in the contribution degree to the per capita carbon emission change of the logistics industry in the three regions. Reducing these differences will contribute to the realization of the regional coordinated development of low-carbon logistics.

Keywords Logistics · Carbon emissions · Regional inequality · Driving factors

1 Introduction

Logistics is an important part of China's national economy. With the rapid development of e-commerce, the logistics has developed rapidly in the past decade, which has also led to serious carbon emissions. Under the background of low-carbon development, the logistics urgently needs to complete the transition to low-carbon logistics. Considering that the development of the logistics has obvious radiation effect and obvious regional characteristics, it also leads to a very serious inequality in the development of the logistics in China. In order to improve the unbalanced status of regional

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development in China, the 19th National Congress of the Communist Party of China pointed out that efforts should be made to speed up the construction of an industrial system of coordinated development. In combination with China's long-term goals of energy conservation, emission reduction and sustainable development, we should pay more attention to the regional differences in the development of low-carbon industries. To build a low-carbon logistics system in an all-round way, it is necessary to break through the barriers brought about by the unbalanced regional development, determine the sources of differences, give play to the driving role of the advantages of each region, and eliminate the development disadvantages of each region as soon as possible, so as to promote the regional coordinated development of low-carbon logistics.

Logistics is a basic and strategic industry supporting the development of China's national economy. The full realization of low-carbon logistics will provide strong support for China to achieve the overall emission reduction target as soon as possible. This paper hopes to analyze the law of carbon emission change of logistics in China and three regions through the accounting of carbon emission of logistics, and reveal the differences of driving factors of carbon emissions inequality of logistics in different regions by investigating the unbalanced status of regional development of logistics, so as to provide a theoretical basis for the construction of low-carbon logistics, which is of great significance to the realization of regional synergy of logistics and the healthy development of low-carbon logistics in China.

2 Literature Review

In recent years, scholars began to study the regional inequality of low-carbon logistics development in China from different angles. For example, Tian studied the performance of logistics in eight regions from 2010 to 2015 under low-carbon constraints, and found that the overall performance of logistics in China is not high, and the regional inequality is obvious [1]. Zhang used Theil index and regional separation coefficient to study the regional differences of carbon emissions of logistics in China from 2003 to 2011, and found that the carbon emissions and their growth rate in eastern region are significantly higher than those in central and western regions [2]. Zhang used the performance measure function to study the regional differences in the carbon emissions performance of the logistics industry in China from 2003 to 2009, and found that the carbon emission performance of the logistics in the eastern region was the best, and the performance in the central region was the worst [3]. Fang used Theil index to analyze the carbon emissions of unit goods in the three regions of China, and found that there is a significant inequality in the three regions, and the carbon emissions of logistics operations among provinces are quite different [4].

Through the analysis, the above research points out that the development of low-carbon logistics in China shows obvious regional inequality. How to reduce regional differences and realize the low-carbon coordinated development of regional logistics is of great practical significance to promote the construction of modern logistics.

In the relevant research on the driving factors of carbon emissions change in logistics, most of the research adopts the decomposition analysis method. The common decomposition analysis methods include structural decomposition analysis (SDA) and index decomposition analysis (IDA). Among them, the log mean division index (LMDI) decomposition method in IDA is widely used in environmental economic research because of its good characteristics such as no residual error and consistency of decomposition results. For example, Liu used LMDI method to decompose and analyze the driving factors of carbon emission change of logistics in China, and proposed that the development of low-carbon logistics should start from improving energy efficiency and energy structure [5]. Ma used the LMDI model to analyze the impact of six factors, including energy structure, energy efficiency, and transportation mode, on the per capita carbon emissions of logistics from 1991 to 2010, and concluded that economic growth is the most important factor leading to the growth of carbon emissions of logistics in China [6]. W.W. Wang used the LMDI method to study the factors affecting the change of carbon emissions from the transportation sector in China from 1985 to 2009, and found that the per capita economic activity effect and the transport mode transfer effect were the main factors driving the growth of carbon emissions from the transportation sector during the study period [7]; Quan calculated the carbon emissions of logistics in China from 2000 to 2016, and decomposed the influencing factors of carbon emissions from five aspects by using the LMDI decomposition model, and it was found that economic growth is the main factor to promote the carbon emissions of logistics, followed by the positive impact of population size and energy structure [8].

The above research has considered the driving factors of carbon emissions change of logistics at the national level. Considering the current situation of unbalanced regional development in China, the development of logistics also has obvious regional differences, and the driving factors of carbon emissions change can not be generalized. Therefore, many scholars have conducted more detailed research on the carbon emission of logistics in China at the regional level. For example, Zhang used LMDI model to study the influencing factors of carbon emissions in logistics from 2005 to 2015, and found that the impact of energy structure, energy intensity, industrial structure and other factors on carbon emissions changes in Beijing, Tianjin and Hebei is very different [9]. Wang used LMDI method to analyze the impact of energy efficiency, industrial structure, economic growth and other factors on the carbon emission of logistics in Anhui, Shanghai, Jiangsu and Zhejiang provinces, and found that energy efficiency inhibited the carbon emissions growth of logistics in Shanghai, Jiangsu and Zhejiang, but promoted the carbon emissions growth of logistics in Anhui Province [10]. Lu analyzed the influencing factors of carbon emissions through LMDI method on the basis of using Theil index to analyze the regional differences of carbon emissions from the transportation industry in the Yangtze River economic belt, and found that the carbon emissions from the transportation industry in the provinces and cities of the Yangtze River Economic Belt showed an obvious uneven distribution [11]. Zheng explored the role of changing regional development patterns in achieving emission reduction targets, and found that the impact of various carbon emission drivers on carbon emission changes varies with regional development patterns [12]. Lu studied the regional differences and influencing factors of the average carbon emissions of the transportation industry in the Yangtze River economic belt from 2005 to 2014, found that there are regional differences in carbon emissions per capita, carbon emission intensity and carbon emissions per conversion turnover, and pointed out that the government should optimize the energy structure, improve transportation efficiency and formulate differentiation policies according to regional conditions [13]. Li studied the regional differences and influencing factors of carbon emissions from urban transportation in China from 2005 to 2015, and found that the total distribution of carbon emissions from the transportation industry is very different in space, and the per capita GDP is the most important factor affecting the growth of emissions [14].

To sum up, based on the calculation and analysis of carbon emissions of logistics in different ranges, these studies can better determine the driving factors and contribution values of carbon emissions changes in various regions by using LMDI model, which has certain guiding significance for the construction of low-carbon logistics. However, these studies also further illustrate the regional inequality of the development of logistics in China. Each driving factor has different effects on the carbon emissions of logistics in different regions. Considering the regional inequality, the study of driving factors can give more targeted suggestions on the low-carbon development of regional logistics.

According to the above literature review, it can be seen that domestic and foreign scholars have achieved phased research results on carbon emissions, regional inequality and related driving factors of the logistics. However, in the existing research, based on the regional inequality of carbon emissions of logistics, there are few articles to analyze the driving factors of carbon emissions inequality of regional logistics in China. Therefore, on the basis of previous studies, this paper will calculate the carbon emissions of 30 provinces in three regions of China from 2007 to 2019, take the per capita carbon emissions of logistics as an indicator to measure the regional inequality, give a comprehensive analysis of the regional inequality of the development of logistics in China, and finally decompose and analyze the driving factors causing the change of the inequality indicators, and give relevant policy recommendations.

3 Models and Methods

3.1 Carbon Emissions Accounting Method

Because the carbon emissions data can not be directly obtained from the statistical yearbook, this paper uses the carbon emission coefficient method to calculate the carbon emission of logistics in China. The logistics mainly consumes four kinds of energy: coal, crude oil, gasoline and kerosene. Therefore, this paper calculates the carbon emissions based on the consumption of these four kinds of energy. The calculation method is shown in formula (1).

$$C = \sum_{\mathrm{i}=1}^{4} E_i \theta_i \delta_i \tag{1}$$

where, C represents the carbon emissions, E_i represents the consumption of coal, crude oil, gasoline and kerosene, θ_i represents the conversion coefficient of standard coal for the four energy sources, and δ_i represents the carbon emission coefficient corresponding to the four energy sources published in the 2006 IPCC guidelines for national greenhouse gas inventories.

3.2 Theil Index

Theil index is an important indicator used to measure regional differences, which can effectively measure the overall regional differences, inter regional differences and intra regional differences. The Theil index is greater than or equal to 0, and the smaller the value, the smaller the regional difference. On the contrary, the greater the regional difference.

This paper uses the index of per capita carbon emission of logistics to measure the regional inequality of carbon emission of logistics in China. The basic form is shown in formula (2)–(4). Among them, T, T_b and T_w represent regional inequality, inter regional inequality and intra regional inequality respectively. j (j = 1, 2, 3,…, 30) represents different provinces, and k (k = 1, 2, 3) represents the eastern, central and western regions. P_j represents the population of province j, and P represents the total population. C_k and P_k respectively represent the total carbon emissions and population of all provinces in region k.

$$T = \sum_j \left(\frac{C_j}{C}\right) \ln\left(\frac{C_j/C}{P_j/P}\right) \tag{2}$$

$$T_{\mathrm{b}} = \sum_{\mathrm{k}} \left(\frac{C_{\mathrm{k}}}{C}\right) \ln\left(\frac{C_{\mathrm{k}}/C}{P_{\mathrm{k}}/P}\right) \tag{3}$$

$$T_{\mathrm{w}} = \sum_{\mathrm{k}} \left(\frac{C_k}{C}\right) T_{\mathrm{ek}} \tag{4}$$

where, $T_{\mathrm{ek}} = \sum_{\mathrm{j}=1}^{J_{\mathrm{k}}} \left(\frac{C_{\mathrm{j}}}{C_{\mathrm{k}}}\right) \ln\left(\frac{C_{\mathrm{j}}/C_k}{P_{\mathrm{j}}/P_k}\right)$ represents the inequality within the region k, and J_k represents the number of provinces included in the region k.

3.3 The Decomposition Analysis Method

The Kaya identity was first proposed by Yoichi kaya [15]. This identity decomposes the carbon emissions generated by energy consumption into the common influence of four factors, as shown in formula (5), where C, E, GDP and P represent carbon emissions, energy consumption, GDP and population respectively.

$$C = \frac{C}{E} \cdot \frac{E}{GDP} \cdot \frac{GDP}{P} \cdot P \tag{5}$$

Because Kaya identities have good characteristics of expansibility, many scholars have proposed extended Kaya identities based on the above initial identities. Fan proposed the following extended Kaya identity for the logistics [16], as shown in formula (6), where C_i represents the carbon emissions generated by the i-th energy consumption, E_i represents the consumption of the i-th energy, EL, GDPL, CT, GDP and P represent the energy consumption, the added value, the converted turnover, GDP and the population of logistics respectively, so the seven factors on the right side of the equation represent the carbon emission coefficient, the energy structure, the energy intensity, the added value of logistics per conversion turnover, the transportation intensity, the per capita GDP and the population are expressed by D_j (j = 0, 1, 2,…, 6) respectively.

$$C = \sum_{\mathrm{i}=1}^{n} \frac{C_i}{E_i} \cdot \frac{E_i}{EL} \cdot \frac{EL}{GDPL} \cdot \frac{GDPL}{CT} \cdot \frac{CT}{GDP} \cdot \frac{GDP}{P} \cdot P \tag{6}$$

LMDI model is a logarithmic mean index method proposed by ang [17]. It has been widely used in the research of energy economy because of its full decomposition, no residual error, easy to use and unique results. The decomposition method of per capita carbon emissions of logistics (CPC) based on LMDI model in this paper is shown in formula (7).

$$CPC = \frac{C}{P} = \sum_{\mathrm{i}} \frac{C_i}{E_\mathrm{i}} \cdot \frac{E_\mathrm{i}}{EL} \cdot \frac{EL}{GDPL} \cdot \frac{GDPL}{CT} \cdot \frac{CT}{GDP} \cdot \frac{GDP}{P} \tag{7}$$

First of all, the change of per capita carbon emissions of the logistics industry can be decomposed into the common influence of the following six driving factors, in which $\Delta C_{P0}^{\mathrm{t}}$, $\Delta C_{P1}^{\mathrm{t}}$, ΔC_{P2}^{t}, $\Delta C_{P3}^{\mathrm{t}}$, $\Delta C_{P4}^{\mathrm{t}}$, $\Delta C_{P5}^{\mathrm{t}}$ represent the change value of CPC in logistics caused by D_0, D_1, D_2, D_3, D_4 and D_5 respectively from the base period to the T period, and the sum is equal to $\Delta C_{P}^{\mathrm{t}}$. Since the carbon emission coefficients of various energy sources used in this study are constant values and have no actual impact on the change of carbon emissions, only the other five driving factors need to be considered. The calculation method of is shown in formula (8).

$$\begin{aligned}
\Delta C_P^t &= \Delta C_{P0}^t + \Delta C_{P1}^t + \Delta C_{P2}^t + \Delta C_{P3}^t + \Delta C_{P4}^t + \Delta C_{P5}^t \\
\Delta C_{P0}^t &= 0 \\
\Delta C_{P1}^t &= \sum_i W\big((C/P)_i^t, (C/P)_i^0\big) \ln\left(\frac{D_1^t}{D_1^0}\right) \\
\Delta C_{P2}^t &= \sum_i W\big((C/P)_i^t, (C/P)_i^0\big) \ln\left(\frac{D_2^t}{D_2^0}\right) \\
\Delta C_{P3}^t &= \sum_i W\big((C/P)_i^t, (C/P)_i^0\big) \ln\left(\frac{D_3^t}{D_3^0}\right) \\
\Delta C_{P4}^t &= \sum_i W\big((C/P)_i^t, (C/P)_i^0\big) \ln\left(\frac{D_4^t}{D_4^0}\right) \\
\Delta C_{P5}^t &= \sum_i W\big((C/P)_i^t, (C/P)_i^0\big) \ln\left(\frac{D_5^t}{D_5^0}\right)
\end{aligned} \tag{8}$$

Of which, $W\big((C/P)_{\mathrm{i}}^{\mathrm{t}}, (C/P)_{\mathrm{i}}^{0}\big) = \frac{(C/P)_i^t - (C/P)_i^0}{\ln(C/P)_{\mathrm{i}}^t - \ln(C/P)_i^0}$.

4 Empirical Research

4.1 Data Source and Description

Considering the availability of data, this study takes 30 provinces in three regions of China as the research object, calculates the carbon emissions of logistics in each province from 2007 to 2019, and analyzes the regional inequality and driving factors based on CPC indicators. Since logistics is mainly composed of transportation, warehousing and postal services, the relevant data of the logistics involved in this study are from the above three industries.

The basic data are mainly from the official website of the National Bureau of statistics, China Statistical Yearbook or China Energy Statistical Yearbook. Among them, the regional year-end resident population data are used for population, and the added value of logistics and GDP are converted at the constant price in 2007. The converted turnover is obtained by multiplying the passenger turnover by the conversion factor plus the freight turnover. The conversion factor is the conversion factor of passenger and freight turnover given by the Ministry of transport. The conversion factors of passenger and freight volumes of different modes of transport are shown in Table 1.

Table 1 Conversion coefficient of passenger volume and freight volume of different transportation modes

Type of shipping	Highway	Railway	Water transport
Conversion factor	0.1	1	1

4.2 Analysis on Carbon Emission Change of Logistics Industry in China

Figures 1 and 2 shows the national carbon emissions, carbon emission intensity and per capita carbon emissions from 2007 to 2019. It can be seen from the figure that except for the decline from 2012 to 2013, the carbon emissions of logistics in China have shown an overall upward trend in the past decade, from 183.28 million tons in 2007 to 307.64 million tons in 2019, an increase of 124.35 million tons, or about 68%. This shows that with the development of logistics, carbon emissions are also increasing.

From the perspective of carbon emission intensity, it can be seen that the carbon emission intensity of logistics is decreasing year by year. From the perspective of CPC, it can be seen that the CPC of logistics have been increasing as a whole in the

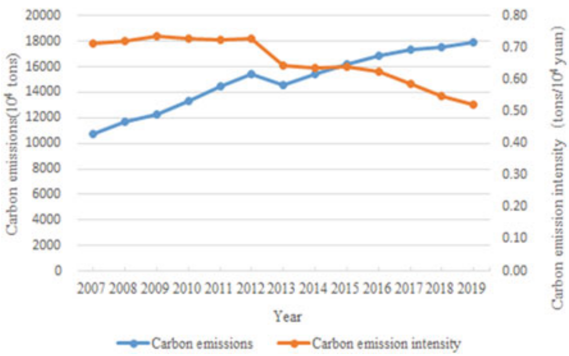


Fig. 1 Carbon emissions and carbon intensity of logistics in China during 2007–2019

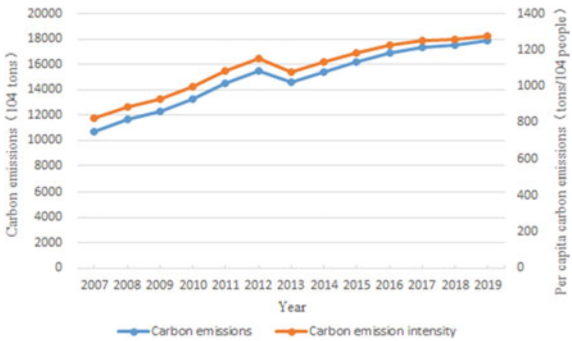


Fig. 2 Carbon emissions and per capita carbon emissions of logistics in China during 2007–2019

past decade, and the change of CPC is highly consistent with the change of carbon emissions, which indicates that the increase of CPC is the key factor leading to the increase of carbon emissions of logistic. How to effectively control the growth of carbon emissions per capita has become an important indicator to control the growth of carbon emissions.

Due to the obvious regional inequality in the development of logistics in China, this paper calculates and analyzes the carbon emissions of the three regions, as shown in Figs. 3 and 4. It can be seen that the carbon emissions of logistics in the three regions are on the rise as a whole, except that the carbon emissions of the eastern and western regions have decreased in some years. Among them, the carbon emission of logistics in the eastern region in 2019 increased by 29.23 million tons, or about 54% compared with that in 2007, showing a fluctuating growth trend. The central and western regions increased by 23.7 million tons and 18.57 million tons respectively, up 95% and 67% respectively.

In contrast, in terms of carbon emissions, the carbon emissions of logistics in the eastern region are significantly higher than those in the central and western regions. In 2007, the carbon emissions of the eastern region were about 29.61 million tons higher than those in the central region, and in 2019, about 35.15 million tons higher. In terms of growth, carbon emissions in the central region are increasing year by year,

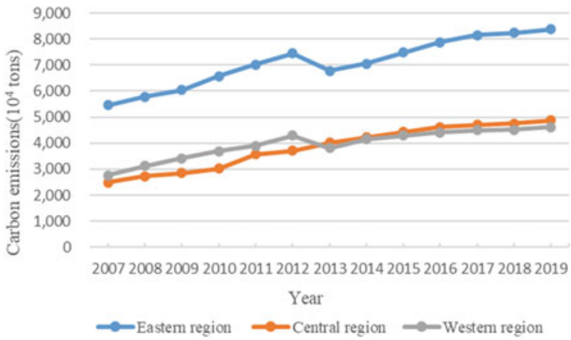


Fig. 3 Carbon emissions of logistics in three regions during 2007–2019

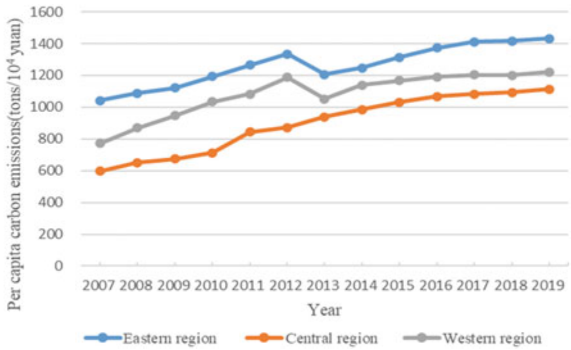


Fig. 4 Per capita carbon emissions of logistics in three regions during 2007–2019

with the highest growth rate, followed by the western region. In general, although the current carbon emissions in the central and western regions are lower than those in the eastern regions, due to the high growth rate, it is still an area that needs to be focused on in controlling the growth of carbon emissions in the national logistics.

In terms of CPC, the CPC of the logistics in the three regions are on the rise as a whole. The growing per capita carbon emission level has brought some pressure to the low-carbon development of the logistics. By comparison, the CPC in the eastern region are the highest in each year, which is higher than the national CPC curve on the whole, indicating that the busy logistics business in the eastern region has also brought more CPC. As an underdeveloped region of logistics, the carbon emission in the western region is close to that in the central region in each year, but its CPC is significantly higher than that in the central region. The central region has the lowest carbon emission per capita in each year, but the annual growth rate is large. Therefore, the growth rate of CPC in the central region also needs further attention.

4.3 Regional Unbalance Analysis

The regional inequality degree of China's logistics industry based on CPC index is abbreviated as T-CPC, which can be further decomposed into inter regional inequality degree and intra regional inequality degree, and the calculation results are shown in Fig. 5. Tb-CPC and Tw-CPC in the figure respectively represent the inter regional inequality and intra regional inequality of China's logistics industry based on CPC index.

It can be seen that the T-CPC is showing a declining trend, from 0.11 in 2007 to 0.07 in 2019, which shows that at the national level, the carbon emissions and population distribution are becoming more balanced.

The Tb-CPC and Tw-CPC also showed an overall downward trend. Tb-CPC decreased from 0.027 in 2007 to 0.006 in 2019, and Tw-CPC decreased from 0.080 to 0.066, with a decrease of 0.021 and 0.013 respectively. Comparing Tb-CPC and

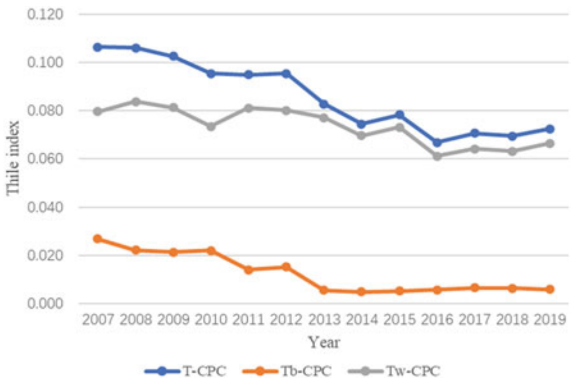


Fig. 5 T-CPC, Tb-CPC and Tw-CPC

Tw-CPC, it can be seen that compared with the inter regional gap, the internal differences of the three regions in China are significantly higher, which is the main reason for the regional inequality of per capita carbon emissions of logistics in China.

In order to further analyze the performance of the three regions in terms of regional inequality, Table 2 shows the contribution rate of the internal differences of the three regions to the regional inequality in the national logistics based on the CPC indicators in the past decade. It can be seen that, from the average value, the eastern region has the largest internal difference, with the highest contribution value of 46%, followed by the western region, with the contribution rate of 25%, while the central region has the smallest internal difference, with the contribution value of 15%.

4.4 Analysis on Driving Factors of Carbon Emissions Inequality in Logistics at National Level

In the analysis of regional inequality, this paper concludes that the degree of internal inequality of the logistics in the three regions based on CPC indicators is higher than that among regions, and the regional inequality is also the main reason for the national regional inequality. In order to explore the causes of the change of the inequality index, this paper decomposes the change of CPC into different driving factors. Among them, the breakdown results of driving factors of CPC change in the national logistics are shown in Table 3.

According to the Table 3, the CPC of the national logistics has increased in the past ten years, which is promoted by the per capita GDP and the added value of logistics per converted turnover, and restrained by the energy structure, energy intensity and transportation intensity.

The energy structure has little impact on the change of CPC of the logistics, and the total contribution rate from 2007 to 2019 is only −2.20%. The energy structure of the logistics represents the use of all kinds of energy by the logistic. Considering that the logistics is a high-energy consuming industry, the main energy consumption of logistics during the study period is still traditional energy such as coal, gasoline, kerosene and diesel. If the logistics can improve the energy structure and use more green energy such as natural gas and clean coal, it will inhibit the growth of CPC.

The energy intensity of the logistics has inhibited the growth of CPC in China, and the total contribution rate has reached -82.46%, which shows that the energy utilization efficiency of logistics is constantly improving, and it has effectively suppressed the growth of CPC of logistics in China.

The added value of the logistics per conversion of turnover plays a role in promoting the growth of CPC of logistics in China. From 2007 to 2019, the CPC increased with a total contribution rate of 37.06%. On the whole, with the continuous improvement of transportation economic benefits of logistics, the role of CPC in logistics has begun to change from a suppression to a promotion role, which shows that the logistics is pursuing the improvement of transportation economic

Table 2 Contribution rate of internal differences of CPC in three regions to regional inequality in China

Region	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)
Eastern region	37	33	36	34	31	29	43	50	49	59	62	70	69
Central region	15	24	20	14	20	15	12	15	13	18	14	8	10
Western region	23	22	24	29	34	40	38	28	31	15	15	13	12

Table 3 Decomposition results of driving factors of CPC in logistics at national level

Year	ΔC_{P1}^{t}	ΔC_{P2}^{t}	ΔC_{P3}^{t}	ΔC_{P4}^{t}	ΔC_{P5}^{t}	ΔC_{P}^{t}
2007–2008	1.41	9.11	−17.85	−18.42	89.94	64.19
2008–2009	−0.19	19.03	−65.82	−4.18	93.24	42.07
2009–2010	0.42	−13.76	−64.14	32.60	111.87	66.99
2010–2011	4.09	−10.19	−36.22	16.52	110.44	84.63
2011–2012	−1.19	8.91	−4.40	−38.67	102.80	67.46
2012–2013	1.66	−135.96	154.72	−184.07	94.58	−69.06
2013–2014	−0.85	−12.56	−56.14	42.42	81.96	54.84
2014–2015	−0.77	7.55	104.42	−141.25	80.16	50.11
2015–2016	−5.26	−24.89	5.96	−10.99	77.48	42.30
2016–2017	−2.90	−78.55	−70.24	−87.99	263.78	24.11
2017–2018	−5.37	−81.44	70.93	−89.09	110.45	5.48
2018–2019	−0.97	−60.07	146.35	−150.83	84.54	19.01
The sum	−9.94	−372.81	167.57	−633.95	1301.26	452.13
Total contribution rate	−2.20%	−82.46%	37.06%	−140.21%	287.81%	–

benefits while the environmental benefits are low. The balance between transportation economic benefits and environmental benefits is one of the key issues in carbon emission governance in the logistics industry in the future.

Transportation intensity has played a major inhibitory role in the growth of CPC of logistics in China, reducing the CPC with a total contribution rate of −140.21% in the past ten years. Transportation intensity reflects the dependence between GDP growth and converted turnover, and the lower the value, the lower the dependence of GDP on converted turnover. The research results show that the dependence of GDP growth of logistics on the real economy has decreased, and it has inhibited the growth of per capita carbon emissions in the logistics industry.

The per capita GDP is the main factor leading to the growth of per capita carbon emissions in the logistics. In the past ten years, it has promoted the growth of CPC with a contribution rate of 287.81%. The improvement of per capita GDP reflects the overall improvement of people's living standards, and in view of its greater role in promoting per capita carbon emissions in the logistics industry, it shows that China should pay attention to improving people's awareness of low-carbon life while improving people's living standards. This can effectively control the growth of CPC in logistics.

4.5 Analysis on Driving Factors of Carbon Emissions Inequality in Logistics at Regional Level

Based on the LMDI method, the decomposition results of the driving factors for the change of CPC of the logistics in the eastern, central and western regions are calculated respectively, as shown in Tables 4, 5 and 6. The total contribution rate of the five driving factors to the change of CPC in the logistics industry is shown in Fig. 6. It can be seen that the energy structure of the logistics industry has a relatively small impact on the change of CPC of the logistics in the whole country and the three regions, and its contribution rates to the three regions in the Eastern, central and western regions are −1.90%, −2.06% and −3.75% respectively.

According to Fig. 6, the logistics energy intensity has inhibited the growth of CPC of logistics in the three regions. For the eastern region, the change of energy intensity during 2007–2019 has restrained the CPC with a total contribution rate of −132.12%. Comparing the central region with the eastern region, the inhibition effect of energy intensity on the CPC of logistics in the central region is lower, and the absolute difference of contribution rate is 97.45%. To further reduce the CPC of logistics, the central region should move closer to the eastern region in terms of controlling energy intensity, so as to give more effective play to the inhibitory effect of energy intensity on CPC; The inhibitory effect of energy intensity on the growth of CPC in the western region is between the eastern and central regions. It has inhibited the CPC with a total contribution rate of −83.11% during 2007–2019.

Table 4 Decomposition results of driving factors of CPC in logistics in eastern region

Year	ΔC_{P1}^{t}	ΔC_{P2}^{t}	ΔC_{P3}^{t}	ΔC_{P4}^{t}	ΔC_{P5}^{t}	ΔC_{P}^{t}
2007–2008	−0.84	−12.02	187.89	−227.24	100.22	48.01
2008–2009	−0.28	10.56	−113.28	34.69	100.39	32.07
2009–2010	0.07	−8.00	−92.28	60.65	111.77	72.22
2010–2011	−0.86	−31.91	−33.74	23.27	114.74	71.49
2011–2012	−0.06	2.84	35.09	−73.64	105.87	70.10
2012–2013	1.02	−202.38	238.35	−267.05	101.65	−128.40
2013–2014	−0.40	−33.19	−113.04	101.15	86.34	40.88
2014–2015	−1.76	20.64	89.39	−127.68	86.25	66.84
2015–2016	−1.25	−18.37	−11.15	11.03	79.46	59.71
2016–2017	−2.66	−76.85	−164.54	14.43	267.35	37.73
2017–2018	−1.05	−95.96	146.09	−154.83	111.88	6.14
2018–2019	0.64	−73.05	154.02	−152.31	85.75	15.05
The sum	−7.43	−517.69	322.81	−757.53	1351.67	391.84
Total contribution rate	−1.90%	−132.12%	82.39%	−193.33%	344.96%	–

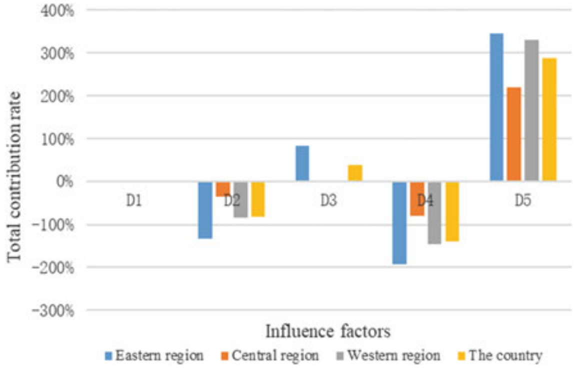
Table 5 Decomposition results of driving factors of CPC in logistics in central region

Year	ΔC_{P1}^{t}	ΔC_{P2}^{t}	ΔC_{P3}^{t}	ΔC_{P4}^{t}	ΔC_{P5}^{t}	ΔC_{P}^{t}
2007–2008	2.233	40.213	−245.306	202.436	97.423	96.999
2008–2009	−0.500	49.469	−35.758	−48.845	111.161	75.528
2009–2010	−1.907	−8.751	−39.321	−2.666	140.183	87.538
2010–2011	1.643	−44.585	−48.268	6.650	134.769	50.208
2011–2012	8.619	36.587	−46.538	−19.634	126.864	105.898
2012–2013	5.064	−207.790	143.378	−185.581	107.339	−137.590
2013–2014	−4.294	25.031	5.356	−26.565	88.575	88.104
2014–2015	−0.957	−11.600	86.712	−131.123	85.521	28.552
2015–2016	−16.833	−31.296	28.716	−42.954	83.699	21.333
2016–2017	−4.699	−82.172	48.688	−247.786	299.380	13.411
2017–2018	−3.348	−85.871	−63.427	29.021	121.741	−1.885
2018–2019	−1.881	−52.723	174.083	−188.026	89.835	21.288
The sum	−16.86	−373.49	8.32	−655.07	1486.49	449.38
Total contribution rate	−3.75%	−83.11%	1.85%	−145.77%	330.78%	–

Table 6 Decomposition results of driving factors of CPC in logistics in western region

Year	ΔC_{P1}^{t}	ΔC_{P2}^{t}	ΔC_{P3}^{t}	ΔC_{P4}^{t}	ΔC_{P5}^{t}	ΔC_{P}^{t}
2007–2008	2.233	40.213	−42.870	−202.436	299.859	96.999
2008–2009	−0.500	49.469	−84.602	48.845	62.316	75.528
2009–2010	−1.907	−8.751	−41.987	2.666	137.517	87.538
2010–2011	1.643	−44.585	−41.618	−6.650	141.419	50.208
2011–2012	8.619	36.587	−66.171	19.634	107.230	105.898
2012–2013	5.064	−207.790	−42.203	185.581	−78.242	−137.590
2013–2014	−4.294	25.031	−21.209	26.565	62.010	88.104
2014–2015	−0.957	−11.600	−44.411	131.123	−45.603	28.552
2015–2016	−16.833	−31.296	−14.237	42.954	40.745	21.333
2016–2017	−4.699	−82.172	−199.098	247.786	51.594	13.411
2017–2018	−3.348	−85.871	−34.406	−29.021	150.762	−1.885
2018–2019	−1.881	−52.723	−13.943	188.026	−98.191	21.288
The sum	−16.86	−373.49	−646.76	655.07	831.42	449.38
Total contribution rate	−3.75%	−83.11%	−143.92%	145.77%	185.01%	–

Fig. 6 Contribution rate of driving factors to CPC in China and three regions during 2007–2019



The added value of logistics industry per converted turnover has promoted the growth of CPC of logistics in the eastern region, with a total contribution rate of 82.39% during 2007–2019. The improvement of this factor is the performance of the improvement of the transportation economic benefits of the logistics, and the improvement of this factor promotes the improvement of CPC to a great extent. Therefore, how to balance the transportation economic benefits and environmental benefits is one of the urgent issues in the eastern region. At the same time, the added value of logistics industry per converted turnover has restrained the CPC of logistics in the central region, with a total contribution rate of −3.33%. The added value of logistics industry per converted turnover has also played a certain role in promoting the growth of CPC of logistics in the western region.

The change of transportation intensity has a certain inhibitory effect on the growth of CPC of logistics in the three regions, of which the contribution rate to the CPC growth in the eastern region is −193.33%. This shows that the dependence of GDP growth in the eastern region on the converted turnover has decreased, which has played a good role in curbing the growth of CPC. At the same time, the change of transportation intensity has also played a certain role in restraining the growth of CPC of logistics in the central and western regions, with contribution rates of −79.36% and −145.77% respectively. However, in terms of absolute value, the transportation intensity in the western region is much higher than that in the eastern and central regions, indicating that there is still much room for decline in the transportation intensity in the western region. Improving the transportation intensity is an important way for the western region to control the growth of CPC of logistics in the future.

According to Fig. 6, the change of per capita GDP is the most important factor to promote the growth of CPC of logistics in the three regions. First of all, from the perspective of cumulative effect, the CPC of logistics in the eastern, central and western regions increased by 392 tons, 517 tons and 449 tons per 10 thousand people respectively from 2007 to 2019, of which the CPC growth value caused by the change of per capita GDP reached 1352 tons, 1135 tons and 1486 tons per 10 thousand people respectively, all exceeding the actual CPC growth value of the three regions. This showed that the added value of CPC in the three regions is much higher than the actual level if other factors are not considered and only the impact of changes in per capita GDP is considered. According to China's national conditions, the level of per capita GDP will continue to improve in the future, but the huge role of per capita GDP change in Promoting CPC growth is a common problem that the three regions should face in the process of developing low-carbon logistics. To realize the decoupling relationship between per capita GDP growth and CPC of logistics by improving consumers' awareness of environmental protection and other ways will help to achieve effective control over the growth of CPC of logistics in China.

5 Conclusions and Policy Recommendations

In order to study the inequality of carbon emissions of regional logistics in China, this paper first calculates and analyzes the carbon emissions of three regions in China from 2007 to 2019, and then analyzes the changes of carbon emissions per capita in the three regions. In order to quantify the regional inequality of carbon emissions of regional logistics in China, this paper calculates the regional inequality degree of regional logistics in China based on the per capita carbon emissions index through Theil index, and further decomposes it into the degree of inter regional inequality and intra regional inequality. Finally, the LMDI model is used to analyze the driving factors of carbon emissions inequality of regional logistics in China.

The main conclusions of this paper are as follows:

(1) From 2007 to 2019, the carbon emissions and per capita carbon emissions of logistics in China continued to increase, while the carbon emission intensity continued to decrease. The development of low-carbon logistics has achieved some results; The change of per capita carbon emissions of logistics is highly consistent with the change of carbon emissions, indicating that the increase of per capita carbon emissions is the key factor leading to the growth of carbon emissions. How to effectively control the growth of per capita carbon emissions has become an important indicator to control the growth of carbon emissions; From a subregional perspective, the carbon emissions and per capita carbon emissions of the logistics in the eastern region are higher than those in the central and western regions.
(2) The degree of regional inequality of regional logistics in China based on per capita carbon emission index shows an overall downward trend. In addition, the degree of regional inequality of regional logistics in China is significantly higher than that between regions; The internal difference of logistics in the eastern region has a high contribution rate to the national regional inequality, and the contribution rate is still rising in recent years.
(3) At the national level, the change of logistics added value and per capita GDP per conversion turnover from 2007 to 2019 has promoted the growth of per capita carbon emissions of regional logistics in China, while the change of logistics energy intensity and transportation intensity has restrained the increase

of per capita carbon emissions, while the change of logistics energy structure has no obvious effect on per capita carbon emissions; From the perspective of subregions, the contribution directions of each driving factor to the change of carbon emissions per capita in the three regions are basically the same, but the contribution rates are quite different. Narrowing these differences will help to achieve the coordinated development of low-carbon logistics.

Based on the above conclusions, the following policy recommendations can be obtained:

(1) Energy structure of logistics. The energy structure of the logistics represents the use of various types of energy by the logistics. Among the five driving factors concerned, the impact of the energy structure of the logistics on the per capita carbon emissions of the logistics in the three regions is small. To give full play to the potential role of the energy structure in controlling the growth of carbon emissions in the logistics, the state can increase support for the research and use of new energy, and promote the logistics to increase the proportion of clean energy in energy investment, so as to improve the energy structure.
(2) Energy intensity of logistics. The energy intensity of the logistics represents the energy utilization efficiency of the logistics. The central and western regions need to learn from the eastern regions in controlling the energy intensity. They can improve the energy utilization efficiency of the logistics by introducing relevant patented technologies and implementing high energy consumption taxes, narrow the gap with the Eastern regions, and more effectively play the role of the energy intensity of the logistics in restraining the growth of carbon emissions per capita.
(3) Value added of logistics per conversion turnover. The added value of the logistics per conversion Turnover represents the economic benefits that each conversion turnover can bring. The development of logistics in China should fully balance the environmental benefits while improving the economic benefits. As the most developed and prosperous region of logistics in China, the eastern region should take the lead in incubating advanced logistics management concepts, using data mining and other technologies to improve transportation routes, improve transportation efficiency, reduce the no-load rate and avoid too far logistics, so as to improve the transportation rationality and efficiency of the logistics, and promote the green logistics system to realize the healthy economic ecological development in theory, technology and other aspects.
(4) Transportation intensity. Transportation intensity reflects the dependence between GDP growth and conversion turnover. The contribution of transportation intensity in the central and western regions to reducing per capita carbon emissions of the logistics is significantly lower than that in the eastern region. Local governments in the central and western regions should strengthen the management and control of high emission logistics projects by adjusting industrial structure and production layout, and improve the management and control of high added value Low emission logistics projects should be supported to

improve the per capita carbon emissions of the logistics industry and further exert the restraining effect of transportation intensity on carbon emissions.

(5) Per capita GDP. We should continue to improve our people's understanding of low-carbon logistics, guide people to choose green and low-carbon travel modes as much as possible, advocate a low-carbon and green consumption concept, and force the logistics to pay attention to the realization of low-carbon operation modes such as green packaging, green processing and green circulation in the process of the whole industrial chain, so as to curb the growth of carbon emissions of the logistics with the help of the improvement of the overall low-carbon awareness of the people.

(6) In order to improve the unbalanced regional development in the process of low-carbon development of logistics in China, we should also focus on the problem of excessive differences within the three regions. We can take advantage of geographical proximity to strengthen the cooperation and exchange between provinces and cities in logistics operation and management mode, so as to effectively reduce the unbalanced development of low-carbon logistics within the region.

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Measurement of China's Regional Logistics Industry Carbon Emission Efficiency and Its Influencing Factors

Zengguo Liu

Abstract To achieve the goal of carbon peaking and carbon neutrality through the development of green logistics in China, this paper uses SBM model to calculate the carbon emission efficiency of logistics industry in 30 provinces in China from 2011 to 2019, and empirically studies the influencing factors of carbon emission efficiency of logistics industry with panel Tobit model. The results show that: (1) China's logistics industry carbon emission efficiency shows a slowly upward trend of volatility, which has a large space for improvement. (2) There are significant differences in the carbon emission efficiency of logistics industry among different regions. During the study period, the carbon emission efficiency of logistics industry in eastern China is always higher than that in central and western China. (3) The degree of opening-up and the level of transportation infrastructure have a significant positive effect on the carbon emission efficiency of China's logistics industry, and government logistics regulation is not conducive to the improvement of the carbon emission efficiency of logistics industry. (4) Urbanization level has a significant negative impact on the carbon emission efficiency of logistics industry in eastern China, while transportation infrastructure level has a significant positive impact. Urbanization level and government logistics regulation have a significant negative impact on the carbon emission efficiency of logistics industry in central China. The degree of opening-up and environmental regulation have a significant negative impact on the carbon emission efficiency of logistics industry in western China. This study believes that improving the foreign investment environment of logistics industry, strengthening the construction of transportation infrastructure and optimizing the government logistics regulation system will be of great help to improve the carbon emission efficiency of China's logistics industry and achieve the goal of carbon peaking and carbon neutrality.

Keywords Logistics industry · Carbon emission efficiency · Influencing factors

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1 Introduction

Since the reform and opening up, the development mode of "high input, high consumption and high emission" has enabled China to achieve rapid economic growth, but this development mode has also led to the inefficient utilization of a large number of resources and the intensification of environmental pollution. In 2006, China surpassed the United States to become the world's largest carbon dioxide emitter. In order to cope with the increasingly serious environmental problems, China has promised the international community to achieve clear emission reduction targets. China has pledged to strive to peak carbon emissions by 2030, and strive to achieve carbon neutrality by 2060.

With the rapid development of domestic economy, international trade, and globalization, demand for logistics service is surging in many countries. In China, logistics industry has emerged and experienced dramatic growth. It is known as the "accelerator" and the "third profit source" of economic development. In 2021, the construction of China's logistics system was steadily promoted, and the logistics supply services maintained rapid growth. The total revenue of the logistics industry in the whole year was 11.9 trillion yuan, an increase of 15.1% year-on-year. However, the development of the logistics industry still belongs to the factor input type, with high energy consumption and high emissions. With the increasingly serious problems of resources and environment in China, the traditional and extensive development mode of logistics industry cannot be sustained. Evaluating the carbon emission efficiency of logistics industry and exploring its influencing factors are of great significance to reduce China's overall carbon emissions and build a green logistics system. Promoting the logistics industry from factor input driven to efficiency-oriented development is also an important way to achieve the sustainable development of logistics.

Many scholars have been exploring how to improve the carbon emission efficiency of logistics industry, and seeking the coordination strategy between economic growth and carbon emission reduction. In terms of efficiency evaluation, scholars mainly use stochastic frontier method and data envelopment analysis to evaluate the carbon emission efficiency of logistics industry [1–3]. For the carbon emission indicator, some studies regard it as an input, and some studies use linear transformation and distance function to deal with it. In terms of influencing factors, scholars have explored the impact of information technology, industrial structure, management system and other factors on the efficiency of the logistics industry based on the provincial and urban levels. The regression methods mainly include Tobit model, spatial lag model (SLM), and spatial error model (SEM) [4, 5].

The major contributions of this article are: (1) We add the carbon emission index to the efficiency evaluation index system of the logistics industry, and calculate the carbon emission efficiency of China's logistics industry by using the SBM model with undesirable output, so as to evaluate the efficiency of the logistics industry more comprehensively and scientifically. (2) We explore the influencing factors of carbon emission efficiency of logistics industry from the three aspects of regional economic environment, logistics industry environment and logistics policy environment, and empirically test the impact of each factor on carbon emission efficiency and its regional heterogeneity by constructing a panel Tobit model. The results of empirical analysis can provide reference for the formulation of relevant policies.

The remainder of this paper is arranged as follows. A related literature review is present in Sect. 2. Section 3 constructs the methodologies. The results together with discussions are present in Sect. 4. Section 5 concludes this article and proposes corresponding policy recommendations.

2 Literature Review

2.1 Calculation Methodology

DEA model is the main method to measure the carbon emission efficiency of logistics industry. It can deal with a system with multiple inputs and outputs, and can avoid inaccurate results due to the use of incorrect functions [6]. Scholars have evaluated the carbon emission efficiency of logistics industry by using different DEA models.

Some scholars used radial DEA model to calculate the carbon emission efficiency of logistics industry. Lan and Zhang took the capital stock, labor force and carbon dioxide emissions of the transport sector as input indicators, took the added value of the transport sector as an output indicator, and applied the CCR model to calculate the carbon emission efficiency of the logistics industry in 30 provinces of China between 2006 and 2010 [7]. Yang et al. used BCC model and Malmquist index to evaluate logistics industry carbon emission performance at the city level [8]. Chen et al. took the carbon dioxide emission of the transportation sector as an important input index, and used CCR model and BCC model to calculate the carbon emission efficiency of Beijing's logistics industry from 2000 to 2017 [9].

However, the treatment of undesirable outputs by CCR model and BCC model may lead to inaccurate efficiency measurement results. Considering that carbon emission is an important indicator for the efficiency evaluation of logistics industry, scholars began to use SBM model to evaluate the carbon emission efficiency of logistics industry. For example, Mariano et al. applied the SBM model to measure and rank the logistics performance of 104 countries [10]. Li et al. took carbon dioxide emissions as an indicator of undesirable output, and applied the super-SBM DEA model with undesirable output to calculate China's integrated transport efficiency [11].

2.2 Influencing Factors

In terms of influencing factors, industrial economics believes that demand growth, ownership structure and information technology are crucial to logistics efficiency

[12, 13]. Enterprise economics focuses on the impact of business strategy, management system and organizational management on the logistics industry [14, 15]. In the empirical research, scholars mainly focus on the regional logistics industry efficiency and enterprise logistics efficiency to explore the influencing factors of carbon emission efficiency of logistics industry.

The main methods to analyze the influencing factors mainly include traditional econometrics and spatial econometrics. In terms of traditional econometric methods, scholars mainly use Tobit model to explore the influencing factors of carbon emission efficiency of logistics industry. For example, Cui and Li applied Tobit model to conduct empirical analysis on the basic factors affecting carbon emission efficiency in the transportation process. They found that technology and management were the most important factors [16]. Some scholars use spatial econometric methods to explore the influencing factors of carbon emission efficiency of logistics industry. For example, Yuan et al. used SLM model and found that energy saving level had a significant positive impact on transport carbon intensity, while transport structure, income level, transport intensity and population size had a significant negative impact on transport carbon intensity [17].

2.3 General Summary

Based on the existing research, it can be found that scholars pay more and more attention to the measurement of carbon emission efficiency of logistics industry, and have conducted relatively extensive empirical research. However, the existing research still has the following aspects that can be expanded and deepened: (1) The radial DEA model assumes that the input indicators or output indicators change in the same proportion, which makes it impossible to deal with the problem of slack variables. At the same time, the radial DEA model takes the undesirable output as the input index or carries on the linear transformation to it, which will lead to the inaccurate calculation results. Therefore, the results of scholars using radial DEA model to measure the carbon emission efficiency of logistics industry may be inconsistent with the reality. (2) A large number of literatures mainly study the influencing factors of logistics industry efficiency, but there is little research on the influencing factors of logistics industry carbon emission efficiency. At the same time, in the selection of influencing factors of logistics industry carbon emission efficiency, the existing research is lack of systematic integration of influencing factors, unable to comprehensively explore the influencing factors of logistics industry carbon emission efficiency.

Therefore, this paper measures the carbon emission efficiency of China's logistics industry by constructing a SBM model with undesirable output, and evaluates the carbon emission efficiency from two aspects of time change and spatial distribution. We select the influencing factors of logistics industry carbon emission efficiency from the three aspects of regional economic environment, logistics industry environment and logistics policy environment for empirical analysis, and further analyze the regional heterogeneity of the impact of various factors on logistics industry carbon emission efficiency.

3 Methodology

3.1 The SBM DEA Model with Undesirable Output

As a nonparametric analysis method, data envelopment analysis (DEA) does not need to set the specific form of the function in advance, and mainly includes radial model and non-radial model. The radial DEA model assumes that the input indicators or output indicators change in the same proportion, and the slack improvement is not reflected in the measurement of efficiency value. At the same time, when the radial DEA model is used to solve the undesirable output problems, the undesirable output must be transformed into input index or processed by using distance function. However, this kind of transformation will lead to the loss of the authenticity of the data itself.

Therefore, this paper uses the SBM model with undesirable output to evaluate the carbon emission efficiency of logistics industry proposed by Tone [18], which can not only solve the problem of slack variables, but also solve the problem of undesirable outputs. The SBM model with undesirable output is constructed as follows:

$$min\ E_0 = \frac{1 - \frac{1}{m}\sum_{t=1}^{m}\frac{s_t^-}{X_0}}{1 + \frac{1}{q_1+q_2}\left(\sum_{k=1}^{q_1}\frac{s_k^+}{Y_0^g} + \sum_{l=1}^{q_2}\frac{s_l^-}{Y_0^b}\right)}$$
$$\begin{cases} X\lambda + s_t^- = X_0 \\ Y^g\lambda - s_k^+ = Y_0^g \\ Y^b\lambda + s_l^- = Y_0^b \\ s_t^- \geq 0; s_k^+ \geq 0; s_l^- \geq 0; \lambda \geq 0 \end{cases} \tag{1}$$

In Eq. (1), X_0, Y_0^g and Y_0^b respectively represent the input, desirable output and undesirable output of DMU_0; there are m inputs, q_1 desirable outputs and q_2 undesirable outputs in each DMU; the efficiency value E_0 varies from 0–1; s_t^-, s_k^+, s_l^- denote the slacks of input, desirable output and undesirable output respectively; λ represents weight.

3.2 Tobit Regression Model

In order to further reveal the influencing factors of logistics industry carbon emission efficiency, we take the logistics industry carbon emission efficiency of each province as the explained variable, and construct a multiple linear regression model. Since the efficiency measured by Eq. (1) is truncated data, the use of least square regression will produce biased results. And using panel Tobit model can reduce the estimation deviation [19]. Therefore, we choose Tobit regression model, which is shown in Eq. (2):

$$\begin{aligned} y_i^* &= x_i'\beta + \mu_i \quad u_i \sim N\left(0, \sigma^2\right) \\ y_i &= \begin{cases} y_i^* \text{ if } y_i^* > 0 \\ 0 \text{ if } y_i^* \ll 0 \end{cases} \end{aligned} \tag{2}$$

In Eq. (2), y_i is the explained variable; x_i is the explanatory variable; and β is the regression coefficient.

3.3 Variables and Data

3.3.1 The Indicators of Carbon Emissions Efficiency

The carbon emission of the logistics industry mainly comes from the consumption of energy, but the energy consumption must be combined with capital and labor to play its role. Therefore, based on previous relevant research [20, 21], this paper has established a full factor index system, which is shown in Table 1.

The input indicators mainly include human, material and energy input. The logistics industry is a typical labor-intensive industry. In this paper, the number of employees in the logistics industry is used to represent human input. In addition, the construction of logistics infrastructure, logistics parks and demonstration parks also need a lot of capital investment. This paper uses the fixed asset investment of logistics industry to represent capital investment. The carbon emission of logistics industry mainly comes from the consumption of various energy sources, so this paper uses the energy consumption of logistics industry to represent the energy input. The

Table 1 The indicators of carbon emissions efficiency

Indicator types	Indicators	Variables and unit
Input indicators	Capital	Fixed capital investment (10^8 yuan)
	Labor	Employed population (10^4)
	Energy	Energy consumption (10^4 t of standard coal)
Output indicators	GDP	GDP (10^8 yuan)
	Carbon emission	Carbon emissions (10^4 t)

Table 2 Standard coal coefficient, carbon emissions coefficient of different fuel types

Fuels	Standard coal coefficient kgce/kg	Carbon emissions coefficient (kg-CO_2/kg)
Raw coal	0.7143	0.7559
Gasoline	1.4714	0.5538
Natural gas	1.3300	0.4438

output indicators mainly include GDP of logistics industry and carbon emissions, of which carbon emissions are undesirable outputs.

For the calculation of carbon emission of logistics industry, this paper determines that the carbon emission source of logistics industry is formed by the consumption of raw coal, gasoline and natural gas, and uses the most widely used IPCC emission coefficient method for calculation. The equation is as follows:

$$C = \sum_{i=1}^{4} E_i \times Q_i \times T_i \tag{3}$$

In Eq. (3), C denotes the total carbon emissions; E_i, Q_i, T_i represent the consumption of fuel i, standard coal coefficient, carbon emissions coefficient. The standard coal coefficient and carbon emissions coefficient are listed in Table 2.

3.3.2 The Variables of Influencing Factors

Based on the existing research [22, 23], this paper explores the comprehensive driving factors of carbon emission efficiency of logistics industry from three aspects: regional economic environment, logistics industry environment and logistics policy environment. The meaning and measurement method of each variable are shown in Table 3.

We collect data of Tables 1, 2 and 3 from 2011 to 2019. The data is cited from National Bureau of Statistics of China (2012–2020).

Table 3 Main variables and their measures

Level	Variable	Variable name	Calculation method
Regional economic environment	Urbanization level	ul	Proportion of urban population
	Degree of opening-up	fdi	Proportion of foreign direct investment in regional GDP
Logistics industry environment	Informatization level	inf	Number of Internet broadband access users per 100 people
	Transportation infrastructure level	tra	Length of traffic route per unit area

(continued)

Table 3 (continued)

Level	Variable	Variable name	Calculation method
Logistics policy environment	Government logistics regulation	gov	Proportion of transportation expenditure in provincial financial expenditure
	Environmental regulation	er	Proportion of completed investment in industrial pollution control in regional GDP

4 Empirical Results and Discussion

4.1 Carbon Emissions Efficiency Measurement

4.1.1 Analysis of Time Evolution Characteristics of Carbon Emission Efficiency

The SBM model with undesirable output is used to calculate the carbon emission efficiency of logistics industry in 30 provinces of China from 2011 to 2019 by using MATLAB software. The calculation results of carbon emission efficiency are shown in Table 4. In order to analyze the time evolution characteristics of carbon emission efficiency of logistics industry, this paper draws the time evolution chart of carbon emission efficiency, and the results are shown in Fig. 1.

From the national level, the carbon emission efficiency of China's logistics industry changed slowly during the investigation period. The carbon emission efficiency of logistics industry increased from 0.27 to 0.34, with a growth rate of 26%. Although the investment in capital, labor and energy increased, the carbon emission increased at the same time. The overall efficiency value did not show a rapid upward trend, indicating that the utilization rate of various resources was low and the carbon emission efficiency did not significantly improve.

From the regional level, the carbon emission efficiency of logistics industry in the eastern, central and western regions of China showed a fluctuating upward trend, and the regional differences were gradually expanding. Among them, the carbon emission efficiency of logistics industry in the eastern region increased from 0.34 to 0.48, with a growth rate of 41%. The carbon emission efficiency was higher than the national level. The carbon emission efficiency of logistics industry in the central region increased from 0.29 to 0.33, with a growth rate of 14%. The carbon emission efficiency was close to the national level. The carbon emission efficiency of logistics industry in the western region increased from 0.17 to 0.20, with a growth rate of 18%, and the carbon emission efficiency was lower than the national level. The reason is that the eastern region has strong economic strength, superior logistics industry environment, high technology and management level, and the development of logistics industry is at the national leading level. The economic foundation of the central region and the western

Table 4 Calculation results of carbon emission efficiency of logistics industry

Area	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean	Rank
Beijing	0.24	0.18	0.25	0.19	0.22	0.26	0.24	0.40	0.38	0.26	11
Tianjin	0.39	0.31	0.61	0.34	0.34	0.40	1.00	1.00	0.53	0.54	4
Hebei	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
Shanxi	0.14	0.15	0.16	0.15	0.16	0.17	1.00	0.21	0.19	0.26	12
Inner Mongolia	0.16	0.15	0.17	0.17	0.17	0.19	0.21	0.42	0.34	0.22	15
Liaoning	0.13	0.13	0.13	0.12	0.16	1.00	1.00	0.28	0.33	0.36	8
Jilin	0.18	0.18	0.19	0.15	0.13	0.13	0.12	0.19	0.18	0.16	22
Heilongjiang	0.09	0.10	0.11	0.10	0.08	0.08	0.08	0.12	0.10	0.09	30
Shanghai	0.34	1.00	1.00	1.00	1.00	1.00	0.60	1.00	1.00	0.88	2
Jiangsu	0.46	1.00	0.49	0.33	0.24	0.25	0.23	0.40	0.35	0.42	7
Zhejiang	0.22	0.20	0.24	0.21	0.20	0.21	0.18	0.22	0.22	0.21	17
Anhui	1.00	1.00	1.00	0.40	0.29	0.30	0.27	1.00	1.00	0.69	3
Fujian	0.30	0.30	0.24	0.20	0.19	0.20	0.18	0.21	0.22	0.22	13
Jiangxi	0.26	0.33	0.64	0.25	0.22	0.24	0.28	0.30	0.27	0.31	9
Shandong	0.32	0.33	0.52	0.41	0.38	0.41	0.45	1.00	0.56	0.49	5
Henan	0.29	0.42	0.50	1.00	0.27	0.32	0.38	0.56	0.49	0.47	6
Hubei	0.17	0.17	0.20	0.19	0.19	0.18	0.18	0.22	0.23	0.19	18
Hunan	0.22	0.25	0.24	0.21	0.20	0.20	0.19	0.22	0.20	0.22	16
Guangdong	0.19	0.20	0.23	0.21	0.21	0.22	0.19	0.29	0.26	0.22	14
Guangxi	0.15	0.14	0.17	0.14	0.14	0.14	0.13	0.15	0.14	0.15	24
Hainan	0.20	0.19	0.16	0.14	0.15	0.15	0.15	0.21	0.37	0.19	19
Chongqing	0.26	0.19	0.18	0.16	0.15	0.16	0.14	0.17	0.17	0.18	20
Sichuan	0.09	0.08	0.09	0.10	0.10	0.11	0.10	0.14	0.14	0.11	28
Guizhou	0.12	0.12	0.12	0.12	0.12	0.13	0.12	0.15	0.15	0.13	27
Yunnan	0.10	0.13	0.14	0.12	0.13	0.14	0.13	0.18	0.18	0.14	26
Shaanxi	0.14	0.16	0.19	0.18	0.16	0.18	0.16	0.19	0.20	0.17	21
Gansu	0.21	0.21	0.20	0.12	0.12	0.11	0.10	0.14	0.14	0.15	23
Qinghai	0.13	0.11	0.11	0.10	0.09	0.09	0.08	0.09	0.12	0.10	29
Ningxia	0.40	0.49	0.41	0.24	0.21	0.21	0.20	0.25	0.32	0.30	10
Xinjiang	0.09	0.11	0.11	0.11	0.10	0.12	0.09	0.27	0.28	0.14	25
East China	0.34	0.44	0.44	0.38	0.37	0.46	0.47	0.55	0.48	0.44	(1)
Central China	0.29	0.33	0.38	0.31	0.19	0.20	0.31	0.35	0.33	0.30	(2)
West China	0.17	0.17	0.17	0.14	0.14	0.14	0.13	0.20	0.20	0.16	(3)
China	0.27	0.31	0.33	0.27	0.24	0.28	0.31	0.37	0.34	0.30	

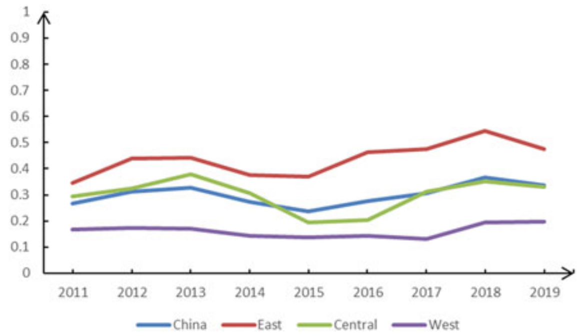

Fig. 1 The evolutionary trend of carbon emission efficiency in China's logistics industry

region is weak, and the industrial development and human resources conditions are far behind those of the eastern region. However, with the national key support and policy inclination, as well as the continuous improvement of the marketization process, the carbon emission efficiency of the logistics industry continues to rise.

From the provincial level, during the investigation period, the carbon emission efficiency of logistics industry in 18 provinces showed an increasing trend. Xinjiang, Shanghai and Liaoning ranked among the top three. The carbon emission efficiency of logistics industry in 10 provinces showed a downward trend. Gansu, Chongqing and Fujian ranked among the top three. The change of carbon emission efficiency of logistics industry at the provincial level shows that with the continuous improvement of China's economic development level and the strong promotion of national policies, the development environment of logistics industry is getting better and better. Most provinces pay more attention to the improvement of logistics industry efficiency and environmental protection.

4.1.2 Analysis of Spatial Differentiation Characteristics of Carbon Emission Efficiency

This paper further analyzes the spatial differentiation characteristics of carbon emission efficiency of China's logistics industry, and draws the carbon emission efficiency sub-bitmaps of China's logistics industry in 2011, 2015 and 2019. The darker the color in the figure, the greater the carbon emission efficiency value. The results are shown in Fig. 2.

From the regional level, the spatial distribution of carbon emission efficiency of China's logistics industry was quite different during the study period, and the overall spatial differentiation was characterized by "East, middle and west" descending step by step. The carbon emission efficiency of logistics industry in the eastern region was significantly higher than that in the central and western regions. Specifically, during the investigation period, the high-efficiency provinces of the logistics industry were concentrated, mainly in the eastern coastal areas of China. These regions have obvious

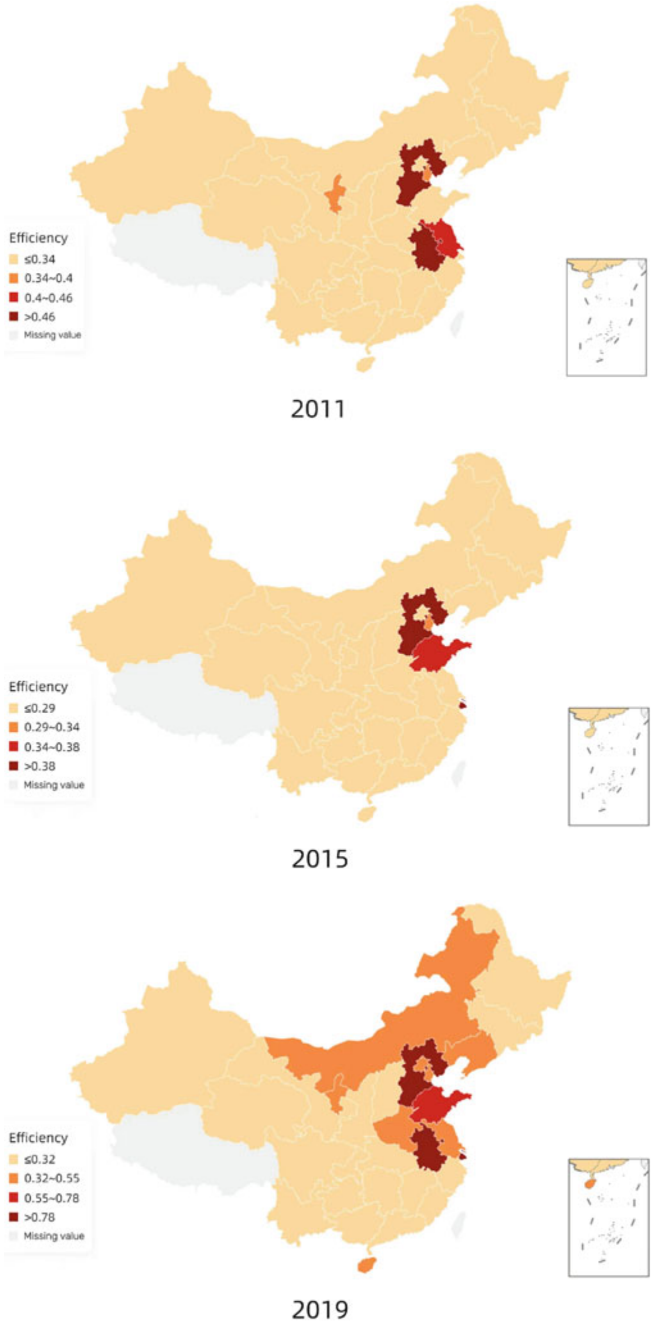

Fig. 2 Temporal and spatial distribution of carbon emission efficiency in China's logistics industry

location and policy advantages, which provide a good environment for the development of logistics industry. On the one hand, since China's reform and opening up, it has implemented many economic development policies in the eastern coastal areas and continuously introduced a large number of professional technical personnel, which have brought great advantages to the development of the logistics industry. On the other hand, there are many ports in the eastern coastal areas, and the total amount of import and export trade is in the leading position in China, which make the logistics industry develop rapidly. The provinces with low carbon emission efficiency of the logistics industry are mainly distributed in the western region. The economic development of the western region is relatively backward, the logistics industry facilities are few and the environmental protection experience is insufficient. The environment in which the logistics industry is located lacks development advantages, so it is at a low efficiency level.

From the provincial level, the carbon emission efficiency values of logistics industry in Hebei, Shanghai, Anhui, Tianjin and Shandong were relatively high. These provinces are mainly distributed in the eastern and central regions. Among them, the carbon emission efficiency value of Hebei Province during the investigation period is 1, which is at the high efficiency level. The port construction in Hebei Province is eximious and the logistics industry infrastructure is developing rapidly, which make the logistics industry in good condition. Shanghai's economic strength, degree of marketization, talent accumulation and environmental protection experience are all at the national leading level. The logistics industry has significant internal and external environmental advantages, and the carbon emission efficiency of the logistics industry is also at the high efficiency level. The low-carbon logistics industry in Anhui, Tianjin and Shandong has developed rapidly, and the carbon emission efficiency of the logistics industry has gradually entered the stage of high efficiency. The carbon emission efficiency values of logistics industry in Yunnan, Guizhou, Sichuan, Qinghai and Heilongjiang were below 0.2, and the efficiency values were relatively low. These provinces are mainly distributed in the central and western regions. T level of economic development in these regions is relatively backward, the development of logistics industry lags behind, and the low-carbon transformation of logistics industry needs to be accelerated. Compared with the eastern region, there is still a large gap.

4.2 Analysis of Influencing Factors

4.2.1 Construction of Regression Model

According to Eq. (2) and variable selection of influencing factors, a Tobit regression equation of carbon emissions efficiency of logistics industry is constructed in Eq. (4):

$$E_{it} = \beta_0 + \beta_1 ul_{it} + \beta_2 fdi_{it} + \beta_3 inf_{it} + \beta_4 tra_{it} + \beta_5 gov_{it} + \beta_6 er_{it} + \varepsilon_{it} \quad (4)$$

In Eq. (4): E = Carbon emission efficiency of logistics industry; $\beta_0 - \beta_6$=the estimated parameters; ε_{it}=random disturbance term.

4.2.2 National Level Analysis

The panel Tobit model with random effect is used to empirically test the influencing factors of carbon emission efficiency of logistics industry by Using Stata software. The regression analysis results are shown in Table 5.

Table 5 shows that, at the level of regional economic environment, the impact of urbanization level on the carbon emission efficiency of logistics industry is not significant. Urbanization will promote regional logistics demand, expand the scale of logistics industry, and provide rich material conditions for the development of logistics industry. However, the development of urbanization will also aggravate the pressure on regional environment, increase the carbon emission of regional logistics industry, and weaken the positive effect brought by urbanization development. Therefore, the impact of urbanization development on the carbon emission efficiency of logistics industry is not significant. The degree of opening-up has a significant positive impact on carbon emission efficiency, and is significant at the 1% level. On the one hand, the improvement of the degree of opening-up can increase the regional import and export trade, thus promoting the development of the logistics industry. On the other hand, the improvement of the degree of opening-up can introduce advanced technology and high-end professionals, which are conducive to the improvement of the efficiency of the logistics industry.

At the level of logistics industry environment, the impact of informatization level on the carbon emission efficiency of logistics industry is not significant. At present, the informatization level in China is relatively low, which plays a weak role in promoting the integrated development of transportation, warehousing, packaging, distribution and other links of the logistics industry, and does not play a strong role

Table 5 Influencing factors of carbon emission efficiency at the national level

Influencing factors	Carbon emission efficiency of logistics industry	
ul	−0.006	(0.004)
fdi	0.216***	(0.072)
inf	−0.001	(0.002)
tra	0.183**	(0.078)
gov	−1.440*	(0.753)
er	−0.007	(0.038)
Constant term	0.498**	(0.203)
LR test	134.76***	

Note '*', '**', '***' represent passing significant levels of 10%, 5% and 1%, respectively in supporting the innovation of the operation mode and the professional development of the logistics industry. And information interference and information asymmetry will have a negative impact on the coordinated operation between the upstream and downstream of the logistics industry and between regions. Therefore, the impact of informatization level on carbon emission efficiency of logistics industry is not significant. The level of transportation infrastructure can effectively promote the carbon emission efficiency of logistics industry, and is significant at the 5% level. With the continuous improvement of transportation infrastructure, it can provide an important guarantee for the development of logistics industry. Perfect transportation infrastructure can ensure the effective operation of transportation, distribution and other links of the logistics industry, optimize the rational allocation of production factors of the logistics industry and reduce operating costs, so as to improve the carbon emission efficiency of the logistics industry.

At the level of logistics policy environment, government logistics regulation will hinder the improvement of carbon emission efficiency of logistics industry, and is significant at the 10% level. First of all, the government logistics regulation will interfere with the market-oriented development of the logistics industry and affect the logistics decision-making and operation of enterprises. Secondly, the government's large amount of capital investment in the development of the logistics industry will make enterprises reduce their own logistics system optimization and hinder the improvement of the logistics industry efficiency. The effect of environmental regulation on carbon emission efficiency of logistics industry is not significant. On the one hand, the improvement of the efficiency of the logistics industry is a medium and long-term process, and the development of the logistics industry has not yet reached the advanced stage. The initial environmental regulation will increase the cost, reduce profits, and thus reduce the production efficiency of enterprises. On the other hand, the existing environmental regulation ignores industrial differences, and the environmental regulation act for the development of logistics industry is not perfect, which are also important reasons for the failure of environmental regulation to improve logistics production efficiency.

4.2.3 Regional Level Analysis

Considering that different regions in China have different characteristics, this paper divides the research sample into eastern region, central region and western region, and uses the panel Tobit model of random effect to investigate whether there are differences in the impact of various factors on the carbon emission efficiency of logistics industry in eastern, central and western regions of China. The regression analysis results are shown in Table 6.

For the eastern region, the carbon emission efficiency of the logistics industry will be mainly affected by the regional economic environment and the logistics industry environment. Among them, the level of urbanization has a significant negative impact on the carbon emission efficiency of the logistics industry, and is significant at the 5% level. The environmental pressure and the increase of carbon emission from

Table 6 Influencing factors of carbon emission efficiency at the regional level

Influencing factors	Eastern region	Central region	Western region
ul	−0.021**	−0.034**	−0.000
	(0.011)	(0.016)	(0.004)
fdi	0.174	0.312	−0.220**
	(0.113)	(0.565)	(0.105)
inf	0.000	0.005	0.002
	(0.004)	(0.011)	(0.002)
tra	0.620**	0.042	−0.051
	(0.275)	(0.151)	(0.046)
gov	−1.313	−5.911**	−0.355
	(1.619)	(2.804)	(0.324)
er	−0.116	0.297	−0.031**
	(0.107)	(0.191)	(0.015)
Constant term	1.068*	2.168**	0.269
	(0.573)	(0.839)	(0.179)
LR test	58.18***	8.63***	21.70***

Note '*', '**', '***' represent passing significant levels of 10%, 5% and 1%, respectively

logistics industry brought by urbanization in eastern China have a significant negative impact on the development of logistics industry, and thus hinder the improvement of carbon emission efficiency of logistics industry. The level of transportation infrastructure has a significant positive impact on the carbon emission efficiency of the logistics industry, and is significant at the 5% level. The eastern region has a high level of economic development and more perfect transportation infrastructure, which can guarantee the effective operation of the transportation link of the logistics industry, improve industrial production efficiency and reduce carbon emissions in the transportation process.

For the central region, the carbon emission efficiency of logistics industry is mainly affected by the regional economic environment and logistics policy environment. Among them, the level of urbanization has a significant negative impact on the carbon emission efficiency of the logistics industry, and is significant at the 5% level. The impact of urbanization level on carbon emission efficiency in the central region is the same as that in the eastern region, and its negative effect exceeds the positive effect. The government logistics regulation has a significant negative impact on the carbon emission efficiency of the logistics industry in the central region, which is consistent with the situation at the national level. The government logistics regulation in the central region interferes with the market-oriented operation and development of the logistics industry, and has a negative impact on the decision-making of enterprises, thus hindering the improvement of carbon emission efficiency of the logistics industry.

For the western region, the carbon emission efficiency of logistics industry is mainly affected by the regional economic environment and logistics policy environment. Among them, the degree of opening-up inhibits the improvement of carbon emission efficiency of logistics industry in the western region, and is significant at the 5% level. The development of logistics industry in western region is still at a low level, which is difficult to form effective competition with the high-end logistics industry led by foreign-funded enterprises, resulting in less market income for enterprises. At the same time, the entry of highly polluting enterprises has led to an increase in carbon emissions and hindered the improvement of carbon emission efficiency. Environmental regulation has a significant negative impact on the carbon emission efficiency of logistics industry in the western region, and is significant at the 5% level. The development level of the logistics industry in the western region is low. The government environmental regulation policies increase the operating costs and reduce the investment for logistics system optimization and carbon emission control of enterprises, thus reducing the carbon emission efficiency of the logistics industry.

5 Conclusions and Policy Implications

This study uses SBM model with undesirable output to measure the carbon emission efficiency of China's logistics industry, and analyzes the influencing factors of carbon emission efficiency. The conclusions are as follows:

(1) The overall level of carbon emission efficiency of China's logistics industry is relatively low, showing a slowly upward trend of volatility. During the investigation period, the average carbon emission efficiency of logistics industry is 0.3, with a large room for improvement. The carbon emission efficiency of logistics industry among regions is significantly different. The carbon emission efficiency of logistics industry in the eastern region is always higher than that in the central and western regions. (2) The carbon emission efficiency of logistics industry will be affected by regional economic environment, logistics industry environment and logistics policy environment. Among them, the degree of opening-up and the level of transportation infrastructure play a significant role in promoting the carbon emission efficiency of China's logistics industry. Government logistics regulation is not conducive to the improvement of carbon emission efficiency of logistics industry. Urbanization level, informatization level and environmental regulation have no obvious effect on carbon emission efficiency of logistics industry. (3) Various factors have different effects on carbon emission efficiency of logistics industry in different regions of China. The level of urbanization has a significant negative impact on the carbon emission efficiency of logistics industry in the eastern region, while the level of transportation infrastructure has a significant role in improving the carbon emission efficiency of logistics industry. Urbanization level and government logistics regulation have significant negative impact on the carbon emission efficiency of logistics industry in the central region. The degree of opening-up and environmental regulation have

significantly hindered the improvement of carbon emission efficiency of logistics industry in the western region.

Based on the above conclusions, this paper puts forward the following suggestions. (1) At the level of regional economic environment, the government should pay attention to improving the quality of economic development in the process of urbanization, and insist on promoting the urbanization process with low energy consumption and low environmental cost. The government should build an open logistics economy, optimize the system and market environment for foreign investment in the logistics industry, introduce advanced technology and high-end professionals, and accelerate the low-carbon development of the logistics industry. (2) At the level of logistics industry environment, enterprises should strengthen the construction of logistics information platform, adopt information technology to effectively realize the information transmission of logistics supply chain, and realize the integration and rational allocation of logistics resources, so as to optimize all links of logistics activities and reduce energy consumption. Government departments should improve the infrastructure of the logistics industry, vigorously build transportation infrastructure, improve the operation efficiency of the transportation link of the logistics industry and reduce the carbon emissions from the transportation link. (3) At the level of logistics policy environment, the government should regulate and control the problems of environmental pollution and industrial information asymmetry in the development of logistics industry based on market orientation. Government financial investment can be used to improve logistics infrastructure, so as to improve logistics efficiency. At the same time, the government should formulate environmental regulation policies suitable for the logistics industry according to the development status of the logistics industry, strengthen the limit of carbon emissions in the transportation link of enterprises, so as to reduce the energy consumption and carbon emissions of the logistics industry. (4) The government should strengthen the positive interaction between the eastern region and the central and western regions in the development of logistics industry, implement resource introduction and tax preferential policies for the backward regions in the central and western regions, narrow the gap between regions, and achieve the overall development of logistics industry. At the same time, the government needs to introduce relevant policies according to the comprehensive development of the region. The eastern region needs to improve the economic quality of urbanization development and further improve the transportation infrastructure. The central region should control the discharge of pollutants in the process of urbanization and reduce government intervention in the market-oriented development of logistics industry. The western region needs to raise the entry threshold for foreign-funded enterprises, restrict the entry of highly polluting enterprises, and formulate appropriate environmental regulation policies according to the current situation of regional logistics development.

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Operational Efficiency Analysis of China's Electric Power Industry Based on Two-Stage DEA Model

Bingqian Ma

Abstract As a major industry that consumes coal and other fossil energy, the power industry accounts for more than 40% of carbon emissions, ranking first among all industries all year round. Therefore, in the process of achieving the "double carbon" goal, the power industry is the heaviest task and the most arduous responsibility, and will also play the role of the main force. This study uses a two-stage network structure to simulate the operation process of power system. Through introducing the dynamic slack-based measure algorithm into this structure, the operational efficiencies of the entire industry and each stage (power generation and transmission-distribution) in each period are evaluated. On this basis, this paper uses Tobit model to carry out regression analysis on the efficiency measurement results, and obtains the key factors affecting the operation efficiency of power system in each stage. The results show that (I) there are obvious differences in power system efficiency among provinces in China (II) there are also great differences in the efficiency of each stage within the power system, and the efficiency of the generation stage is significantly higher than that of the transmission and distribution stage. (III) The level of economic development, scientific and technological investment and power structure are the main factors affecting the operation efficiency of power system.

Keywords Electric power industry · Two-stage DEA · Tobit

1 Introduction

Actively addressing climate change is a major historical undertaking for China to promote the construction of a community with a shared future for mankind. Achieving carbon peak and carbon neutrality is a solemn commitment made by the Party Central Committee to address global climate issues. As a major industry that consumes coal and other fossil energy, the power industry accounts for more than 40% of carbon

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emissions, ranking first among all industries all year round [1]. Therefore, in the process of achieving the "double carbon" goal, the power industry is the heaviest task and the most arduous responsibility, and will also play the role of the main force.

At the same time, China's power industry is still dominated by thermal power generation, which accounts for 70%, much higher than the world average of 40%. China's new energy power generation is still in its infancy, and there is still much room for development on the instability of new energy power generation and the response to costs. Therefore, thermal power will exist for a long time and occupy an important position in China's power system. Therefore, to alleviate the high carbon emission of the power industry, we should not only promote the construction of new power systems and develop new energy power generation, but also continue to explore ways to improve the operation efficiency of the power industry, improve the resource utilization rate of the industry, and realize the low-carbon and clean development of the power industry.

With the deepening of the system reform of the power industry, the development of the power industry is also moving towards a new stage. From the initial comprehensive monopoly under the national vertical management to the gradual refinement of the power system, the competition mechanism is introduced in different stages of power production, which makes the operation process of China's power system more scientific, and the interaction and interaction between various departments in the system more complex. At the same time, as power is a kind of social public goods, the operation of power system should not only consider economic interests, but also take into account social interests. The dual objectives of power system determine that its efficiency evaluation is a complex system work.

This research proposed a dynamic network slack-based measure (SBM) approach to operational efficiency analysis of the electric power industry and then applied it to China to acquire implications for policy adjustment. These research efforts result in the following main contributions: (I) Based on the in-depth analysis of China's power system, the operation process of the power system is divided into stages. (II) The network structure and dynamic SBM method are used to evaluate the operation efficiency of power system in each stage. (III) On the basis of efficiency measurement, the regression analysis of influencing factors is carried out, and the key factors affecting the efficiency of each stage are obtained, so as to put forward corresponding suggestions for efficiency improvement.

The rest of this paper is organized as follows. Section 2 reviews the existing literature related to this research. In Sect. 3, a two-stage network structure is developed based on SBM algorithm, and the regression equation of influencing factors is established. Then the efficiency measurement and the index selection of factor regression are explained. In Sect. 4, the calculation results of China's power industry operation efficiency and the regression results of influencing factors are analyzed in detail. Section 5 summarizes the research and provides policy implications.

2 Literature Reviewed

Power system is a complex system composed of multiple departments, each department has a variety of different inputs, such as the power generation Department has fuel, manpower, capital, equipment input, and the transmission department has transmission lines, transformer capacity, etc. In terms of output, it will not only produce the expected output of power generation, but also produce unexpected output such as carbon dioxide, "three wastes" and other pollutants, line loss power and auxiliary power consumption. Therefore, it is the best choice to select the multi input and multi output decision analysis method to evaluate the efficiency of power system.

2.1 Efficiency Analysis of Electric Power Industry

The application of DEA in the power system dates back to the 1980s, and is mainly concentrated in the power generation department. For example, Färe et al. [2] studied the efficiency of power generation enterprises in Illinois. After that, DEA has been widely used in the four links of power system, i.e. generation, transmission, distribution and sales, to measure the efficiency of each link [3–5]. Considering the impact of pollutants such as carbon dioxide as unexpected output on the performance of power generation enterprises, scholars began to use the DEA method containing unexpected output to study the efficiency level of power plants [6–10]. Lozano included pollutants in the output indicators, and verified the applicability of the network DEA model through 92 coal-fired power plants and 23 EU and OECD countries [11]. In order to explore the environmental efficiency of the power industry, Liu et al. established a DEA cross evaluation model based on data envelopment analysis to study the efficiency of the power industry in 30 provinces in China from 2011 to 2014 [12]. Sueyoshi et al. used data envelopment analysis discriminant analysis to test the unified efficiency measures of China's provincial power industry from 2009 to 2015 [13].

Using DEA method to study the efficiency of transmission and distribution grid enterprises began in the 1990s, including the study of grid enterprises and distribution companies. Weyman Jones measured the efficiency of 12 distribution companies in Ingra and Wales with DEA model in 1991 and 1995, and compared the efficiency with that before and after the introduction of privatization in 1990 [14]. Giannakis et al. calculated the efficiency value of British power grid enterprises with DEA method, verified the possibility of introducing incentive regulation into power grid enterprises for service quality, and found that there is a balance between cost and service quality [15]. In order to further study the efficiency of each link of the power system, Mika goto et al. [16] calculated the technical efficiency of the three links of power generation, power transmission and distribution and power sales in the United States from 1992 to 2000, and discussed the impact of environmental variables and relaxation rules on the efficiency of each link. The study found that deregulation had a great impact on the power generation and power sales links, but had no impact on the power transmission and distribution links.

With the process of the new round of power system reform, some scholars, starting from the utilization efficiency of power grid equipment, selected the power supply bureaus of 19 cities as samples of Guangdong Power Grid Corporation, and used the Three-stage DEA model to measure the input–output indicators of power grid enterprises, so as to improve economic and social benefits [17]. In order to study the relationship between market power and power grid efficiency since the power reform in 2015, Yao et al. Used the SBM model to calculate the unconditional efficiency and conditional efficiency of China Power Grid Corporation, indicating that the power grid efficiency is at a low level, and the market power has a significant negative impact on the power grid efficiency [18].

2.2 Study on Influencing Factors of Power System Efficiency

Scholars mostly explore the reasons that affect their efficiency changes from the aspects of transmission and distribution enterprises, power plants, power systems and so on. Chen estimates the efficiency of power grid enterprises in Taiwan [19]. The research shows that the average efficiency of regions with high customer density is higher than that of regions with low customer density. Mullarkey et al. used DEA method to explore the impact of the restructuring and integration reform of Irish distribution network on the efficiency of distribution companies [20]. The research shows that the overall efficiency of the company's restructured power grid can be positively promoted. Under the background of the new round of power reform, Wu explored the influencing factors of investment decision-making of China's power grid enterprises, and established an auxiliary decision-making model for incremental distribution network reform investment from the dimensions of economic efficiency, project importance, and government attitude [21].

In the power generation stage, See et al. found that they have a significant impact on the technical efficiency of power plants in Malaysia from the perspective of ownership, plant size, fuel type and other factors [22]. At present, the research on the factors affecting the efficiency of power plants abroad is mostly focused on photovoltaic, hydraulic, wind and other new energy power generation. Xu et al. [23] based on the panel data of OECD and non OECD countries from 2007 to 2016, explored the power generation efficiency of new energy including solar energy, wind energy, geothermal energy and biofuels, and found out the energy price, technological progress, industrial structure Opening up and other factors have a significant impact on efficiency.

3 Method Model

3.1 Two-Stage Efficiency Evaluation Model

Suppose there are n decision making units (DMUs), which represent the provinces that should be evaluated. In the process of power production, each DMU uses human, capital, energy and other resources to generate power, and then uses the transmission network to transmit and distribute power. Therefore, the power system can be divided into two stages in terms of structure: generation stage and transmission and distribution stage. During the operation of the power system, it is inevitable to produce some unexpected output. In the power generation stage, the unexpected output is mainly the environmental pollutants produced in the power generation process; In power transmission and distribution, unexpected output is the loss of electricity generated in the process of power transmission. Figure 1 shows a two-stage operating system for the power industry.

As shown in Fig. 1, the link variable between the above two stages is power generation, that is, the output of the power generation stage is the input of the transmission stage. The input variables in the power generation stage are power grid construction input, labor, installed capacity and energy consumption, and the input variables in the transmission distribution stage are power grid construction input. The electricity consumption of the whole society is the final output of the second stage.

The undesired output conversion function and slacks-based measure (SBM) model are two important methods for considering undesired outputs. However, the SBM model, a nonradial and nonangle model, considers the influence of slack variables fully and obtains objective results. Therefore, this paper uses the SBM model to address undesirable outputs.

Based on the above analysis, the efficiency calculation model of power generation stage is as follows:

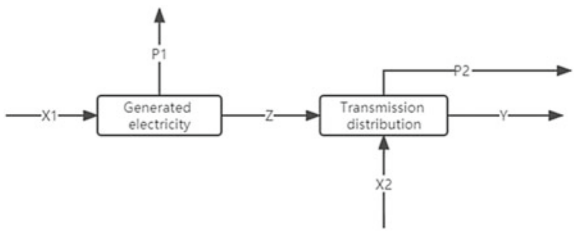


Fig. 1 Two stage operation structure of power system

$$E_A^0 = min\frac{1-\frac{1}{m_1}\sum_{i=1}^{m_1}\frac{s_{i1}^-}{X_{A_0}}}{1+\frac{1}{q_1+h1}\left(\sum_{k=1}^{q_1}\frac{s_k^+}{Z_0}+\sum_{r=1}^{z_1}\frac{s_{t1}^-}{P_{A_0}}\right)}$$
$$\text{s.t}\begin{cases} X_A\lambda^A + s_i^- = X_{A_0} \\ Z\lambda^A - s_k^+ = Z_0 \\ P_A\lambda^A + s_r^- = P_{A_0} \\ s_i^- \geq 0;\ s_k^+ \geq 0;\ s_r^- \geq 0;\ \lambda^A \geq 0 \end{cases} \tag{1}$$

In Eq. (1), E_A^0 refers to the efficiency value of the power generation phase of the current decision-making unit; m_1, q_1 and h_1 is the number of inputs (X_A), intermediate outputs (Z_0) and unexpected outputs(P_{A_0}) respectively, s_i^-, s_k^+ and s_{t1}^- relaxation variables of current decision-making unit input, intermediate output and unexpected output respectively, λ^A is the weight.

Equation (1) is a fractional programming, if $t = 1+\frac{1}{q_1+h_1}\left(\sum_{k=1}^{q_1}\frac{s_k^+}{Z_0}+\sum_{r=1}^{z_1}\frac{s_{t1}^-}{P_{A_0}}\right)$, then the model can be linearized, as shown in Formula (2):

$$E_A^0 = mint - \frac{1}{m_1}\sum_{i=1}^{m_1}\frac{S_{i1}^-}{X_{A_0}}$$
$$\text{s.t.}\begin{cases} X_A\Lambda^A + S_i^- = tX_{A_0} \\ Z\Lambda^A - S_k^+ = tZ_0 \\ P_A\Lambda^A + S_r^- = tP_{A_0} \\ t+\frac{1}{q_1+h_1}\left(\sum_{k=1}^{q_1}\frac{S_k^+}{Z_0}+\sum_{r=1}^{z_1}\frac{S_{t1}^-}{P_{A_0}}\right) = 1 \\ S_{i1}^- \geq 0;\ S_k^+ \geq 0;\ S_{t1}^- \geq 0;\ \Lambda^A \geq 0 \end{cases} \tag{2}$$

where, $S_{i1}^- = ts_i^-$; $S_k^+ = ts_k^+$; $S_{t1}^- = ts_{t1}^-$; $\Lambda^A = t\lambda^A$

The efficiency calculation model at the transmission and distribution stage is as follows:

$$E_B^0 = min\frac{1-\frac{1}{m_2+z_1}\left(\sum_{j=1}^{m_2}\frac{s_{i2}^-}{X_{B_0}}+\sum_{t=1}^{z_1}\frac{s_k^-}{Z_0}\right)}{1+\frac{1}{q_2+h_2}(\sum_{t=1}^{z_1}\frac{s_{t2}^-}{P_{B_0}}+\sum_{l=1}^{q_2}\frac{s_l^+}{Y_{B_0}})}$$
$$\text{s.t.}\begin{cases} X_B\lambda^B + s_j^- = X_{B_0} \\ Z\lambda^B + s_t^- = Z_0 \\ P_B\lambda^B + s_{t2}^- = P_{B_0} \\ Y_B\lambda^B - s_l^+ = Y_{B_0} \\ Z\lambda^A = Z\lambda^B \\ s_{i2}^- \geq 0;\ s_{t2}^- \geq 0;\ s_l^+ \geq 0;\ \lambda^B \geq 0 \\ s_{i1}^- \geq 0;\ s_k^+ \geq 0;\ s_{t1}^- \geq 0;\ \lambda^A \geq 0 \end{cases} \tag{3}$$

In Formula (3), E_B^0 represents the efficiency of power transmission and distribution stage, m_2, z_1, q_2 and h_2 represent the number of input, intermediate variables, expected output and unexpected output in the transmission and distribution stage respectively; s_{i2}^-, s_k^-, s_l^+ and s_{t2}^- relaxation variables of current decision-making unit input, intermediate variable, expected output and unexpected output respectively; λ^A and λ^B are the weight coefficient of power generation and transmission; $Z\lambda^A = Z\lambda^B$ serves as a constraint to ensure the effective connection of intermediate output in the two stages.

Similarly, setting $k = 1 + \frac{1}{q_2+h_2}(\sum_{t=1}^{z_1} \frac{s_{t2}^-}{P_{B_0}} + \sum_{l=1}^{q_2} \frac{s_l^+}{Y_{B_0}})$ the linear programming model can be obtained, as shown in Eq. (4):

$$E_B^0 = mink - \frac{1}{m_2+z_1}\left(\sum_{j=1}^{m_2} \frac{S_{i2}^-}{X_{B_0}} + \sum_{t=1}^{z_1} \frac{S_k^-}{Z_0}\right)$$
$$\text{s.t.} \begin{cases} X_B\Lambda^B + S_{i2}^- = kX_{B_0} \\ Z\Lambda^B + S_k^- = kZ_0 \\ P_B\Lambda^B + s_{t2}^- = kP_{B_0} \\ Y_B\Lambda^B - S_l^+ = kY_{B_0} \\ k + \frac{1}{q_2+h_2}(\sum_{t=1}^{z_1} \frac{s_{t2}^-}{P_{B_0}} + \sum_{l=1}^{q_2} \frac{S_1^+}{Y_{B_0}}) = 1 \\ Z\Lambda^A = Z\Lambda^B \\ S_{i2}^- \geq 0;\ S_{t2}^- \geq 0;\ S_l^+ \geq 0;\ \Lambda^B \geq 0 \\ S_{i1}^- \geq 0;\ S_k^+ \geq 0;\ S_{t1}^- \geq 0;\ \Lambda^A \geq 0 \end{cases} \tag{4}$$

where, $S_j^- = ks_j^-$; $S_t^- = ks_t^-$; $S_l^+ = ks_l^+$; $\Lambda^B = k\lambda^B$; $S_i^- = ts_i^-$; $S_k^+ = ts_k^+$; $S_r^- = ts_r^-$; $\Lambda^A = t\lambda^A$.

In the current Two-stage DEA efficiency evaluation model, different scholars have different methods to calculate the overall efficiency. For example, when calculating the overall efficiency, Wu and Chen regard the evaluation system as a whole and eliminate intermediate variables for calculation [24]; Wu et al. Calculated their weighted average as the overall environmental efficiency by setting weights for the two stages; In the two-stage efficiency evaluation system, Zha and Liang, Yu and Shi used the product of quantity and two-stage efficiency to measure the overall efficiency [25, 26]. In the two-stage efficiency evaluation model, the weights of the two stages will be different. Considering the differences of different regions and the objectivity of the evaluation results, this paper uses the two-stage efficiency product to measure the overall environmental efficiency. That is, the overall efficiency value E^0 of the currently evaluated decision-making unit (DMU_0) is defined as:

$$E^0 = E_A^0 * E_B^0 \tag{5}$$

For the effectiveness of each stage and the whole based on the model, we make the following definitions:

(1) If E_A^0 (E_B^0) = 1, the slack variables are equal to 0 in a given stage, and $DMU0$ in the power generation stage (or transmission and distribution stage) is efficient.
(2) If E_A^0 (E_B^0) < 1, $DMU0$ in the power generation stage (or transmission and distribution stage) is inefficient.
(3) If and only if E_A^0=E_B^0 = 1 and the slack variables are 0 in each stage, then $DMU0$ is efficient.

3.2 Regression Analysis of Determinants

In order to explore the influencing factors of power system efficiency in China, a multiple linear regression model should be established. Since the efficiency value of power system is within the range of [0, 1], a common method to analyze the determinants is to use Tobit estimator. However, as Simar and Wilson proved, this is not appropriate. Since the efficiency of power system is not observed, but estimated by DEA, it is difficult to assume that the error term is distributed independently. In addition, the estimation of power system efficiency is based on the samples of provinces, so the estimation of efficiency is biased. On this basis, a SIMAR Wilson program is proposed. The program is based on a double boot program, which can make consistent inferences within the model explaining efficiency scores, and generate standard errors and confidence intervals for these efficiency scores. In this study, the industrial water use efficiency is taken as the explanatory variable, and the following regression specifications are assumed and tested:

$$yi = \alpha + xi\beta + \mu i \tag{6}$$

In Formula (6), yi is the explained variable, β is the regression coefficient, xi is the explained variable vector, and μi.

3.3 Variables and Data

3.3.1 The Inputs and Outputs of the Industrial Water Consumption Efficiency Model

This paper referred to some existing studies [21, 22, 27] and considered the investment in power grid construction, power supply construction, installed capacity and other indicators are taken as inputs. The whole society electricity consumption and per capita electricity consumption are taken as the model output. The indicators are shown in Table 1.

3.3.2 The Relevant Influential Factors

There are many factors that affect the generation efficiency, transmission and distribution efficiency and overall efficiency of the power industry. Specifically, with the continuous development of China's power system, the influencing factors on each stage and overall efficiency of the power system are as follows. (According to the above analysis, there are differences in the efficiency of each stage within the power system, and the influencing factors are complex. Therefore, when exploring the influencing factors of each stage and overall efficiency within the power system, this paper

Table 1 Power industry efficiency indicators

Indicator types	Indicators	Variables and units
X_A	Capital investment	Power supply construction investment(10^8 yuan)
	Power industry labor	Power industry employment population (10^4)
	Power production capacity	Installed capacity(10^8 kwh)
	Energy input	Energy consumption of power industry
Z	Power production	Generating capacity((10^8 kwh)
P_A	Pollutant emission during power generation	CO2 emission(10^4 t)
X_B	Construction investment in power transmission and distribution	Investment in power grid construction(10^8 yuan)
P_B	Power loss in transmission and distribution links	Line loss(10^8 kwh)
Y_B	Power consumption	Total electricity consumption(10^8 kwh)

The data in this table were collected from the *China Statistical Yearbook (2012–2021)*, *China Power Yearbook(2012–2021)*, *China Environmental Statistics Yearbook (2012–2021)* and the *Compilation of power industry statistics(2012–2014)*

considers from the three aspects of economic development, energy consumption and policy regulation, and selects the following indicators for specific analysis on the basis of a large number of references.).

(1) Economic development factors

Economic development is the basic environment for the development of the power industry, and the local per capita GDP can directly reflect the local economic development level; Industry is also the main field of power production and consumption. The industrial structure of each region has an important impact on the efficiency of the local power system. Therefore, the per capita GDP of each region represents the economic level (pdi), and the proportion of the secondary industry in GDP of each region represents the industrial structure (ins).

(2) Energy factor

Electric power is an important energy in our country's production and life. The energy utilization around the country plays an important role in driving the efficiency of the power system, especially the environmental efficiency of the power generation link. The energy consumption structure of each region can simply and directly reflect the energy utilization status of the local power industry. At the same time, energy intensity is an important indicator to measure energy efficiency. The higher the energy intensity, the higher the energy efficiency; Therefore, this paper selects the energy

Table 2 Index system of efficiency influencing factors analysis

Influential factors	Variable names	Variable meanings
Economic development	Per capita disposable income (pdi)	Per capita disposable income of urban residents (104 yuan)
	Industrial Structure (ins)	Industrial development proportion (%)
Energy consumption index	Energy consumption structure (ecs)	Proportion of electricity consumption (%)
	Energy intensity (ei)	Proportion of production value in power industry (%)
Government regulation	Technological innovation level (til)	R&D funding (108 yuan)
	Power structure(ps)	Proportion of thermal power generation (%)

All the data for the abovementioned indicators were collected from the *China Statistical Yearbook (2012–2021)*, *China Power Yearbook (2012–2021)*, *China Environmental Statistics Yearbook (2012–2021)* and the *national research network*

consumption proportion of the power industry to represent the energy consumption structure (ecs), and the ratio of the power industry production value of each region to the local total social production value to represent the energy consumption intensity (ei).

(3) Government regulation

The local power structure can reflect the local government's environmental regulation on the power industry. The larger the proportion of traditional thermal power generation, the looser the government's environmental regulation on the local power industry. The investment in the power industry can directly reflect the government's support for technological innovation. Therefore, this paper selects the proportion of thermal power generation to represent the power structure (ps), and the R&D investment to represent the scientific and technological innovation level (til). The indicators are shown in Table 2.

4 Results and Discussion

4.1 Analysis of Power System Efficiency Measurement Results

4.1.1 National Analysis of Power System Efficiency

This research calculates the power system efficiency of 30 provinces (excluding Hong Kong, Macao, Taiwan, and Tibet) in China from 2011 to 2020 by using the data in

Table 1 and the calculation results in 2011, 2015 and 2020 are summarized in Table 3. Figure 2 shows the change of power system efficiency in China from 2011 to 2020. It can be seen from the chart that the efficiency fluctuation of China's power system at each stage is highly consistent, but the efficiency of the power generation stage is always higher than that of the power transmission and distribution stage, indicating that China's power system presents a situation of "emphasizing power generation rather than power transmission and distribution".

Table 3 Power system efficiency measurement results of 30 provinces in China

	2011			2015			2020		
	E^A	E^B	E^0	E^A	E^B	E^0	E^A	E^B	E^0
Beijing	0.41	1	0.64	0.47	1	0.69	0.33	1	0.57
Tianjin	0.62	0.69	0.65	0.73	0.85	0.79	0.41	0.63	0.51
Hebei	0.46	1	0.68	0.56	1	0.75	0.4	0.33	0.36
Shanxi	0.55	0.3	0.41	0.56	0.4	0.47	0.56	0.26	0.38
Inner Mongolia	0.58	1	0.36	0.83	1	0.61	1	1	1
Liaoning	0.39	0.43	0.41	0.62	1	0.79	0.38	0.31	0.34
Jilin	0.3	0.42	0.35	0.32	0.68	0.47	0.35	0.25	0.29
Heilongjiang	0.33	0.37	0.35	0.44	1	0.66	0.72	0.46	0.58
Shanghai	1	0.86	0.76	1	1	0.91	1	1	1
Jiangsu	1	0.24	0.93	1	1	1	0.76	1	0.87
Zhejiang	0.98	0.49	0.49	1	0.31	1	0.48	0.46	0.47
Anhui	0.7	0.19	0.7	0.76	0.24	0.56	0.53	0.19	0.32
Fujian	0.77	0.36	0.36	0.86	0.53	0.42	1	0.44	0.66
Jiangxi	0.47	1	0.53	0.62	0.31	0.67	0.43	0.38	0.41
Shandong	0.56	0.23	0.69	1	0.37	0.44	0.74	1	0.86
Henan	0.58	0.25	0.38	0.54	0.25	0.37	0.34	0.2	0.26
Hubei	0.68	0.19	0.36	0.92	0.22	0.46	0.85	0.17	0.38
Hunan	0.43	0.26	0.33	0.37	0.34	0.36	0.38	0.25	0.31
Guangdong	1	0.21	0.41	0.78	1	0.44	0.62	1	0.79
Guangxi	0.59	0.38	0.29	0.76	0.54	0.36	0.46	0.27	0.35
Hainan	1	0.61	0.78	0.63	0.63	0.63	0.38	0.67	0.51
Chongqing	0.37	0.47	0.46	0.39	0.5	0.88	0.49	0.45	0.47
Sichuan	0.56	0.15	0.47	1	0.13	0.64	1	0.23	0.48
Guizhou	0.63	0.22	0.37	1	0.46	0.68	0.78	0.35	0.52
Yunnan	0.6	0.22	0.36	1	0.21	0.46	1	0.16	0.4
Shaanxi	0.52	0.34	0.42	0.51	0.56	0.54	0.35	0.17	0.24
Gansu	0.63	0.46	0.54	0.37	0.6	0.47	0.66	0.26	0.41

(continued)

Table 3 (continued)

	2011			2015			2020		
	E^A	E^B	E^0	E^A	E^B	E^0	E^A	E^B	E^0
Qinghai	1	1	1	1	1	1	1	1	1
Ningxia	0.81	1	0.9	1	1	1	1	1	1
Xinjiang	0.42	0.46	0.44	1	1	1	1	1	1

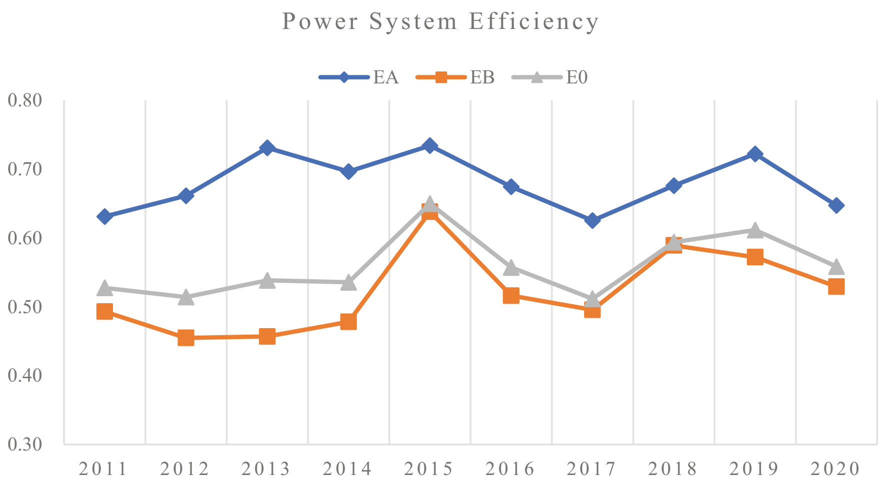


Fig. 2 Efficiency variation diagram of China's power system

At the same time, it can be noted that after 2015, the efficiency gap between the power generation stage and the transmission and distribution stage is gradually decreasing, which has a lot to do with the "new power reform" policy implemented in 2015. In 2015, the reform of the power system improved the policy system of separating government from enterprises, separating power plants from power grids, and separating main and auxiliary power. At the same time, the new distribution business was liberalized, and the price of electricity in the competitive link was liberalized, further breaking the monopoly of power grid companies on the power industry in the transmission and distribution links. The empirical results of this study show that after the implementation of the new power reform policy, all departments and departments of the power system begin to develop in an all-round and balanced way, which also confirms the correctness of China's power system reform.

4.1.2 Regional Difference Analysis of Power System Efficiency

Based on previous studies [22, 23] and the regional division of China's power grid system, 30 provinces (excluding Hong Kong, Macao, Taiwan, and Tibet) in China

Table 4 Provinces in each region

Region	Province
North China	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, and Shandong
Northeast China	Inner Mongolia, Liaoning, Jilin, and Heilongjiang
East China	Shanghai, Jiangsu, Zhejiang, Anhui and Fujian
Central China	Jiangxi, Henan, Hubei, Hunan, Chongqing and Sichuan
South China	Guangdong, Guangxi, Hainan, Guizhou and Yunnan
Northwest China	Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang

are divided into six regions: North China, Northeast China and East China, as shown in Table 4. Figures 2, 3 and 4 show the power system efficiency calculation results of the six grid regions.

As shown in the Fig. 3a, in terms of power generation stage, the power generation efficiency in East China is significantly higher than that in other regions. Resource endowment and economic development have a strong influence on the power generation efficiency in this region. The provinces in East China are rich in coal resources, most of which are located in coastal areas. They are rich in wind resources and have good power generation conditions. The advanced level of economic development has

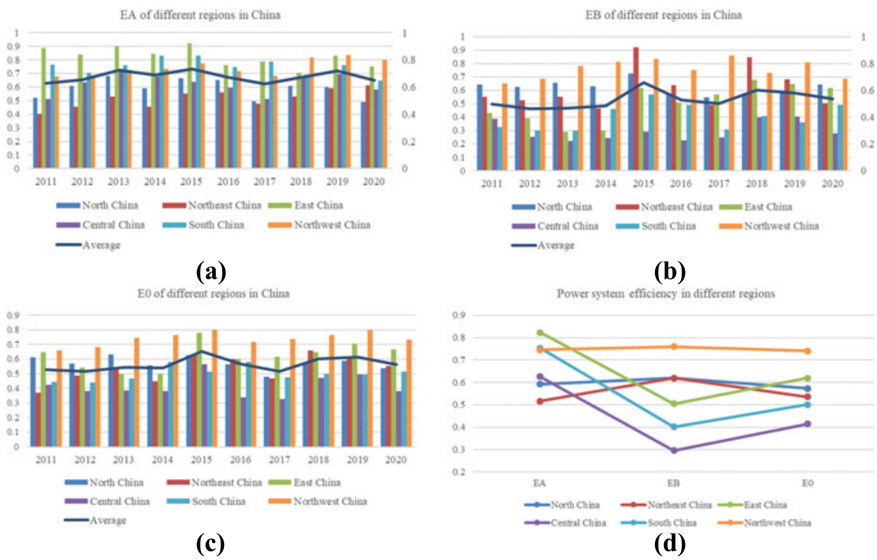
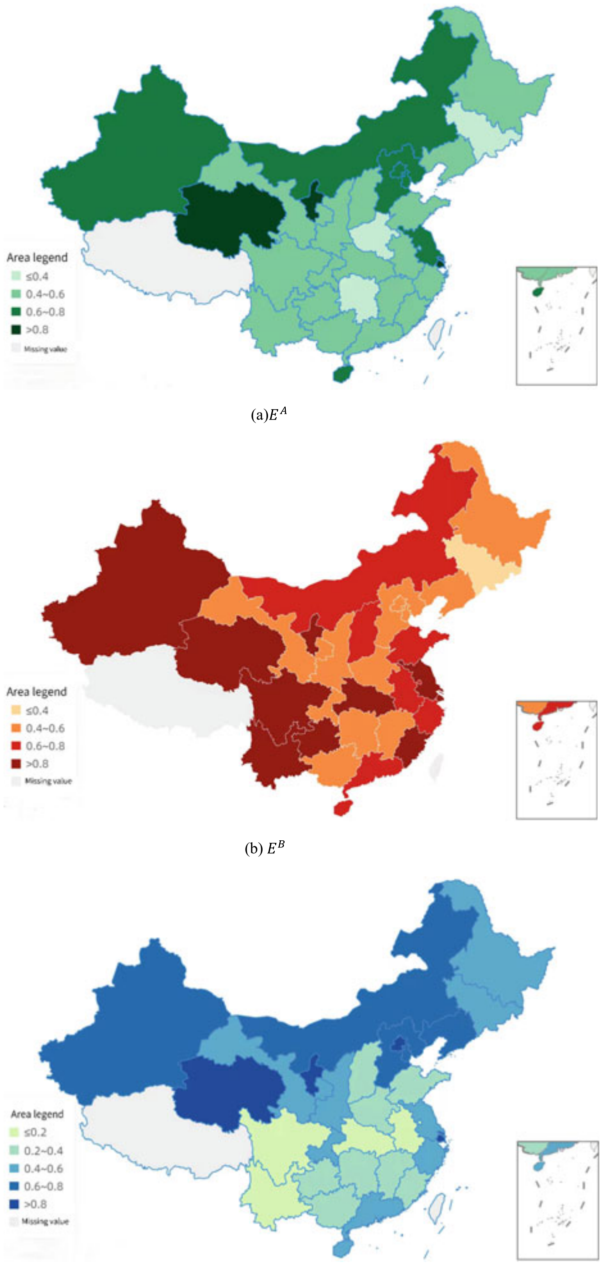


Fig. 3 **a–d** Power system efficiency in different regions



(a)E^A

(b) E^B

(c) E^0

Fig. 4 Power efficiency distribution map of provinces in China also promoted the local attention to environmental quality, thus promoting the power generation enterprises to reduce pollutant emissions and improving the local power generation efficiency in many aspects. However, due to the previous overexploitation of natural resources in Northeast China, the phenomenon of resource depletion has become increasingly prominent in recent years. In addition, with the decline of old industrial cities, the growth rate of economic development has decreased, and a large number of people have lost, so advanced technology cannot be used in time to improve power generation efficiency.

In the stage of power transmission and distribution, the transmission efficiency in Northwest China is significantly higher than that in China. This is mainly due to the "West- East power transmission" project, which has been constructed and implemented for a long time. The central government has given a lot of capital, technology and policy support to the power grid construction in Western China, reducing the power loss in the process of power transmission. In addition, the northwest region is vast and sparsely populated, and the per capita power consumption is much higher than that of other regions, which is also an important reason for the high transmission and distribution efficiency in this region. Similarly, the large number of people in central and southern China leads to a low per capita electricity consumption index as the final output. In addition, central China and South China have rugged terrain, difficult power grid construction, high investment, and more power loss in the transmission process. Due to multiple reasons, the transmission and distribution efficiency of the two regions is far lower than that of other regions.

Figure 3d shows the average efficiency and overall efficiency of the power system in each stage of the six power grid regions. Among them, the power generation efficiency in East China, South China and central China is significantly higher than the transmission and distribution efficiency, while the transmission and distribution efficiency in northwest, North China and Northeast China is higher than the power generation efficiency. This situation reflects that the relationship between the generation stage and the transmission stage within China's power system needs to be further coordinated to achieve the optimal resource allocation, so as to further improve the utilization efficiency of electric power in China.

4.1.3 Provincial Analysis Difference of Power Efficiency

On the whole, there are significant differences in the average level of efficiency between provinces and urban areas, as shown in Table 3 and Fig. 4. There are great differences in power generation efficiency and transmission and distribution efficiency among different provinces. Among them, the environmental efficiency of power generation stage in Beijing, Inner Mongolia, Hebei and other provinces is significantly lower than the transmission and distribution efficiency, indicating that these regions have not yet coordinated the relationship between environmental protection and economic development, and do not pay enough attention to environmental protection when using their own resources and regional advantages for economic development and power production. On the contrary, the efficiency of power generation in Zhejiang, Fujian and other provinces is significantly higher than that of power transmission and distribution. Those provinces with a higher degree of economic development pay more attention to the problem of pollution control in power generation. However, the economic development in these areas is highly dependent on the power industry, coupled with the long-term monopoly of the power transmission and distribution departments, which leads to the low operating efficiency of the power transmission and distribution departments in these areas and reduces the efficiency of the power transmission and distribution links.

In addition, the power generation efficiency and transmission and distribution efficiency of Liaoning, Jilin, Henan and other provinces are all at a relatively low level in the country. In the process of the development of the power industry, they have neither made full use of natural resources to create economic efficiency nor done a good job in environmental protection. In these areas, there is excessive development of resources, and due to the low level of economic development, production technology and equipment are not advanced enough, thus reducing the overall production efficiency of the power industry. However, the efficiency of Shanghai, Ningxia, Qinghai and other provinces at all stages is at the national leading level, which shows that these provinces pay attention to environmental protection while pursuing the economic benefits of the power industry, creating a win–win result. Among them, due to its developed economic level, Shanghai has enough capital and technology to improve the level of power production and control environmental pollution; However, Ningxia, Qinghai and other places have provided a lot of policy support because of the fragile ecological environment and the high degree of national attention. Moreover, these areas are sparsely populated and have high per capita power consumption, which improves the efficiency of transmission and distribution links.

4.2 Analysis of the Influential Factors

According to Formula (6) and Table 2, in order to analyze the determinants of industrial water efficiency, we adopted the approach of Simar and Wilson. The regression model was established as shown in Formula (7):

$$Yit = \beta 0 + \beta 1 \times pdiit + \beta 2 \times insit + \beta 3 \times ecsit + \beta 4 \times eiit + \beta 5 \times tilit + \beta 6 \times fpsit + \varepsilon it \quad (7)$$

where *Yit* represents the efficiency of province i in year t, βj ($j = 0, 1, 2, \ldots, 9$) represents the regression coefficients, and εit represents the statistical noise. The results are shown in Table 5.

According to Table 5, different influencing factors have different effects on the efficiency of the power industry, and the same influencing factor also has obvious differences on the efficiency of the power system at different stages.

Table 5 Tobit regression results of power industry efficiency

Classifications	Indicators		E^1	E^2	E^0
Economic development	Per capita disposable income (pdi)	Coef	0.294	0.070	0.455
		p > z	0.019**	0.007***	0.000***
	Industrial structure (ins)	Coef	0.0023	−0.010	−0.003
		p > z	0.84	0.069*	0.227
Energy consumption index	Energy consumption structure (ecs)	Coef	0.0035	−0.001	0.003
		p > z	0.204	0.895	0.407
	Energy intensity (ei)	Coef	−0.003	−0.06	−0.003
		p > z	0.825	0.305	0.259
Government regulation	Technological innovation level (til)	Coef	−1.72e − 09	−2.35e − 09	−1.43e − 09
		p > z	0.010**	0.080*	0.026**
	Power structure (ps)	Coef	−0.059	−0.001	−0.004
		p > z	0.000***	0.875	0.259

Note *, **, *** represent passing significant levels of 10%, 5% and 1%, respectively

(1) Analysis of the effect of the economic factor

The increase of per capita GDP has a significant positive impact on the efficiency of each stage and the overall efficiency of the power system, of which the impact on the efficiency of the transmission stage is the most significant. Because the per capita GDP directly reflects the local economic development and people's living standards, the higher the degree of economic development and the better the people's living standards, the higher the demand for electricity in production and life, and the higher the power consumption as an output indicator; The industrial structure also has a significant negative impact on the transmission stage. This is mainly because when the proportion of the secondary industry increases, the power demand will increase greatly, which will lead to local power shortage, which will inevitably cause a certain degree of power loss and reduce the operation efficiency of the transmission and distribution system.

(2) Analysis of the effect of the energy factor

Both energy factor indicators on the efficiency of the power system is insignificant, but it is worth noting that the impact of the energy consumption structure on the overall efficiency of the power generation link and the power system is positive, while the impact on the efficiency of the transmission link is negative. This is because the current power industry is still dominated by thermal power generation. The higher the power consumption, the more the power generation, and the higher the power generation efficiency. Similarly, the increase of power generation will also lead to the increase of power transmission, which will lead to the line loss of power transmission and distribution links, and lower the efficiency of the transformation links; Although the impact of energy intensity on each link is not significant, it shows the same negative correlation with the efficiency of each link. This is mainly because the increase of energy intensity in the power industry will lead to the increase of investment and labor costs in the power industry, thus reducing the efficiency of each link in the power system to a certain extent.

(3) Analysis of the effect of government regulation

The level of scientific and technological innovation has a significant impact on the various stages and overall efficiency of the power system, but unexpectedly, the improvement of the level of scientific and technological innovation has not brought about the improvement of the efficiency of the power system, which may be caused by the low conversion rate of local scientific and technological input. The government's scientific and technological input has not been fully transformed into productivity that can improve efficiency, resulting in high capital input and low scientific and technological output; There is a negative relationship between the power structure and the overall power system and the operating efficiency of each link, especially the most significant impact on the environmental efficiency of the power generation link, which is in line with the expected judgment. The increasing proportion of thermal power generation means that the CO_2 emissions generated by thermal power generation will increase, which is not conducive to environmental protection, thus inhibiting the improvement of the environmental efficiency of the power generation link.

5 Conclusions and Policy Implications

This research uses a network structure for the operational efficiency analysis of the electric power industry. This structure divides the power system into generation and transmission-distribution stages. The inputs of the former stage are capital labor, energy, and installed capacity. The output of this stage is generated electricity. As a link variable between the above two stages, this output is also an input of the latter stage. Other inputs of the latter stage is investment in power grid construction. The output of the latter stage and the entire system is electricity consumption. Installed capacity is set as the carryover variable of the first stage, and transmission line length and transformer capacity are set as the carryover variables of the second stage. Through introducing the SBM algorithm into this structure, it can evaluate the operational efficiencies of the entire industry and each stage in each period.

Empirical analysis of China's electric power industry reveals the following major findings. (I) The operational efficiency levels of provinces and regions are relatively different. Ningxia, Yunnan and Sichuan provinces have the highest efficiency scores, while Beijing, Qinghai, Ningxia Province has the lowest efficiency grade. As to China's seven major regions, East China and has the highest power generation efficiency and South China has the highest transmission and distribution efficiency.

And lowest efficiencies, respectively. Radical electric and environmental policies supported by a high economic level or rich resource endowment of renewable energies are the major reasons for the high efficiency, whereas the low efficiency is mainly caused by the overcapacity of this industry and the high electricity consumption share of households. (II) Generally, the operational efficiency of the generation stage is significantly higher than that of the transmission-distribution stage. The median efficiencies of all considered provinces of the above two stages are 0.65 and 0.43, respectively. (III) The main factors affecting efficiency are the local economic development level (GDP per capita), scientific and technological innovation level and power structure.

Key policy directions to improve the operational efficiency of China's electricity power industry are as follows: (I) through technical exchange and cooperation, provinces with high system efficiency, such as Shanghai, should give full play to the role of radiation, and provinces with low efficiency should continue to learn from and learn from the development experience of high-efficiency provinces. In addition, advanced talents and modern management concepts are introduced into the system to improve the management level based on local conditions, develop and effectively utilize renewable energy, narrow the regional gap, improve economies of scale, pay attention to environmental governance, and improve the system efficiency of the national power industry. (II) Given the large difference in electricity generation efficiencies among provinces, prompting interregional electricity transmission is a feasible measure. The key is to break down the interprovincial barriers that are set to support local socioeconomic development. (III) Continue to deepen the reform of the power system and intensify the reform of the power transmission and distribution departments. Since 2002, the power industry has gradually realized the "separation of government and enterprises, separation of power plants and networks, and separation of main and auxiliary". Although power generation enterprises have achieved competition, they are still monopolistic in a certain region, and power grid companies are the only buyers and sellers. Although the power market reform in 2015 focused on the policy orientation of opening up the two ends and controlling the middle, the power generation sector has achieved some results in this reform, but the transmission and distribution grid sector has not achieved satisfactory results, possibly because the policy role is lagging behind or the focus of policy formulation is different.

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Effect of Financial Support on the Development of Marine Equipment Manufacturing Industry in China—Evidence from 30 Listed Companies

Huang Chongzhen and Li Lan

Abstract Marine equipment manufacturing industry is an important priority development area defined in China's "14th Five-Year Plan" and *Made in China 2025*. It is an important foundation and guarantee for China to realize the strategy of building a powerful marine power. In its development process, financial support plays an irreplaceable role. This paper selects China's marine equipment manufacturing industry as the research object, constructs the financial service support system from the three perspectives of direct, indirect and policy, and collects the financial data and financial indicators of 30 listed companies in China's marine equipment manufacturing industry from 2011 to 2020, so as to establish a dynamic panel model and make an empirical analysis. The results show that the equity financing rate has a negative effect on the development of sample marine equipment enterprises, and the government subsidy rate has a positive effect on the sample enterprises, while the borrowing rate of financial institutions and the commercial credit rate have no significant influence on the development of sample enterprises. According to the current situation analysis of financial support and sys-GMM empirical research, explore the ways of financial support, so as to promote the sound and rapid development of China's marine equipment manufacturing industry.

Keywords Marine equipment manufacturing industry · Listed company · Financial data · Financial support · sys-GMM

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1 Introduction

Made in China 2025 and "the 14th Five Fear Plan" have made marine equipment manufacturing an important priority area for development. At present, with the increasing competition in marine resources and space, Marine equipment manufacturing industry has gradually become a strategic marine pillar industry. It is clearly proposed in *the Action Plan for the Sustainable and Healthy Development of Marine Equipment Manufacturing Industry (2017–2020)* to strengthen the financial service support capacity of China's marine equipment manufacturing industry. Therefore, this paper selects the marine equipment manufacturing industry as the main research object, and formulates the methods of financial support related to the marine equipment manufacturing industry according to the principle of the economic impact of financing support.

At present, foreign research on financial support for marine equipment manufacturing industry mainly focuses on government support and bank loans. By analyzing the essence and micro basis of enterprises, Teece(2010) [1] explained the dynamic development ability of enterprise business performance under financial support. Los (2001) [2] established an input–output model for the development of strategic emerging industries from a dynamic perspective. Neusser (1998) [3] speculated the cointegration of GDP and total factor productivity in the financial sector. In terms of financial support path, Hellmann (2011) [4] believed that financial venture capital can encourage enterprise innovation, and Peneder (2005) [5] confirmed that government financial support can stimulate its technological innovation more than personal investment. Winskel (2007) [6] explored the reality behind the "energy system transformation" by observing the changes and impact of the policies and systems of the UK marine energy sector, and proposed that the level of investment and innovation under the support of policies should be continuously improved.

China's research on marine equipment manufacturing industry started late, but it is highly valued, and there are a lot of academic research results. Dan (2016) [7] mainly analyzed the development status of China's marine platform market and puts forward relevant paths to improve the competitiveness of China's marine equipment manufacturing industry. Based on the analysis of the development status of traditional industries, Wei (2020) [8] proposed the significance of lean workforce literacy in the context of intelligent transformation of manufacturing industry. Rong (2018) [9] believed that the biggest problem facing the marine equipment manufacturing industry is the problem of capital, and financial support is an important guarantee. Sun (2016) [10] and others put forward suggestions on increasing human capital investment by measuring the total factor productivity of China's marine equipment manufacturing industry. Within the enterprise, Wu (2021) [11] pointed out that the marine equipment manufacturing industry is a high-tech industry, which should increase R&D investment and enhance the value chain. Outside the enterprise, Changshi (2012) [12] believed that bank loans can solve the problem of large capital demand. Of course, single mode can not meet the needs of development. Wang (2020) [13] pointed out that we need to support the development of manufacturing base with various financial services modes. Guo (2014) [14] focused on the market development of marine engineering products and suggested the establishment of a "six in one" financing model.

To sum up, scholars at home and abroad generally recognized the role of financial support in promoting marine equipment manufacturing industry, but the existing research has the following limitations: most of the research on financial support is measured from the macro perspective at the national level, ignoring the research at the micro and enterprise levels. Therefore, this paper selects the financial data of 30 listed companies in marine equipment manufacturing industry, studies it with the help of econometric model, and puts forward relevant suggestions.

2 Status of Financial Support for the Development of China's Marine Equipment Manufacturing Industry

With the deepening of the national strategy of "fasten the step of building a powerful marine power", China has established a considerable scale marine equipment manufacturing agglomeration area, and there have been a number of enterprises with outstanding strength and strong market competitiveness.

The state has vigorously promoted the effective integration of marine equipment manufacturing industry and financial industry, and strengthened the financial industry's support for marine equipment manufacturing industry. For the way of financial support, this paper analyzes the direct, indirect and policy financial support for the development of marine equipment manufacturing industry. The author found that although various financial channels have achieved certain results in supporting the marine equipment manufacturing industry, there are still many problems that restrict the further development of China's marine equipment enterprises and even the industry.

2.1 Current Situation of Marine Equipment Manufacturing Industry

At present, China has established a basic modern, relatively complete marine equipment product design and manufacturing industry standard system, the industry prospect is broad. At present, a basically modern and relatively complete industrial standard system for marine equipment product design and manufacturing has been established, and the industry has broad prospects. As China has the world's first-class ship manufacturing industry infrastructure, the world marine equipment production center has gradually moved to China. Historical data show that from 2018 to 2020, the operating revenue of China's marine equipment manufacturing enterprises increased year by year. It increased to 43.960 billion yuan in 2020., an increase of 19.30% year-on-year in 2019.

2.2 Financial Demand Characteristics of Marine Equipment Manufacturing Industry Equations

2.2.1 Large Financing Demand

Marine equipment manufacturing industry is not a single individual, but also an excellent complex, which needs to be coordinated and jointly developed with multiple related industries. While developing the marine equipment manufacturing industry, we must also build many related infrastructure to adapt to the production and operation of marine equipment manufacturing industry. At the same time, the complex marine environment puts forward higher requirements for relevant R&D and technology, which requires a large amount of capital investment.

2.2.2 Long Financing Cycle

Due to the cyclical characteristics of industrial construction, the relatively long financing period is another feature of the financial demand of marine equipment manufacturing industry. This is inevitably related to the large financing demand proposed in the previous section. Fundamentally speaking, this is not in line with the general law of capital accumulation in the financing market. Therefore, the slow return of funds in the financial demand of marine equipment manufacturing industry must exist.

2.2.3 High Financing Risk

Firstly, marine equipment manufacturing industry is different from land manufacturing industry. There are interference factors such as natural environment and seawater corrosion that have little impact on land manufacturing industry; Secondly, the marine equipment manufacturing industry has a great demand for funds, which itself makes investors bear great risks. Finally, the long financing cycle is also one of the sources of huge risks.

2.2.4 High Policy Dependence

The strong support of the government is a strong support for the development of marine equipment manufacturing industry. Due to the long financing cycle, the financing risk is greatly increased, and investors are deterred. At this time, the government's supportive financial policies can stimulate investors' willingness to invest and enhance their investment in marine equipment manufacturing industry.

2.3 Current Situation of Financial Support for Marine Equipment Manufacturing Industry

2.3.1 Direct Financial Support

(1) Stock market financing

According to the data of the State Securities Regulatory Bureau, by the end of 2020, there were 258 listed domestic special equipment manufacturing companies, including 6 marine equipment related companies. Other secondary categories under the main categories of enterprises still include marine equipment related companies. A total of 30 listed enterprises have been selected. There are 18, 7 and 5 enterprises listed on the main board, small and medium-sized board and gem respectively, of which state-owned enterprises account for the largest proportion. In addition, due to the fact that the equity investment in the direct financing support of Listed Companies in marine equipment manufacturing industry is mainly realized through the main board channel, Therefore, most companies are state-owned enterprises.

(2) Bond market financing

By the end of 2020, the number of bonds issued by the 30 listed companies of marine equipment in the sample was only 13, and most of the bonds were issued for a period of 1–5 years, which could not meet the company's long-term investment needs on the whole, and the proportion of corporate assets was small. It can be seen that the power of bond investment and financing methods to support the development of marine equipment manufacturing industry is relatively limited compared with other investment and financing methods. And due to the lack of data, this paper excludes the item of bonds payable.

(3) Commercial credit financing

As a direct financing channel, commercial credit has the advantages of obtaining convenience and eliminating guarantee. It is also the main method for financial institutions to support the development of marine equipment production enterprises. From 2011 to 2020, the commercial credit rate of the sample companies fluctuated in the range of 3.64–166.41%.

2.3.2 Indirect Financial Support

Indirect financial support, also known as debt financing, of which the most important part is bank financing. In 2011–2020, the ratio of short-term and long-term borrowing in the investment scale of China ‘s marine equipment manufacturing bank is close to the same, that is, the company relies on both bank financial support and its investment amount has been relatively stable in recent years.

2.3.3 Policy Financial Support

The government’s policy financial support for marine equipment manufacturing enterprises includes tax preference, special subsidies and so on. Among them, the organic integration of industrial capital and financial capital through government investment guidance fund is a fruitful policy fund support program. By the end of 2020, 30 sample enterprises had raised a total of 23.45 billion yuan. At this stage, the increase of total government subsidies has gradually slowed down, and it is expected that marine equipment production enterprises will gradually enter the optimization stage of capital stock.

3 Financial Support Result of China’s Marine Equipment Manufacturing Industry

In this chapter, the author uses the empirical analysis method to explain how different financial support methods will affect the development of marine equipment manufacturing industry. After analyzing the experimental results, the author puts forward some countermeasures for the financial support of marine equipment manufacturing industry.

3.1 Research Design

3.1.1 Sample Selection and Data Sources

The research selects the national listed companies of marine equipment as the research sample to ensure the availability and comprehensiveness of financial data. 30 representative listed joint-stock companies of marine equipment are selected as samples. This paper will select the annual comprehensive financial report of China marine equipment manufacturing listed company from 2011 to 2020.

3.1.2 Variable Definition

(1) Explained variable

Return of Earning (roe): This paper selects roe as the explained variable to measure the overall effect of listed companies in marine equipment manufacturing industry supported by various financing methods, that is, operating performance. And because this variable is the main technical index used in DuPont financial analysis, it has considerable representativeness and authority. Its calculation formula is as follows:

$$\begin{aligned} \text{roe} = &(\text{net profit of shareholders in the current period} \\ &- \text{net profit of shareholders in the previous period}) / \\ &\text{net profit of shareholders in the previous period} \end{aligned} \tag{1}$$

(2) Explanatory variable

(1) Bank credit financing rate (bfr): the investment carried out by enterprises using financing intermediaries is the most important investment method for listed joint-stock companies in marine equipment manufacturing industry to raise capital. The use of bank credit funds can raise social idle capital to the greatest extent, so as to disperse business risks and reduce investment costs at the same time. Therefore, the borrowings in the balance sheet of a listed company can be roughly expressed as the capital that can be raised by the general loan method. Its calculation formula is as follows:

$$\text{bfr} = (\text{short term loan} + \text{long term loan}) / \text{total assets} \tag{2}$$

(2) Equity financing rate (sfr): equity financing refers to the public or private offering of listed companies to raise the capital required for the company's operation. Due to the sustainability of equity financing, The listing of marine equipment company is precisely in the hope of using equity to obtain the required financing. Its calculation formula is as follows:

$$\text{sfr} = \text{share capital} / \text{total assets} \tag{3}$$

(3) Commercial credit rate (bcr): commercial credit financing refers to that listed joint-stock companies can conduct commodity transactions through debt, advance receipt and invoicing. This is a common way of direct financial support. At the same time, the importance of enterprise reputation in this way is self-evident. Its calculation formula is as follows:

$$\text{bcr} = (\text{advances received} + \text{accounts payable} + \text{notes payable}) / \text{total assets} \tag{4}$$

(4) Government subsidy rate (gsr): the government subsidy rate is the representative of policy financial support. Obtaining policy subsidies can release to the outside and convey the positive information of enterprise quality and development, promote the company to obtain financial support from banks and other institutions. Its calculation formula is as follows:

$$\text{gsr} = \text{government subsidies} / \text{total assets} \tag{5}$$

(3) Control variable

Asset liability rate (dar): the asset liability ratio of an enterprise, which is the main indicator reflecting the debt level of an enterprise and the rationalization of its financial structure. The appropriate enterprise asset liability ratio of China's listed marine equipment companies can help them effectively use financial leverage for research and development, improve operation, and achieve higher investment income. However, if the value is too high, it will inevitably have a negative impact on the business activities, business reputation and financing ability of enterprises. Its calculation formula is as follows:

$$\text{dar} = \text{liabilities} / \text{total assets} \tag{6}$$

3.1.3 Research Hypothesis

This study assumes that:

Hypothesis 1: the loan rate of financial institutions is directly proportional to the operating performance of listed companies in marine equipment manufacturing industry.

The borrowing of financial institutions has brought huge credit support to the development of strategic emerging industries. Therefore, judging the loan rate of financial institutions has a positive impact on the performance development of listed joint-stock companies.

Hypothesis 2: the equity financing rate is directly proportional to the operating performance of listed companies in marine equipment manufacturing industry.

The cost of equity financing is low, and it can achieve long-term and sustainable help to the marine equipment manufacturing industry. Therefore, it is speculated that the equity financing rate also has a positive impact on the listed companies of China's marine equipment manufacturing industry.

Hypothesis 3: the commercial credit rate is directly proportional to the operating performance of listed companies in marine equipment manufacturing industry.

In the production and operation activities, the company is often unable to fully pay for both money and goods. Therefore, it must be supported by means of arrears, provision of commercial bills and advance receipt in order to establish the first mover advantage in the early stage of development. Therefore, judging the commercial credit rate also has a positive impact on China's marine equipment manufacturing listed companies.

Hypothesis 4: the government subsidy rate is directly proportional to the operating performance of listed companies in marine equipment manufacturing industry.

It is difficult for marine equipment companies to obtain a large amount of credit, stocks and bonds in the initial stage and growth period, and they need a considerable part of financial subsidies. Therefore, it is speculated that the government subsidy rate also has a positive impact on listed companies in China's marine equipment manufacturing industry.

3.2 Descriptive Statistics

This paper uses StataSE15 to make descriptive statistical analysis on the financial data of various financing schemes of listed companies of China's marine equipment, as shown in Table 1.

From the data results, the overall operating performance and profitability of China marine equipment manufacturing company were slowly improving from 2011 to 2020. From 2011 to 2020, the average return of earning of the company was 0.012. However, due to the great differences in profitability among companies in China's marine equipment manufacturing industry, the highest return of earning is 2.17, while the lowest return of earning is even negative. In addition, from the mean value of various financing methods, it can also be found that listed companies in China's marine equipment manufacturing industry prefer to use loans from financial institutions, which is different from the equity financing of listed companies generally proposed by scholars. Followed by commercial credit rate and equity financing rate, there is little difference between them. The government subsidy rate accounts for the smallest proportion, with an average of only 0.004.

Table 1 Descriptive statistical analysis results of each variable

Index	Mean	Standard deviation	Minimum	Maximum
roe	0.012	0.229	−1.736	0.217
bfr	0.287	0.479	0	3.308
sfr	0.136	0.098	0.021	0.523
bcr	0.203	0.125	0.046	0.745
gsr	0.004	0.004	0	0.022
dar	0.458	0.192	0.091	0.898

3.3 Empirical Research

3.3.1 Construction of Panel Model

Because the change of return on net assets of listed companies is a moving process, it is not only closely related to a variety of different long-term investment, but also directly restricted by the change of return on net assets in a certain period. In order to reduce the interference of endogenous problems in the process of system modeling, we introduce the lag phase of the explained variable as the explanatory variable into the modeling process. According to the system GMM method, the dynamic panel regression model is adopted for analysis. As follows:

$$\begin{aligned} \text{roe}_{it} &= \alpha_0 + \beta_1 \text{roe}_{it-1} + \beta_2 \text{bfr}_{it} + \beta_3 \text{sfr}_{it} \\ &\quad + \beta_4 \text{bcr}_{it} + \beta_5 \text{gsr}_{it} + \beta_6 \text{dar}_{it} + \mu_{it} + \varepsilon_{it} \end{aligned} \tag{7}$$

Roe stands for the return of earning, bfr stands for the bank credit financing rate, sfr stands for the equity financing rate, bcr stands for the commercial credit rate, gsr stands for the government subsidy rate, dar stands for the asset liability rate, t stands for the period, i stands for the number of listed companies of marine engineering equipment, β is the coefficient of each financing method, μ_{it} refers to the unobservable individual differences among listed companies, ε_{it} is a random error term.

3.3.2 Unit Root Test

Check whether the unit root exists in the panel data results to ensure the stable and effective operation of the panel data results and prevent pseudo regression. The unit root test is realized by StataSE15. The test results of unit root of panel data are shown in Table 2.

After the unit root test, the author found that some explanatory variables are not significant under some methods. In order to eliminate the unit root, difference is needed. However, the author considers that the data in this paper only includes 2011–2020, a total of 10 years, but the section is 30, which belongs to the typical large-N and small-T panel data, and all variables selected in this paper are ratios. If the difference is made, the data sequence will be shorter, a considerable part of information will be lost, and the accuracy of the model will be greatly reduced. Therefore, this paper still uses the original data for analysis.

3.3.3 Regression Analysis

This chapter will gradually set four empirical models: first, only roe(-1) and bfr are added to the explanatory variables to set the initial model 1; Add sfr to model 1 and set model 2; Add bcr and gsr to model 2 and set it as model 3; Add dar

Table 2 Unit root test of panel data

Variable	Levin-Lin-Chu	Im-Pesaran-Shin	Fisher-ADF	Fisher-PP
roe	−13.6449 (0.0000)	−5.16006 (0.0000)	129.013 (0.0000)	107.192 (0.0002)
bfr	−8.72606 (0.0000)	−2.32667 (0.0100)	97.2797 (0.0017)	97.6593 (0.0015)
sfr	−4.82498 (0.0000)	−0.37857 (0.3525)	79.4081 (0.0475)	97.0967 (0.0017)
bcr	−4.90671 (0.0000)	−0.29875 (0.3826)	71.6269 (0.1447)	56.6424 (0.5992)
gsr	−13.2693 (0.0000)	−6.0544 (0.0000)	150.927 (0.0000)	162.893 (0.0000)
dar	−5.57457 (0.0000)	−1.13519 (0.1281)	74.7942 (0.0946)	61.8243 (0.4107)

as the control variable in model 3 and set it as model 4. By selecting appropriate instrumental variables, generalized moment estimation is carried out for models 1 to 4 respectively, as shown in Table 3.

From the estimation results in Table 3, we need to determine whether the sys-GMM method is feasible. The judgment methods are Sargan test and abond test. Observe the AR (2) item in Table 3. The AR (2) values of the four models show that there is no second-order autocorrelation, indicating that the model is feasible. Observing Sargan term, the P values of the four models passed the significance test, which proved that the instrumental variables were effective and the problem

Table 3 Dynamic regression results of China's listed equipment enterprises

Explanatory variable (control variable)	Explained variable			
	Model 1	Model 2	Model 3	Model 4
roe	0.419* (0.220)	0.356* (0.185)	0.338* (0.184)	0.171** (0.0772)
bfr	−0.0244 (0.123)	−0.00581 (0.143)	−0.0133 (0.141)	−0.00425 (0.0781)
sfr		−0.834* (0.473)	−0.894** (0.445)	−0.885** (0.402)
bcr			−0.151 (0.251)	0.250 (0.318)
gsr			8.687* (4.740)	10.29** (4.281)
dar				−0.894*** (0.311)

Note 1. Cross section: 30
2. Sample interval: December 2011 to December 2020
3. *, ** and *** are significant at the significance levels of 10%, 5% and 1%, respectively

of over identification did not exist. It can be seen that the model is effective. From the research conclusions in Table 3, we can confirm that roe(−1) has a significant positive impact on roe, which is mainly because the operation of marine equipment company has sustainable development. The better the company's performance, the easier it will be favored by relevant financial institutions, and it will develop better in the next period, so it will continue to cycle. Secondly, at the 5% significance level, sfr was negatively correlated with roe and gsr was positively correlated with roe; However, there is no obvious relationship between bfr, bcr and roe, which shows that bank credit investment or commercial credit investment will not have a significant impact on the operation of China's marine equipment manufacturing enterprises. In addition, dar has a negative correlation with roe at the significance level of 1%.

4 Conclusions and Countermeasures

Based on the conclusion of regression analysis of panel data, the above research hypotheses are tested: the borrowing rate of financial institutions does not have a significant indigenous effect on the return on net assets, the equity financing rate has a negative significant indigenous effect on the return on net assets, and the commercial credit rate does not have a significant indigenous effect on the return on net assets. Hypothesis 1, 2 and 3 are not valid. The government subsidy rate has a positive impact on the return of earning, and hypothesis 4 is tenable. Based on the results of empirical tests, this paper gives specific financing strategy suggestions as follow.

(1) The bank credit financing rate will not have a significant impact, which is determined according to the actual situation of the country. Formal institutional credit generally tends to large companies with strong operating ability and good social credit foundation, while marine equipment manufacturing companies are difficult to obtain long-term and stable credit support because they have no commercial guarantee or pledged loans. It can be seen that, first of all, commercial banks should improve the internal evaluation integrity system, entrust special personnel to investigate and evaluate the marine equipment manufacturing industry, and put forward corresponding credit support countermeasures according to the marine equipment manufacturing industry. Second, local commercial banks actively promote the diversification of financial service products such as patent pledge and industrial chain investment. Third, actively develop technical and financial services, establish technical commercial banks, and carry out low interest rate, low-cost credit, patent pledge and other businesses according to the characteristics of marine equipment enterprises, and even participate in companies.
(2) Equity financing rate has a negative impact. But for the current marine equipment listed companies, equity financing is relatively important. Based on this, the state should actively cultivate the listing reserve resources, help the listed companies that have obtained the listing qualification to sign up for financing,

and correspondingly liberalize the listing standards and market entry threshold. In addition, it is necessary to form a sound board transfer incentive mechanism to achieve a reasonable connection between the boards and a smooth way of delisting. At the same time, it is necessary for listed companies in China's marine equipment manufacturing industry to continuously improve the effect of equity financing through strict regulation of shareholding institutions. In addition, the government can continue to innovate bond financing varieties, and vigorously promote the healthy development of the bond market. Bond development and application can provide strong financial support for the development of marine equipment manufacturing industry.

(3) Commercial credit rate has no obvious impact on marine equipment enterprises. Commercial credit investment is a direct investment method with low cost, low threshold and no guarantee. It has inherent advantages in market liquidity and penetration. Excessive reliance on commercial credit financing will increase the repayment pressure of enterprises and inhibit the growth of enterprise income. On the one hand, the continuous development of China's commercial credit needs a sound commercial financial system as a guarantee. When the commercial credit relationship cannot be carried out due to the lack of good reputation of all trading parties, banks and other financial institutions can guarantee their own reputation. On the other hand, the marine equipment production company should strengthen its self hematopoietic function, promote product upgrading and structural adjustment, innovate science and technology, update technical equipment. In this way, we can maintain its independence and market competitiveness in commercial credit activities, and make commercial credit play a better role.

(4) The government subsidy rate has a positive impact on marine equipment enterprises, highlighting the key position of policy fund support in the national fund support marine equipment manufacturing system. Because the influence coefficient of policy capital support is much higher than that of other market capital methods, it is prone to the risk of excessive intervention in violation of market rules. Therefore, government departments should increase cooperation with scientific research institutions and universities to form an investment guarantee chain covering the whole life cycle of China's marine equipment manufacturing enterprises. In terms of investment channels, the government should give full play to the function of policy guidance and further develop low-risk investment. At the same time, the government should pay special attention to preventing companies from implementing the strategy of rapid expansion and low-cost competition in order to obtain government policy subsidies. Due to the limited capacity of the domestic market, it will also greatly increase the possibility of enterprises flowing into foreign markets at higher prices and being affected by government countervailing measures. Therefore, for the development of enterprises in foreign markets, government departments also need to be more cautious in policy subsidies. On the one hand, the government should try its best to take non financing guarantee measures such as perfect business environment and supply information guarantee to support the development of enterprises; On the

other hand, the government should also form a complete early warning system for international trade frictions, timely warn the risk of foreign trade export relief and formulate corresponding measures in advance.

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Research on Pricing and Design Optimization of Cause Marketing Products

Zhishuai Yan and Wei Xing

Abstract Nowadays, corporate philanthropy has gradually transformed into a corporate marketing strategy, which is an act that not only benefits commercial interests but also serves social organizations or individuals. When customers purchase related products, the company donates a portion of the sales proceeds to charity. Based on the method of game theory, this paper studies the pricing decision and product quality decision of a CM company, analyzes two different supply chain product pricing models, and conducts quantitative research on issues related to product quality, product price and donation amount. Comprehensive consideration is given to consumer differences, product utility value differences, and supply chain structure differences. We found that the company's choice of product price and quality is closely related to the scale of public welfare consumers. When the scale is large enough, the enterprise will implement CM, and after implementing CM, it may be the best to improve product quality; At the same time of donation, it may be the best decision for enterprises to reduce the price of products; thirdly, manufacturers can influence retailers' donation amount and pricing by controlling the quality of products, and high-quality products may make the donation amount smaller. All in all, the current findings help companies develop optimal sales strategies for different consumer groups.

Keywords Cause marketing · Game theory · Prosocial behavior · Pricing decisions

1 Introduction

In the twenty-first century, "corporate social responsibility" is no stranger to us, and a survey of unilever (China) Co., Ltd. employees on "Consumer Awareness of Corporate Social Responsibility and Attitude towards Public Welfare Marketing" pointed

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out that more than 95% of employees know about corporate social responsibility, and nearly 50% of employees have heard of good cause marketing.

Cause marketing was first produced in the United States. As early as 1981 and 1983, American Express greatly improved the market share of its credit cards and established a strong brand image by sponsoring the restoration of the Statue of Liberty. "One penny that the company's existing customers use is donated to the repair fund, and every new user adds $1 to the fund," it said. In the three promotional periods from September to December 1986, American Express usage rose by 28% points compared with the previous year, and the application rate for new cards increased by 17% points, because the restoration of the Statue of Liberty is extremely attractive to every American. The event of American Express became the first charity marketing campaign widely recognized by the academic community. After this, more and more enterprises began to devote themselves to the good cause marketing activities. Wal-mart, Coca-Cola, procter & l, l'Oreal, Microsoft, MOTOROLA, Avon, from our known international chain retail giants to high-tech industry, the owners of the international famous brand without exception in education, environmental protection, health and other public welfare undertakings at the same time, set up the company is caring, responsible, actively solve the social problems of public concern, and the positive image of the public, and promoting their own brand.

Similarly, in China, with the increasing popularity of "sustainable development" and "economic globalization", more and more enterprises cooperate with public welfare organizations to make full use of their authoritative and public welfare resources to build a marketing platform that consumers can identify with and promote market sales. For example, Alibaba provides an online public fundraising platform for public welfare organizations and public welfare projects,—"Charity Baby". Consumers buy charity projects with "charity baby" labels or public welfare projects on Taobao. Over the years, "Charity Baby" has relied on the platform network business to raise funds for a number of public welfare organizations, so that the platform will donate a certain amount to the charity group according to the proportion of the seller to obtain sustainable sources of funds to help the groups in need. Such as nongfu spring from "buy a bottle of nongfu spring, to donate a penny" to "every bottle of nongfu spring, you donate a penny for water poor children", to the spring of 2010 southwest China nongfu spring donated 380,000 boxes of natural water, during the nongfu spring constantly through public welfare events into the line of sight of consumers, to attract the attention of consumers.

Nowadays, the corporate charity behavior has gradually been transformed into a corporate marketing strategy, which is conducive to the business interests and serves the social organizations or individuals. With the continuous change of business philosophy of enterprise managers and the continuous demand of external stakeholders for corporate charitable behavior, enterprises pay more and more attention to the added value brought by charitable behavior to enterprises and the maintenance of a good relationship with stakeholders.

Good cause marketing has become a form of marketing for both product sales and social problems or public welfare undertakings. While donating for charitable matters, it can better achieve its established sales target, and maintain and enhance the image and value of the brand while achieving the expected profits. Good cause marketing effectively balances the dual goals of corporate social responsibility and the realization of their own interests, with both public welfare and benefit, and has the characteristics of mutual benefit and win–win results. Due to the successful implementation of good for marketing greatly depends on the response of consumers, enterprises in the process of good for marketing, need to arouse the enthusiasm of consumers to participate in charity, make its involved in improving the enterprise brand influence and reputation of marketing activities, thus to realize their own survival and development at the same time meet the growing consumer demand, to promote social progress.

This paper integrates and complements the relevant theoretical studies. Taking corporate charity behavior as the research object, we will summarize and review it compared with domestic and foreign research, and construct the research ideas on the basis of previous human theoretical research. This paper considers consumer differences, quality differences, platform intervention and distribution channels comprehensively. We establish a new theoretical model for the study of corporate charitable behavior. This paper tries to absorb and learn from the research of charitable behavior of domestic and foreign enterprises, sort out and integrate the benefits and equilibrium results of various charitable behavior models of enterprises, and use relevant theories to establish a systematic research framework.

The practical significance of the article lies in: first, by combining enterprises with non-profit organizations, especially charitable organizations, combining product sales with public welfare undertakings, to improve product sales, realize corporate profits and improve corporate social image for related undertakings; secondly, it is beyond the significance of ordinary marketing projects, effectively mobilize the enthusiasm of sales personnel, to develop the optimal marketing plan to improve their performance. Then, the company strengthens the importance of enterprises to assume social responsibility. As an important part of the society, enterprises should consider the overall interests of the society and the long-term development of the society, consciously assume the corresponding social responsibility, and the good cause marketing is largely the concrete performance of the social responsibility.

2 Literature Review

In the current research on good cause marketing, the influencing factors of the effect of good cause marketing are roughly studied through the following three characteristics: consumer characteristics, enterprise characteristics, and the attribute characteristics of public welfare matters.

The supply chain and related game theory involved in this paper are also mainly related to the following two fields:

Research on supply chain and e-commerce; Research based on different distribution channels of products.

2.1 *Review of the Influencing Factors of Good Cause Marketing*

2.1.1 Consumer Characteristics

In recent years, good cause marketing has become an important strategy for enterprises to increase their own business value. Many of the existing studies on the factors affecting the effectiveness of good-cause marketing are conducted from the perspective of consumers, such as: the characteristics, classification and psychology of consumers. Based on the analysis from different perspectives, the classification of consumers is also different. Thomas (2020) believes that young consumers and women are less suspicious of CRM, and shows that knowledge and awareness are important factors influencing the degree of doubt [1]. Moraet et al. (2021) analyzed the attitude impact of public marketing activities spread through social networks, and observed the response to this activity in three Internet user groups with different affinity levels [2]. Ma Wenming (2020) took young consumers as the survey object, and empirically analyzed what factors of good cause marketing affect this consumer group with the characteristics of self-attention to their needs and high level of education [3]. Guan Yanan (2019) studied consumers ‘participation intention in good cause marketing from a prosocial perspective. He used the overall score level of "prosocial reasoning" proposed by Eisenberg et al. to express the prosocial level of consumers, and showed that consumers' level of prosocial will affect their participation intention to participate in good cause marketing [4].

2.1.2 Enterprise Characteristics

From the perspective of enterprises, the existing research studies different schemes and profits of enterprises. Ye et al. (2021) compares two donation schemes of enterprises, namely part of the proceeds of selling donated products or simply donating their products, and analyzes the impact of these two methods on consumers' willingness to buy [5]. Sheikh (2011) compares public welfare marketing (CRM) and corporate social responsibility (CSR) and shows that the high cause specificity of CSR is preferred only when the market has a broad causal relationship or the company faces negative public sentiment caused by product hazard crisis [6].

At the same time, many existing scholars have explored the scale of donations. Amel et al. (2020) considers the impact of the donation scale related to causal-related marketing (CRM) practices on the purchase intention, indicating that the size of the donation does not directly affect the purchase intention, but instead raises the suspicion of in the case of large donations. Fan et al. [7] (2020) Charity marketing will be more effective when the brand is familiar, product utilitarian, donation scale, and not more familiar with the business. However, neither the cultural orientation nor the type of business significantly affects the effectiveness of business marketing [8].

2.1.3 Property and Characteristics of Public Welfare Matters

Among the influencing factors of marketing related activities, many scholars have conducted empirical research on the impact of good cause marketing products and brand fit on sales volume. Silva (2020) [9] Hu Yaru (2019) [10] Li Shanshan (2014) [11] Nan (2007) [12] all shows that brand-charity matching fit has a positive impact on consumers' willingness to buy. Zhang et al. (2020) proposed that the fit between business and brand is an important factor affecting consumer cognition and behavior. However, there is disagreement about the impact of brand fit on consumer responses with different corporate reputations [13].

Many scholars also classified the fit types and discussed the influence of different fit types on consumers' purchase intention. Based on the theory of similarity dual-channel processing model, Huo Jiale et al. (2021) explored the influence of different fit types on consumers' sharing of good cause marketing information on social media. It is found that relative classification fit, theme fit can bring higher perceived trust, social media sharing willingness, and perceived trust plays an intermediary role in the influence of fit type and social media sharing willingness [14]. Yang et al. (2021) examines the fit of perceived brand social reasons (i.e., function fit and image fit) and consumer suspicion affect consumers' views of brand opportunism. The results show that the lack of brand social reasons matching leads to poor consumer attitude [15]. Zhu Yimin (2014) studied the influence of the fit type of enterprise and charity under different information frameworks on consumer response, indicating that the main effect of the fit type, text expression mode and picture presentation mode on consumer attitude is significant in [16]. In addition, Cao Zhongpeng et al. (2012) found that not only the fit and publicity focus had significant main effect on consumer behavior and attitude, but also the interaction effect of the two was significant. The preferred fit for enterprises to position public welfare events, and how to weigh the publicity focus in marketing communication have clear guiding significance [17].

2.2 Summary of Supply Chain and Related Game Theory Research

2.2.1 Research Status of Supply Chain and E-commerce

Many scholars are based on the game theory knowledge of supply chain management, Guo Songbo et al. (2021) with drug procurement policy of pharmaceutical reform as the background, using the method of game theory, build a single drug manufacturer and two competitive asymmetric drug retailer supply chain structure model, analyzes the competitive drug supply chain optimal pricing decision, discusses the size of different asymmetric drug retailers drug group supply chain system coordination mechanism [18]. Under the premise of limited rationality, Shao Bilin et al. (2021) clarified the influence path of constructing evolutionary game models, analyzing the game relationship and stability strategy of the two sides, and using system dynamics, and clarifying the influence path of key factors on the government and enterprise participation behavior of green supply chain [19].

Currently, e-commerce has become an important part of people's life. Shopping is no longer limited to offline, online shopping, online payment, online price comparison and other emerging models have become normal. With the development of the Internet, e-commerce has advanced by leaps and bounds, and the traditional business model has been difficult to adapt to the needs of the social market, and many physical enterprises and physical stores have been transformed to test the water of e-commerce. Many scholars have also conducted a series of research on e-commerce to help enterprises solve the problems in production, sales, platform docking, supply chain, settlement and other links. Lu (2019) made a certain analysis of the current situation of cross-border e-commerce supply chain. By comparing the advantages and disadvantages of various supply chain models, the macro factors and specific factors affecting the supply chain models were obtained as [20]. Lin Qiang (2021) et al. discussed the impact of credit payment impact factor and commission ratio in e-commerce on the optimal decision, expected profit and sales model choice of both parties, and found that in the wholesale model, credit payment makes the expected profit of platform enterprises always higher than the cash payment [21]. Hu Yuzhen and others considered the site location and transportation planning of overseas warehouses for the coordinated transfer of goods between overseas warehouses in different locations, and solved the problems of site selection and transportation planning of overseas warehouses on cross-border e-commerce platforms [22].

2.2.2 Consider the Current Supply Chain Research Status of Product Distribution Channels

Current many scholars are based on the game analysis of the supply chain, to study the supply chain distribution channels and revenue size, Zhu (2020) based on the three-stage Stackelberg dynamic game analysis, built by a manufacturer of three supply distribution channels (direct channels, retail channels and mixed channels) product quality control strategy model. Analyanalyzes how three distribution channel strategies influence manufacturers 'product quality decisions and quality prevention strategies, retailers' product pricing decisions and quality inspection strategies, and end customer product demand decisions [23]. Zhu Lirong and Sun Shuhui (2019) based on four stage Stackelberg master dynamic game, studied the innovation investment manufacturers decentralized and centralized decision, analyzes the three kinds of distribution channel strategy (online direct channel, traditional retail channels, mixed channel), manufacturer innovation investment strategy on product quality, sales price, market demand, expected profit and consumer surplus influence [24].

3 Base Model

3.1 Problem Description

In the basic model, assuming that a company makes and sells a certain product, in addition to determining the product price p and quality q, it also determines the donation amount k for each unit sold in a CM event that, if k is 0, amounts to no CM implementation. In this market, consumer preferences for the product itself and charitable reasons are heterogeneous, there are two types of customers in the market, non-prosocial customers have the product valuation of $\theta_n q$, they do not care about CM activities, only the quality of the product. Therefore, the utility value is $\theta_n q - p$ regardless of the donation amount k. Pro-social customers value the product as p q, and they receive an additional positive utility s(k) from the purchase of the charity donation amount k, so the utility value of pro-social customers buying the product is $\theta_p q - p + s(k)$. Among them, the function s(k) has the following characteristics: Koschate-Fischer et al. found a positive and concave relationship between the consumer's willingness to pay and the donation amount; therefore, s′ (k) > 0 and s″ (k) < 0. Furthermore, k = 0 corresponds to cases where there is no donation to the cause and, therefore, s (0) = 0. In addition, we assume that $\lim_{k\to\infty} s(k) = 0 \lim_{k\to\infty} s(k) = 0$ (i.e., the additional increase in donation value k has little effect on consumer shopping behavior when the donation value k is already sufficiently high enough) (Fig. 1).

As not general, we standardize the total number of consumers on the market to one. Suppose that prosocial customers constitute the [0, 1] of the total population; the remaining $1 - \alpha$ is a non-prosocial customer. Interactions between consumers and companies can be modeled as a sequential game. First, the company decided to produce the quality of the products, and second, the company announced the product price p and the unit donation amount k. Third, if the utility value is non-negative (i.e., 0 or more), the consumer buys the product. The profits of the Company may be expressed as follows:

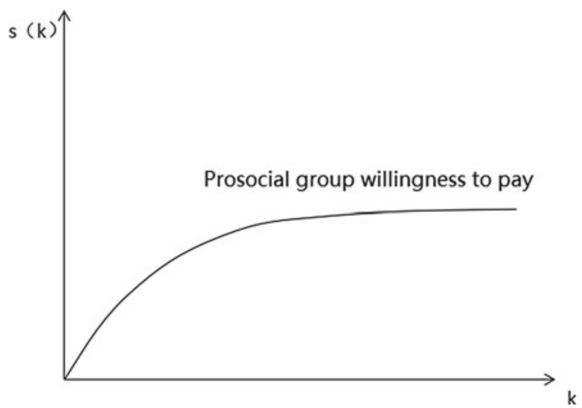

Fig. 1 Characteristics of the willingness-to-pay curve of prosocial groups

Fig. 2 Basic game sequence

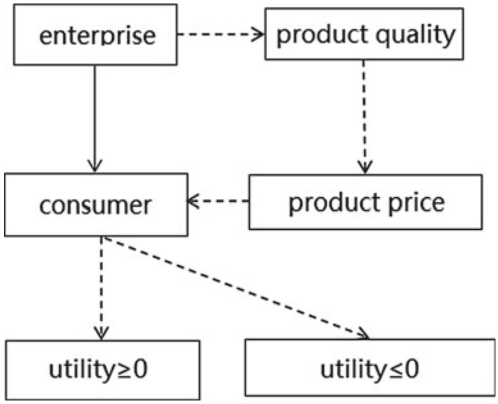

Table 1 Relevant symbol description

Symbol	Symbol description
un	Non-prosocial consumer utility value
up	Prosocial consumer utility value
P	Product price
k	The amount of unit donations made by enterprises to CM products
q	Product quality
π	The value of the enterprise profit
S(k)	Prosocial consumer payment willingness function
θp	Prosocial consumer unit quality product valuation
θn	Non-prosocial consumer unit quality product valuation

$$Max(p,k) = \left(p - k - \frac{\delta q^2}{2}\right) \cdot \left[\alpha I_{up \geq 0} + (1-\alpha) I_{un \geq 0}\right] \tag{1}$$

where, where I_A is a function, $I_A = 1$ if A is true; $I_A = 0$ if A is false (Fig. 2).

The relevant symbols used in the article are described below, as shown in Table 1.

3.2 Analysis of the Second Stage of Price Decision Making Under the Basic Model

In the basic model, we use $\alpha I_{up \geq 0} + (1-\alpha) I_{un \geq 0}$ to represent the size of the sales volume, so there are four cases for product sales:

Scenario 1: Demand is 0.

$$\begin{cases} \theta_n q - p < 0 \\ \theta_p q - p + s(k) < 0 \end{cases} \tag{2}$$

Scenario 2: Demand is α.

$$\begin{cases} \theta_n q - p < 0 \\ \theta_p q - p + s(k) > 0 \end{cases} \tag{3}$$

Scenario 3: Demand is 1 − α.

$$\begin{cases} \theta_n q - p > 0 \\ \theta_p q - p + s(k) < 0 \end{cases} \tag{4}$$

Scenario 4: Demand is 1.

$$\begin{cases} \theta_n q - p > 0 \\ \theta_p q - p + s(k) > 0 \end{cases} \tag{5}$$

We adopt the reverse induction method, first considering the second stage of the enterprise decision on the price and the donation amount. Because the two variables decide at the same time, we use the goal planning method to solve it. The enterprise objective function is

$$Max\pi(p,k) = \left(p - k - \frac{\delta q^2}{2}\right) \cdot \left[\alpha I_{up \geq 0} + (1-\alpha) I_{un \geq 0}\right] \tag{6}$$

For prosocial groups, when k = k*, p = θ_pq + s (k*), the target profit function takes its maximum value, where s′ (k*) = 1。When θ_pq + s (k*) > θ_nq, non-prosocial groups do not buy the product at that decision point; When θ_pq + s (k*) < θ_nq Non-pro-community groups also buy products at this decision-making point.

Therefore, we assume that companies may produce high-quality and low-quality products to meet the quality needs of two different groups of people. When $\theta_p < \theta_n$, the low-quality product is q_l ($q_l < \frac{s(k^*)}{\theta_n - \theta_p}$) Remember high-quality products for q_h ($q_h > \frac{s(k^*)}{\theta_n - \theta_p}$); When $\theta_p > \theta_n$, there is a constant θ_pq + s(k*) > θ_nq, at this time the enterprise only produces one quality specification of the product, recorded as q_o.

Below we will analyze the price and donation amount in each case:

3.2.1 Corporate Decision in the Case of $\boldsymbol{\theta_p \geq \theta_n}$

当 $\theta_p \geq \theta_n$ 时, $\theta_p q + s(k*) > \theta_n q$, Enterprises will only produce one product of quality specifications. There are two types of decisions that companies make:

(1) Make the product meet the utility value of all types of consumers, so that the sales volume is 1.

Then the objective function is $Max\pi(p,k) = \left(p - k - \delta q^2/2\right)$.

The constraint is $p \le \theta_n q$; $p \le \theta_p q + s(k)$.

Seeking: $p_1 = \theta_n q$;$k_1 = 0$, at this time the enterprise profit value is $\pi_{R1} = \theta_n q - \frac{\delta q^2}{2}$

(2) Make the product meet the utility value of the prosocial consumer group, but not the non-prosocial group, so that the sales volume is α.

Then the objective function is $Max\pi(p,k) = \left(p - k - \delta q^2/2\right) \cdot \alpha$.

The constraint is $p > \theta_n q$;$p \le \theta_p q + s(k)$.

Seeking: $p_2 = \theta_p q + s(k^*)$; $k_2 = k^*$, at this time the value of the enterprise profit is $\pi_{R2} = [\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2] \cdot \alpha$

Compare the profits in both cases to get a comparison,

While $\alpha \le \frac{\theta_n q - \frac{\delta}{2}q^2}{\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2}$, $pb = \theta_n q$, $kb = 0$, $\pi_R^b = \theta_n q - \frac{\delta}{2}q^2$;

When $\alpha > \frac{\theta_n q - \frac{\delta}{2}q^2}{\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2}$, $pb = \theta_p q + s(k^*)$, $kb = k^*$, $\pi_R^b = [\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2] \cdot \alpha$.

3.2.2 Corporate Decision in the Case of $\theta_p < \theta_n$

When $\theta_p < \theta_n$, the company may produce two specifications of the product, we first discuss the case of low-quality productsq_l, where $q_l < \frac{s(k*)}{\theta_n - \theta_p}$, the company has three decisions at this time:

(1) Make the product meet the utility value of all types of consumers, so that the sales volume is 1. The objective function is Max $\pi(p,k) = p - k - \frac{\delta}{2}q^2$,

The constraint is $p \le \theta_n q$; $p \le \theta_p q + s(k)$.

Obtained $p_3 = \theta_n q$; $k3 = k^+$, Which is recorded $\theta_p q + s(k^+) = \theta_n q$,

At this point, the enterprise profit value is $\pi_{R3} = \theta_n q - \frac{\delta}{2}q^2$.

(2) Make the product meet the utility value of the prosocial consumer group, but not the non-prosocial group, so that the sales volume is α.

Then the objective function is Max $\pi(p,k) = (p - k - \frac{\delta}{2}q^2) \cdot \alpha$,

The constraint is $p > \theta_n q$; $p \le \theta_p q + s(k)$.

Obtained $p_4 = \theta_p q + s(k^*)$; $k4 = k^*$,

At this point, the enterprise profit value is $\pi_{R4} = [\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2] \cdot \alpha$.

(3) Make the product meet the utility value of the non-prosocial consumer group, but not the prosocial group, so that the sales volume is $1 - \alpha$.

Then the objective function is Max $\pi(p,k) = (p - k - \frac{\delta}{2}q^2) \cdot \alpha$,

The constraint is $p \le \theta nq$; $p > \theta pq + s(k)$.

Obtained $p_5 = \theta_n q$; $k5 = 0$,

At this point, the enterprise profit value is $\pi_{R5} = [\theta nq - \frac{\delta}{2}q^2] \cdot (1 - \alpha)$.

Comparing the three situations, it is possible to obtain,

When$\alpha \le \min\left[\frac{k^+}{\theta_n - \frac{\delta}{2}q^2}, \frac{\theta_n q - \frac{\delta}{2}q^2}{(\theta_n + \theta_p)q + s(k^*) - k^* - \delta q^2}\right]$, $pb = \theta_n q$, $kb = 0$, $\pi_R^b = (\theta_n q - \frac{\delta}{2}q^2) \cdot (1 - \alpha)$;

When $\alpha > \min\left[\frac{\theta_n q - \frac{\delta}{2}q^2}{(\theta_n+\theta_p)q+s(k^*)-k^*-\delta q^2}, \frac{\theta_n q - k^+ - \frac{\delta}{2}q^2}{\theta_p q+s(k^*)-k^*-\frac{\delta}{2}q^2}\right]$, $pb = \theta_p q + s(k^*)$, kb $= k^*$, $\pi_R^b = [\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2] \cdot \alpha$;

When $\min[\frac{\theta_n q - \frac{\delta}{2}q^2}{(\theta_n+\theta_p)q+s(k^*)-k^*-\delta q^2}, \frac{\theta_n q - k^+ - \frac{\delta}{2}q^2}{\theta_p q+s(k^*)-k^*-\frac{\delta}{2}q^2}] \geq \alpha > \min[\frac{k^+}{\theta_n - \frac{\delta}{2}q^2}, \frac{\theta_n q - \frac{\delta}{2}q^2}{(\theta_n+\theta_p)q+s(k^*)-k^*-\delta q^2}]$, $pb = \theta_n q$, $kb = k^+$, $\pi_R^b = \theta_n q - \frac{\delta}{2}q^2$.

We then discuss the situation of high-quality products, among them $q_h q_h > \frac{s(k*)}{\theta_n - \theta_p}$, There are also three types of decisions that companies will make at this time:

(1) Make the product meet the utility value of all types of consumers, so that the sales volume is 1.

The objective function is Max $\pi(p, k) = p - k - \frac{\delta}{2}q^2$,

The constraint is $p \leq \theta nq$; $p \leq \theta pq + s\ (k)$.

Obtained $p_6 = \theta_p q + s(k^*)$; $k6 = k^*$, At this point, the enterprise profit value is $\pi_{R6} = \theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2$.

(2) Make the product meet the utility value of the non-prosocial consumer group, but not the prosocial group, so that the sales volume is $1 - \alpha$.

Then the objective function is Max $\pi(p, k) = (p - k - \frac{\delta}{2}q^2) \cdot \alpha$,

The constraint is $p \leq \theta nq$; $p > \theta pq + s\ (k)$.

Obtained $p_7 = \theta_n q$; $k_7 = 0$, At this point, the enterprise profit value is $\pi_{R7} = [\theta_n q - \frac{\delta}{2}q^2] \cdot (1 - \alpha)$.

(3) Make the product meet the utility value of the prosocial consumer group, but not the non-prosocial group, so that the sales volume is α.

Then the objective function is Max $\pi(p, k) = (p - k - \frac{\delta}{2}q^2) \cdot \alpha$,

The constraint is $p > \theta nq$; $p \leq \theta pq + s\ (k)$.

Obtained $p_8 = \theta_n q$; $k_8 = 0$, At this point, the enterprise profit value is $\pi_{R8} = [\theta_n q - k^+ - \frac{\delta}{2}q^2] \cdot \alpha$.

Comparing the three cases, it is clear that when the sales volume is α, it is not optimal in any case, therefore,

while$\alpha \leq \frac{(\theta_n-\theta_p)q-s(k^*)+k^*}{\theta_n q - \frac{\delta}{2}q^2}$, $pb = \theta_n q$, $kb = 0$, $\pi_R^b = (\theta_n q - \frac{\delta}{2}q^2) \cdot (1 - \alpha)$;

while $\alpha > \frac{(\theta_n-\theta_p)q-s(k^*)+k^*}{\theta_n q - \frac{\delta}{2}q^2}$, $pb = \theta_p q + s(k^*)$, $kb = k^*$, $\pi_R^b = [\theta_n q - \frac{\delta}{2}q^2] \cdot (1 - \alpha)$.

3.2.3 Equilibrium Analysis

After the above analysis, we summarize the second phase of the company's price decisions in Table 2.

Through equilibrium analysis, we found that no matter which product a company chooses to produce, there will be a threshold $\overline{\alpha}$, and when the $\alpha > \overline{\alpha}$, the amount of corporate donation $k > 0$; When $\alpha < \overline{\alpha}$, the amount of corporate donation $k = 0$. This means that when the size of the prosocial group reaches a certain value, the company will choose to implement good cause marketing and donate products; Otherwise,

Table 2 Equilibrium results of price decisions under the basic model

	Restrictions	Equalize the results
$\theta_p \geq \theta_n$	$\alpha \leq \frac{\theta_n q - \frac{\delta q^2}{2}}{\theta_p q + s(k^*) - k^* - \frac{\delta q^2}{2}}$	$p^b = \theta_n q$ $k^b = 0$ $\pi^b = \theta_n q - \frac{\delta}{2} q^2$
	$\alpha > \frac{\theta_n q - \frac{\delta q^2}{2}}{\theta_p q + s(k^*) - k^* - \frac{\delta q^2}{2}}$	$p^b = \theta_p q + s(k^*)$ $k^b = k^*$ $\pi^b = [\theta_p q + s(k^*) - k^* - \frac{\delta}{2} q^2]\alpha$
$\theta_n > \theta_p \geq \theta_n - \frac{s(k^*)}{q}$	$\alpha \leq \min\left(\frac{k^+}{\theta_n q - \frac{\delta q^2}{2}}, \frac{\theta_n q - \frac{\delta q^2}{2}}{(\theta_n + \theta_p) q + s(k^*) - k^* - \delta q^2}\right)$	$p^b = \theta_n q$ $k^b = 0$ $\pi^b = (\theta_n q - \frac{\delta}{2} q^2)(1 - \alpha)$
	$\alpha \leq \max\left(\frac{\theta_n q - \frac{\delta q^2}{2}}{(\theta_n + \theta_p) q + s(k^*) - k^* - \delta q^2}, \frac{\theta_n q - k^+ - \frac{\delta q^2}{2}}{\theta_p q + s(k^*) - k^* - \frac{\delta q^2}{2}}\right)$ $\alpha > \min\left(\frac{k^+}{\theta_n q - \frac{\delta q^2}{2}}, \frac{\theta_n q - \frac{\delta q^2}{2}}{(\theta_n + \theta_p) q + s(k^*) - k^* - \delta q^2}\right)$	$p^b = \theta_n q$ $k^b = \mathrm{k}^+$ $\pi^b = \theta_n q - k^+ - \frac{\delta}{2} q^2$

(continued)

Table 2 (continued)

	Restrictions	Equalize the results
	$\alpha > \max\left(\frac{\theta_n q-\frac{\delta q^2}{2}}{(\theta_n+\theta_p)q+s(k^*)-k^*-\delta q^2}, \frac{\theta_n q-k^+-\frac{\delta q^2}{2}}{\theta_p q+s(k^*)-k^*-\frac{\delta q^2}{2}}\right)$	$p^b = \theta_p q + s(k^*)$ $k^b = k^*$ $\pi^b = (\theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2)\alpha$
$\theta_p < \theta_n - \frac{s(k^*)}{q}$	$\alpha \le \frac{(\theta_n-\theta_p)q-s(k^*)+k^*}{\theta_n q-\frac{\delta}{2}q^2}$	$p^b = \theta_n q$ $k^b = 0$ $\pi^b = (\theta_n q - \frac{\delta}{2}q^2)(1-\alpha)$
	$\alpha > \frac{(\theta_n-\theta_p)q-s(k^*)+k^*}{\theta_n q-\frac{\delta}{2}q^2}$	$p^b = \theta_p q + s(k^*)$ $k^b = k^*$ $\pi^b = \theta_p q + s(k^*) - k^* - \frac{\delta}{2}q^2$

the implementation of good cause marketing by enterprises will not be the optimal decision and will not be donated.

Moreover, through the analysis of the decision-making equilibrium of the second stage of the enterprise, it can be seen that no matter what kind of quality specification product the enterprise produces, the company's choice of price and donation amount will always be selected in several fixed decision points, so after considering the quality decision, we still need to compare.

3.3 Analysis of the Third Stage of Quality Decision-Making Under the Basic Model

Next we discuss the first stage of the decision on quality, where we also discuss it in three cases, and finally arrive at the equilibrium result as shown in Table 3.

From the results, we can find that $\theta_n - \theta_p \leq 0$ when the company implements good cause marketing, it will choose to make the quality as θ_p/δ, and the quality at this time is greater than the quality when the good cause marketing is not implemented. This means that after the implementation of CM, improving product quality may be optimal.

4 Extend the Model

Next, we consider the presence of suppliers, retailers and consumers, In this model, the supplier determines the quality of the product, and the manufacturer determines the price and donation amount of the product, in this game, each party will seek to maximize its own interests, rather than considering the overall optimal, we still use the goal planning method to classify it and discuss, the objective function and constraints are shown in Fig. 3.

The final equilibrium result is shown in Table 4.

In the same way, the equilibrium results of quality decisions are calculated as shown in Table 5.

We found that manufacturers can influence retailers' donations and pricing by controlling the quality of their products, and that high-quality products may make donations smaller.

Table 3 Equilibrium results of price decisions under the basic model

	Conditions	Outcomes
$\theta_n - \theta_p \le 0$	$\alpha \le \frac{\theta_n^2}{\theta_p^2 + 2\delta[s(k^*) - k^*]}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0 \pi^b = \frac{\theta_n^2}{2\delta}$
	$\alpha > \frac{\theta_n^2}{\theta_p^2 + 2\delta[s(k^*) - k^*]}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^* \pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$0 < \theta_n - \theta_p \le \frac{s(k^*)\delta}{\theta_n}$	$\alpha \le \min\left(\frac{2\delta k^+}{\theta_n^2}, \frac{\theta_n^2}{\theta_n^2 + \theta_p^2 + 2\delta[s(k^*) - k^*]}\right)$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0 \pi^b = \frac{\theta_n^2}{2\delta} 1 - \alpha$
	$\alpha > \min\left(\frac{2\delta k^+}{\theta_n^2}, \frac{\theta_n^2}{\theta_n^2 + \theta_p^2 + 2\delta[s(k^*) - k^*]}\right)$ $\alpha \le \max\left(\frac{\theta_n^2 - 2k^+\delta}{\theta_p^2 + 2\delta[s(k^*) - k^*]}, \frac{\theta_n^2}{\theta_n^2 + \theta_p^2 + 2\delta[s(k^*) - k^*]}\right)$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = k^+ \pi^b = \frac{\theta_n^2}{2\delta} - k^+$

(continued)

Table 3 (continued)

	Conditions	Outcomes
	$\alpha > \max\left(\frac{\theta_n^2-2k^+\delta}{\theta_p^2+2\delta[s(k^*)-k^*]}, \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}\right)$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$\frac{s(k^*)\delta}{\theta_n} < \theta_n - \theta_p \leq \frac{s(k^*)\delta}{\theta_p}$	$\alpha \leq \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0\pi^b = \frac{\theta_n^2}{2\delta}(1-\alpha)$
	$\alpha > \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$\theta_n - \theta_p > \frac{s(k^*)\delta}{\theta_p}$	$\alpha \leq \frac{\theta_\mathrm{n}^2-\theta_p^2-2\delta[s(k^*)-k^*]}{\theta_\mathrm{n}^2}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0\pi^b = \frac{\theta_n^2}{2\delta}(1-\alpha)$
	$\alpha > \frac{\theta_\mathrm{n}^2-\theta_p^2-2\delta[s(k^*)-k^*]}{\theta_\mathrm{n}^2}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = \frac{\theta_p^2}{2\delta} + s(k^*) - k^*$

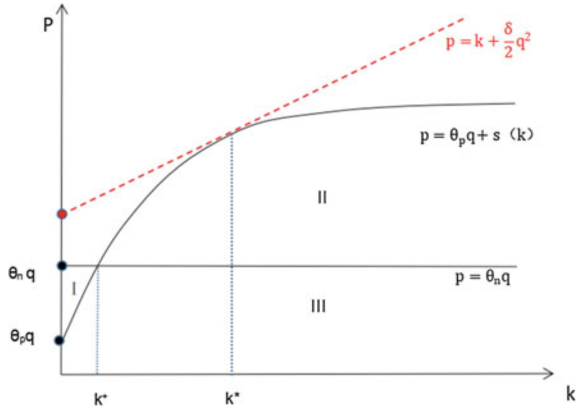

Fig. 3 Objective functions and constraints

5 Conclusion

Based on our analysis, we generated two types of companies and charities participating in CM activities under different supply chain structures. If a product is associated with good cause marketing, consumers basically get two things in a single purchase: the product itself and the opportunity to contribute to society. Our findings in this article highlight the importance of businesses and charities understanding consumer preferences in both areas. Based on the method of game theory, this paper studies the pricing decisions and product quality decisions of a CM company, analyzes two different supply chain product pricing models, and conducts quantitative research on the issues related to product quality, product price and donation amount, and comprehensively considers the differences in consumers, product utility values and supply chain structures. We found that the company's choice of product price and quality is closely related to the scale of public welfare consumers, when the scale is large enough, the enterprise will implement CM, and after the implementation of CM, improving product quality may be optimal; Second, while making a donation, it may be the best decision for the company to reduce the price of the product; Third, manufacturers can influence retailers' donations and pricing by controlling the quality of their products, and high-quality products may make donations smaller. All in all, the current findings help companies develop optimal sales strategies for different consumer groups.

Table 4 Price decisions are balanced

	Conditions	Outcomes
$\theta_n - \theta_p \le 0$	$\alpha \le \frac{\theta_n^2}{\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0 \pi^b = \frac{\theta_n^2}{2\delta}$
	$\alpha > \frac{\theta_n^2}{\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^* \pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$0 < \theta_n - \theta_p \le \frac{s(k^*)\delta}{\theta_n}$	$\alpha \le \min\left(\frac{2\delta k^+}{\theta_n^2}, \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}\right)$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0 \pi^b = \frac{\theta_n^2}{2\delta} 1 - \alpha$
	$\alpha > \min\left(\frac{2\delta k^+}{\theta_n^2}, \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}\right)$ $\alpha \le \max\left(\frac{\theta_n^2 - 2k^+\delta}{\theta_p^2+2\delta[s(k^*)-k^*]}, \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}\right)$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = k^+ \pi^b = \frac{\theta_n^2}{2\delta} - k^+$

(continued)

Table 4 (continued)

	Conditions	Outcomes
	$\alpha > \max\left(\frac{\theta_n^2-2k^+\delta}{\theta_p^2+2\delta[s(k^*)-k^*]}, \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}\right)$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$\frac{s(k^*)\delta}{\theta_n} < \theta_n - \theta_p \le \frac{s(k^*)\delta}{\theta_p}$	$\alpha \le \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0\pi^b = \frac{\theta_n^2}{2\delta}(1-\alpha)$
	$\alpha > \frac{\theta_n^2}{\theta_n^2+\theta_p^2+2\delta[s(k^*)-k^*]}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = [\frac{\theta_p^2}{2\delta} + s(k^*) - k^*]\alpha$
$\theta_n - \theta_p > \frac{s(k^*)\delta}{\theta_p}$	$\alpha \le \frac{\theta_{\mathrm{n}}^2-\theta_p^2-2\delta[s(k^*)-k^*]}{\theta_{\mathrm{n}}^2}$	$q = \frac{\theta_n}{\delta} p^b = \frac{\theta_n^2}{\delta}$ $k^b = 0\pi^b = \frac{\theta_n^2}{2\delta}(1-\alpha)$
	$\alpha > \frac{\theta_{\mathrm{n}}^2-\theta_p^2-2\delta[s(k^*)-k^*]}{\theta_{\mathrm{n}}^2}$	$q = \frac{\theta_p}{\delta} p^b = \frac{\theta_p^2}{\delta} + s(k^*)$ $k^b = k^*\pi^b = \frac{\theta_p^2}{2\delta} + s(k^*) - k^*$

Table 5 Quality decisions are balanced

	Conditions	Outcomes
$\theta_p \geq \theta_n$		$p = \theta_n q k = 0$ $q* = \dfrac{\theta_n - \theta_p \alpha}{\delta(1-\alpha)}$ $\pi_R = \dfrac{(\theta_n - \theta_p \alpha)\theta_n}{\alpha} - \dfrac{\delta}{2}\left[\dfrac{\theta_n - \theta_p \alpha}{\delta(1-\alpha)}\right]^2$
$\theta_p > \theta_n - \frac{s(k^*)}{q}$	$\alpha > \frac{1-\theta_n}{1-\theta_p}$	$p = \theta_n q k = k^+$ $q* = \dfrac{\theta_n - \theta_p \alpha}{\delta(1-\alpha)}$ $\pi_R = \dfrac{(\theta_n - \theta_p \alpha)\theta_n}{\alpha} - \dfrac{\delta}{2}\left[\dfrac{\theta_n - \theta_p \alpha}{\delta(1-\alpha)}\right]^2 - k^+$
	$\alpha > \frac{1-\theta_n}{1-\theta_p}$	$p = \theta_n q k = k^+$ $q* = \dfrac{1}{\delta}$ $\pi_R = \dfrac{2\theta_n - 1}{2\delta} - k^+$
$\theta_p < \theta_n - \frac{s(k^*)}{q}$		$p = \theta_{\mathrm{p}} q + s(k^*) k = k^*$ $q* = \dfrac{\theta_{\mathrm{p}} - \theta_n + \theta_n \alpha}{\delta\alpha}$ $\pi_R = \dfrac{\theta_p(\theta_p - \theta_n + \theta_n \alpha)}{\delta\alpha} - \dfrac{\delta}{2}\left[\dfrac{\theta_p - \theta_n + \theta_n \alpha}{\delta\alpha}\right]^2 + s(k^*) - k^+$

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Research on Green Product Design and Strategic Inventory Based on Dual-Channel Supply Chain

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Abstract In view of the reality that manufacturers invest in green technologies to produce green products and sell them directly to consumers through the Internet and traditional channels, three dual-channel supply chain game models are constructed under different power structures: manufacturer-led Stackelberg game, retailer-led Stackelberg game and equal Nash game. The optimal strategy and maximum profit of manufacturers and retailers under three power structures are compared, and the sensitivity of key factors is analyzed. Comparative analysis is carried out by numerical examples. The results show that the optimal strategy and performance of each power subject under the three games are affected by the green degree of product, retailer's strategic inventory and other key factors. In order to achieve higher profit margins, retailers have always tended to hold on to strategic inventory. Retailers' decisions improve manufacturers' profits and the greening of their products; In addition, the greener the product, the smaller the retailer's strategic inventory, and the higher the profit of the manufacturer and retailer. Therefore, when retailers hold strategic inventory, manufacturers can choose to increase the green investment level of products to enhance their voice and negotiate with retailers. Retailers can also play games with manufacturers by holding strategic inventory to achieve pareto efficiency. Manufacturers and retailers benefit.

Keyword Green investment · Strategy inventory · Dual-channel supply chain · Power structure

1 Introduction

In today's society, environment has increasingly become a key factor in social and economic development. Governments at central and local levels have made increasingly strict environmental regulations for enterprises, and consumers have also shown great concern for environmental management. According to data from the National

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Bureau of Statistics, China's fiscal expenditure on environmental protection reached 739.02 billion yuan in 2019, accounting for 3.1% of the national fiscal expenditure. Even though economic development was greatly hindered by the impact of COVID-19 in 2020, China's fiscal expenditure on environmental protection still reached 631.704 billion yuan. For enterprises, green production can not only increase the economic and social benefits of enterprises, but also improve the competitiveness of enterprises, eliminate the harm caused by the production process of enterprises to the environment, so as to internalize the social cost of enterprises. Therefore, any enterprise can not ignore the "green" factor in its operation process, and have to put it into the agenda of enterprise strategic planning. As consumers' requirements for their own living standards and living environment are greatly improved, people have a more and more profound understanding of environmental damage and excessive waste of natural resources. This shows, green product will gain consumer's love more and more, should develop energetically.

On the occasion of the 100th anniversary of the founding of the communist party of China, the communist party of China leads the Chinese people to open the "2030 carbon carbon neutral", 2060 years ago the great new journey, and "difference" is to fulfill the solemn commitment of critical period in our country, is also two overall situation as a whole, profound changes to promote the development of green low carbon and high quality. In 2020, China's annual carbon emission intensity was 18.3% points lower than that of 2015, and 48.2% points lower than that of 2005, showing significant energy saving and carbon reduction effects. Now the digital economy is booming and the green manufacturing system is taking shape. By February 2021, China had built 2,121 green factories, 171 green industrial parks and 189 green supply chain enterprises, and promoted nearly 20,000 green products. On September 22, 2020, At the general debate of the 75th Session of the United Nations General Assembly, President Xi Jinping announced, "China will increase its nationally determined contribution and adopt more effective policies and measures to peak co2 emissions by 2030 and achieve carbon neutrality by 2060." On December 12, 2020, President Xi Jinping delivered an important speech at the Climate Ambition Summit. He not only announced a reduction in carbon dioxide intensity per unit of GDP and an increase in the share of non-fossil energy, but also pledged to increase the total installed capacity of wind and solar power to over 1.2 billion kilowatts, and promised that China will keep its word. China is the largest manufacturing country in the world, and manufacturing is an important source of carbon emissions. Carbon neutrality will reshape China's industrial competitiveness.

With the development of global economy, the competition of enterprises has been gradually replaced by the competition of supply chain. Realizing the overall optimization and coordination of supply chain and maximizing the potential capacity of supply chain has become one of the important contents to improve the competitiveness of enterprises. However, in the past long-term production practice, the so-called effective production mode is often accompanied by excessive waste of natural resources and great pollution and destruction of the natural environment. This not only affects the production cost of enterprises, but also affects the sustainable development of China's economy. In this context, in order to improve the competitiveness of enterprises and achieve sustainable and high-quality development of the company, it is necessary to integrate environmental issues into supply chain management, and require upstream and downstream enterprises of the supply chain to consider green product design from the whole process of product design, product procurement and product sales, so as to optimize the overall benefit. Therefore, upstream enterprises in the supply chain urgently need to recognize the current situation of product design, and downstream enterprises to formulate corresponding strategic inventory strategy, according to the supply chain management process, to develop a more systematic and scientific pricing and strategic inventory plan.

Much of the current literature on contract theory does not take inventory into account. Most of the literature on supply chain coordination focuses on the development of incentive contracts to achieve optimal inventory levels. The main focus of this literature has been the incentive mechanism to encourage correct behavior in the case of moral hazard or information asymmetry. Similarly, the extensive literature on vertical control incentives in industry organizations ignores the effects of inventory: this section of work examines the current mechanisms for vertical control of production and sales. Existing studies have not considered the interaction between green investment and strategic inventory in dual-channel supply chain under different power structures, which can not well reflect the actual decision-making situation of upstream and downstream enterprises in the supply chain.

2 Format of Manuscript

2.1 Manufacturer's Green Products and Retailer's Strategic Inventory Research

The current research on supply chain mainly involves three aspects: (1) manufacturer's green products and retailer's strategic inventory research; (2) Strategic inventory research of retailers in dual-channel supply chain; (3) Research on decision-making of supply chain enterprises under different power structures.

Green supply chain management, also known as environment-conscious supply chain management, considers the environmental problems in each link of the supply chain, pays attention to environmental protection, and promotes the coordinated development of economy and environment. Green product design is to point to in the design of the whole process of product and its life cycle, fully considering the influence on resources and environment, while fully considering the features of the product, quality, development cycle and cost at the same time, to optimize the design of the related factors, makes the product and its manufacturing process to the overall impact of environment and resource consumption to a minimum. Green product design should take full account of the various impacts on the environment after the product is manufactured, sold, used and scrapped in the design stage, optimize the design process of manufacturing process, assembly scheme, disassembly scheme and recycling treatment, and make it have good economy. Dan Bin and Liu Fei (2000) showed that the theoretical system of green supply chain system should be established, and the philosophy of environmental consciousness (green) should be applied throughout the whole supply chain, and the key technologies of green supply chain system should be researched and applied with the goal of comprehensive optimization of environmental effect, resource utilization and economic benefit [1]. Zheng Yingfei et al. (2001) showed that all green supply chain model enterprises incorporated environmental projects into their supplier selection and supervision system. Some even put forward environmental requirements for potential suppliers to ensure that suppliers in cooperation with them have corresponding environmental awareness and environmental management ability [2]. Zhu Qinghua and Geng Yong (2004) designed a questionnaire for investigation and adopted factor analysis method and social science statistical software SPSS to identify the main factors of pressure/motivation, practice and performance of green supply chain management of Chinese manufacturing enterprises. On the basis of the above, the data results are analyzed and discussed in combination with the situation of Chinese manufacturing enterprises to analyze and identify the main factors in the current understanding, practice and performance of Green supply chain management of Chinese enterprises [3]. From the perspective of green procurement, Liu Bin and Zhu Qinghua (2005) first proposed that environmental factors should be an important part of the evaluation index system. Then, in view of its uncertainty and fuzziness, ahp is used to carry out fuzzy comprehensive evaluation on supplier selection [4]. Dong Yali and Xue Lei (2008), according to the content and characteristics of green supply chain management, a specific green supply chain management performance evaluation index system is designed, and the network analytic hierarchy Process (AHP) theory ANP is used to evaluate [5]. Green et al. (2012) conducted an empirical investigation on the impact of Green supply chain management practices and concluded that consumers' preference to buy Green products would have a significant impact on the economic performance of supply chain members. The expected business benefits of global manufacturers are increasingly coming from green products, and manufacturers are making significant technology investments to incorporate emerging green technologies into their product designs [6]. Wang Lijie and Zheng Yanli (2014) studied the incentive mechanism of the second-order supply chain including manufacturers and suppliers, and proposed an incentive mechanism to improve the green level of raw materials provided by suppliers from multiple perspectives of economic incentive, technical incentive, cooperative incentive and contractual incentive [7]. Jiang Shiying and Li Suicheng (2015) took a two-level green supply chain composed of a manufacturer and a retailer as the background and established four game models of green supply chain considering product greenness: Stackelberg game model dominated by manufacturers, Stackelberg game model dominated by retailers, Nash equilibrium game model of manufacturers and retailers, and centralized control model. Four game models are compared and analyzed in terms of product greenness, product price and wholesale price, and a game model under revenue sharing contract is further established. The influence of revenue sharing coefficient on product greenness, manufacturer's profit and retailer's profit is discussed through numerical simulation [8]. Stone peace YanBo (2016) study fairness concerns such as behavior and green product of green supply chain efficiency pricing strategy, product green degree, supply chain and the influence of the overall profits, the profits found product green degree and the profit of supply chain under decentralized decision making will be lower than the centralized decision-making, and with the improvement of efficiency of green products, gap has become more and more big [9]. Chen et al. (2017) investigated the green supply chain management of various manufacturing industries in China and found that the electrical/electronic industry sector had higher economic performance due to the regulatory pressure on its environmental protection technology [10]. According to liu Huiyan and Ji Shoufeng (2017), when supply chain competition is not fierce, both supply chains produce green products, which is the only balanced structure. When competition is fierce, the coexistence of two products is the best choice. Changes in consumers' green preference and the degree of competition in the supply chain will affect the product choice and benefits of supply chain members [11]. Kaur et al. (2018) show that in order to achieve sustainability, there must be a concerted effort to design products that are easy to reuse, consume less energy and are recyclable. Therefore, green supply chain initiatives not only protect the environment but also improve the overall benefits of the supply chain [12].

2.2 Research on Retailer's Strategic Inventory in Dual—Channel Supply Chain

Cheng Shu and zhang hao (2004), using the theory of optimization method for manufacturing enterprises double channel market oriented supply chain modeling research, by using the monte carlo method to the key parameters of the model, namely the optimal pricing, manufacturers and retailers are simulated calculation, the simulation results show that in the meet certain conditions, the supply chain profit value can have a qualitative leap [13]. Wang Hong and Zhou Jing (2009) consider the optimal decision of supply chain under the condition that demand is affected by both price and advertising input for a supply chain composed of direct sales channel and traditional retail channel. The Stackelberg game model in the non-price consistent mode where channel price is determined by retailers and the non-price consistent mode where channel price is determined by manufacturers and retailers is discussed respectively, and the influence of cooperative advertising on decision-making in the non-price consistent mode is studied [14]. Dragon and Liu Liwen (2009) inventory decentralized decision making system are analyzed some properties of game equilibrium, on this basis, this paper proposes a can reflect the characteristics of dominant retailers and manufacturers are at the same time to effectively control the behavior of contract coordination mechanism, the mechanism and application of the coordination number and price coordination strategy, can strictly improve the expected profits of both parties [15]. Xu Guangye and Dan Bin et al. (2010) studied the coordination between traditional distribution channels and electronic direct marketing channels as well as the coordination between upstream and downstream nodes, constructed a revenue sharing contract model that can realize the coordination of dual-channel supply chain, and provided the calculation formula for the value range of contract parameters when realizing the coordination of dual-channel supply chain. And further discusses the conditions for the existence of perfect win–win coordination in dual-channel supply chain [16]. Xiao Jian and Dan Bin et al. (2010) found that channel price and demand are affected by manufacturers' marginal service cost in electronic channels and retailers' marginal service cost in electronic channels. Manufacturers' service costs in electronic channels are positively correlated with retail channel pricing [17]. Wang Hong and Zhou Jing (2011) studied the dual-channel supply chain model composed of traditional retail channels and online direct sales channels. Considering the fixed wholesale price and traditional retail price, and the random market demand affected by price, the optimal pricing and inventory decision of manufacturers in direct sales channel was determined. And the optimal order quantity of retailers in traditional distribution channels [18]. But Lin and Xu Guangye (2012) under the electronic commerce environment is constructed by a manufacturer and a retailer of dual channel supply chain model, the analysis and comparison of the centralized decision-making and decentralized decision-making under the dual channel supply chain optimal prices, from the perspective of electronic channel and traditional channel cooperation, studies the compensation strategy, dual channel supply chain coordination It is demonstrated that this compensation strategy can realize the coordination of dual-channel supply chain, and to a certain extent, can guarantee the win–win situation of dual-channel supply chain members [19]. Zhao Jinshi and Duan Yongrui et al. (2013) developed a seller dual-channel coordination mechanism including commitment fee, and calculated the supply chain coordination optimization strategy under two different conditions: supplier dominance and retailer dominance. By comparing the profit composition of the supply chain dominated by suppliers and the supply chain dominated by retailers, it is found that supply chain members can seek more profits for themselves through dominance. The overall profit level of the supplier-led supply chain is higher than that of the retailer-led supply chain [20]. In the context of dual-channel closed-loop supply chain, Cao Xiaogang and Zheng Benrong et al. (2015) studied the pricing and coordination decision of dual-channel closed-loop supply chain considering the competition between channels based on consumers' inconsistent demand preferences for traditional retail channels and online direct sales channels [21]. Zhang Guoxing and Fang Shuai et al. (2015) constructed manufacturer-led Stackelberg game, retailer-led Stackelberg game and Nash game model with the same power based on the power differences among members of dual-channel supply chain, and discussed the influence of the three games on channel price, demand and profit of game participants [22]. Liang Xi and Jiang Qiong et al. (2018) analyzed the influence of price competition coefficient, online direct selling cost and commission ratio coefficient on other economic variables under three different dual-channel structures in a manufacturer-led dual-channel supply chain, as well as manufacturers' optimal pricing decisions and channel selection [23].

Increased competition from encroachments makes retailers' demand more sensitive to wholesale price increases. Thus, encroaching suppliers find it profitable to reduce wholesale prices in order to increase purchases of wholesale products by retailers. When the retailer is particularly good at serving customers, the encroaching manufacturer considers it optimal to lower wholesale prices so that the retailer (like the manufacturer and the consumer) benefits from the encroachment of the supplier. There may be some necessary reasons for retailers to carry inventory. Jeason (2013) studied the existing suppliers such as random delivery of retailers and suppliers to dynamic pricing strategy of inventory decision problems, analyzed the stability of supplier level for establishing dynamic pricing, retailers' strategic inventory, the parties to the profits of the supply chain, suggests that retailers in response to the unstable supply set by the buffer stock, At the same time, it plays an important role in restraining suppliers' pricing and improving their own profits [24]. Sun Kangtai and Xu Minghui (2021) found that reference price effect would restrain retailers' strategic inventory behavior. Only under dynamic pricing contracts and when inventory carrying costs are low will retailers strategically hold a certain amount of inventory. Manufacturers always prefer dynamic pricing contracts, while retailers and the overall supply chain's preference for the two contracts depends on the reference price effect factor and inventory carrying cost [25].

2.3 Research on Enterprise Decision-Making Under Different Power Structures

Wang Wenbin and Da Qingli et al. (2011) studied the pricing of closed-loop supply chain under centralized and decentralized decision-making in three channel power structures, compared the differences in pricing and profit under various circumstances, and discussed the coordination method of closed-loop supply chain under different channel power structures by using two-part pricing contract [26]. Zhang Tinglong and Liang Liang (2012) studied the decentralized decision-making of supply chain under the power structure and information structure of different channels, aiming at the manufacturer-retailer two-level supply chain with retailer's sales effort and sales price affecting demand. Based on game theory and modeling methods, corresponding models are established for several power structure and information structure scenarios, and different game equilibria are compared through theoretical and numerical analysis [27]. Zhao Xiaomin and Lin Yinghui et al. (2012) adopted game theory to study the two-level closed-loop supply chain of supplier and retailer composed of one supplier and one manufacturer, focusing on the analysis of pricing strategy and supply chain system performance when supplier strength, manufacturer strength and balance of power between supplier and manufacturer [28]. Wang

Yuyan and Shen Liang (2014) constructed four different MT-CLSC models based on the differences in power structures of the closed loop supply chain (MT-CLSC) channels of manufacturers responsible for recycling waste products, combined with consumers' preferences and influences on new products and remanufactured products. They are the centralized decision-making model of manufacturer and retailer, the decentralized decision-making model in which manufacturer's power is greater than retailer's power, the decentralized decision-making model in which manufacturer's power is less than retailer's power, and the decentralized decision-making model in which manufacturer and retailer's power is equal. According to the different characteristics of each model, The optimal pricing strategy, recovery strategy and corresponding profit and channel efficiency of each model are calculated [29]. Wang Tao and YanBo (2017) to online channels as the research object, built by online retailers and a cross of franchisees decision-making model of competition by building consumer utility function is determined by the price and service, from consumer perspective, combined with optimization methods and game theory, tries to provide a reference for the decision of the online channel participants [30]. Jing and jukun (2018) studied the pricing strategies under different channel power structures, based on game theory, three kinds of pricing decision model is established, and the corresponding analytical solution is given, and analyzed the channel power structure, choice of retailers online channels, and channels of consumer loyalty to the influence of the optimal pricing strategy and profits of the channel member [31]. Yang Yan and Cheng Yanpei et al. (2019) studied the difference in the degree of suppliers' fulfillment of social responsibility under the two power allocation modes of supplier leading and retailer leading, and how to establish a reasonable contract between suppliers and retailers to motivate suppliers' fulfillment of social responsibility [32]. Fan Jianchang and Liang Xuzhuo et al. (2019) constructed a supply chain game model in which manufacturers and retailers jointly fulfill CORPORATE social responsibility. Based on channel power structure, the influence of corporate social responsibility on product quality and profitability of supply chain was investigated, and the optimal social responsibility decision-making of supply chain was studied [33].

Based on the literature summarization and analysis found that green supply chain research starts late in China, although the study of green supply chain from the pursuing of the debate, a simple strategy research into strategic research now, also from the perspective of enterprise itself and the consumer Angle are studied, such as multiple angles but more simple case study, There are few studies considering the game Angle of supply chain parties, and few empirical studies. The conclusions are still uncertain, which is worthy of further study.

This paper summarizes the factors affecting the green level of products in previous literature, analyzes the participants of the enterprise price decision and strategic inventory decision, and constructs a two-channel supply chain model to analyze the influence of the enterprise green investment level and strategic inventory. Supplier occupation, is introduced in this paper, through a dual channel supply chain model, analysis under different power structure, business investment in green technologies and strategic stocks, the influence of both upstream and downstream of the supply chain through game analysis of the optimal decision, game result of compared to two kinds of circumstances, in order to eventually find the key factors that affect the level of green products, It provides a theoretical basis for enterprises to invest in green technology in the future.

3 Research on Dual Channel Supply Chain with Manufacturer in Dominant Position

3.1 Problem Description

We consider a two-stage supply chain with one manufacturer and one retailer, with the manufacturer producing green products and selling through an independent retailer in a consumer market where prices are sensitive to the "green" of the product. The green level of the product is transparent and consumers can clearly identify the green level of the product. The manufacturer encroaches on the retailer's market by selling directly. The encroachment of suppliers will affect the retail price and strategic inventory of retailers to varying degrees. Due to the size of manufacturers and retailers, manufacturers and retailers in the supply chain have three power structures. As shown in the figure, manufacturers and retailers under different power structures in dual-channel supply chain form three games: M-R game indicates that manufacturers are in a dominant position, and manufacturers sell green products not only through independent retailers, but also through direct channels. R-m game indicates that retailer is dominant; Nash shows that manufacturers and retailers are equal. In these games, manufacturers decide their investment in green technology, direct sales volume and optimal wholesale price, while retailers decide their sales volume, strategic inventory and purchase volume (Fig. 1).

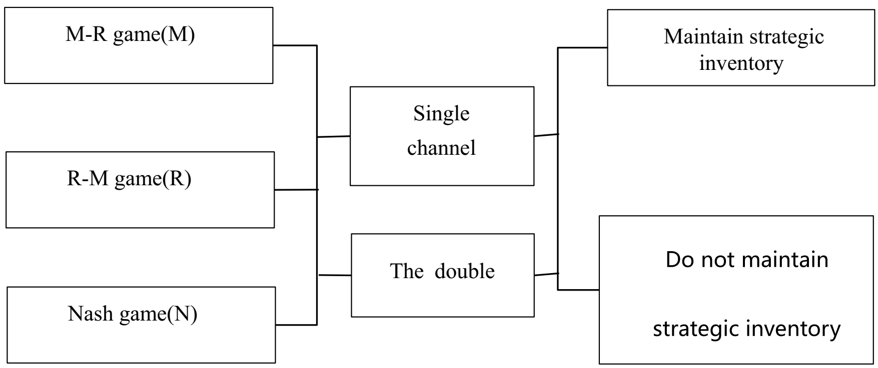

Fig. 1 Supply chain situation

We define the market retail price of green products as a function $(q_R + q_M)$ related to the market demand $P = a - (q_R + q_M) + ke$ and the green degree of the product e. In addition, we define the market demand of the product as a, k as the sensitivity coefficient of the market retail price to the green degree of the product, and bl as the sensitivity coefficient of the market retail price to the market demand. We assume that the cost of the product without green investment is 0. le^2 is the sensitivity coefficient of unit green product cost to product green degree. Therefore, the function of unit cost of product is le^2.

3.2 Benchmark Model

In the static game, green product market retail price function for $P = a - (q_R + q_M) + ke$, among them a for the consumer market, we put the market retail price sensitive coefficient of normalization of market sales, k said the market retail price of the product green degree of sensitive coefficient, e said product green degree. l green products for the unit cost of product green degree of sensitive coefficient, as a result, the unit of product cost function for le^2. Manufacturers according to the standard set of product green degree e industry, green investment, retailers wholesale green product from the manufacturer, its sales at the market retail price to consumers, at the same time, through direct sales, manufacturers to sell the products to consumers directly.

As a benchmark model, first consider supplier without strategic stockpiles. In this case, the manufacturer to determine the product green degree e, give product wholesale price w, choose the direct channel q_M from green technology to maximize the investment demand and double channels in the supply chain profits; Retailers choose the market demand for q_R and wholesale to the customers, in order to maximize its profits. Function, according to the market retail price of a given product green degree e, product wholesale market demand q_R w and retailers, manufacturers choose q_M, the manufacturer's profit function is expressed as the following form

$$\underset{q_M, w}{MAX}\, \pi_M = (a - (q_R + q_M) + ke - c - le^2)q_M + (w - le^2)q_R \tag{1}$$

The first formula is profit gained by the manufacturers direct sales to consumers, the second is the manufacturer gain profits from sales to the retailers. According to the backward induction, optimize in the equation, considering the green degree of the product the market demand of e and retailers q_R, manufacturers the best direct channels under the dual channel supply chain demand $q_M^E(q_R)$ for:

$$q_M^E(q_R) = \frac{-le^2 + ke - q_R - c + a}{2} \tag{2}$$

A given product green degree of e and wholesale price w, and expected manufacturers in formula (2) the response and retailer choose their retail market demand for the biggest profit function for q_R: +

$$\underset{q_R}{MAX}\, \pi_R = (a - (q_R + q_M) + ke - w)q_R \tag{3}$$

The Eq. (2) the replacement of the $q_M^E(q_R)$ into the Eq. (3), and in Eq. (3) can make the retailer's profit maximization of retail Dealer market demand q_R^E(w):

$$q_R^E(\mathrm{w}) = \frac{a + ke + c + le^2 - 2w}{2} \tag{4}$$

The formula (4) to replace into the formula (2), and then plug in formula (1), at the same time the formula (4) generation into the formula (1), we can manufacturer's profits are expressed as the function of the w separately. By maximizing function of w get manufacturers under the dual channel supply chain's optimal wholesale price w^E. w^E replacement into formula (2) and formula (4), can be make the manufacturers and retailers profit maximization of the retail market demand q_M^E and direct selling market demand q_R^E:

$$w^E = \frac{3le^2 + 3ke + 3a - c}{6}, q_R^E = \frac{2c}{3} \text{和} q_M^E = \frac{3a - 5c + 3ke - 3le^2}{6}\text{。} \tag{5}$$

Equation (5) can be easily obtained by the formula of retailers and manufacturers profit:

$$\begin{aligned} &\pi_R^E = \frac{2c^2}{9}\text{和} \\ &\pi_M^E = \left(\frac{3a - 5c + 3ke - 3le^2}{6}\right)^2 + \frac{c(3a - c + 3ke - 3le^2)}{9} \end{aligned} \tag{6}$$

The equalization results of the benchmark model are shown in Table 1.

Table 1 Equilibrium game results of the benchmark model

Variable	Balanced results
w^E	$\frac{3le^2+3ke+3a-c}{6}$
q_M^E	$\frac{3a-5c+3ke-3le^2}{6}$
q_R^E	$\frac{2c}{3}$
π_M^E	$\left(\frac{3a-5c+3ke-3le^2}{6}\right)^2 + \frac{c(3a-c+3ke-3le^2)}{9}$
π_R^E	$\frac{2c^2}{9}$

3.3 The Manufacturer is in the Dominant Position of the Game Model

In a manufacturer in a dominant position of double channels in the supply chain, the first stage, the manufacturer first, according to industry standards to determine the product green degree e products wholesale price of w_1^M and direct sales channels q_{M1}^M: according to the manufacturer's decision, retailers to determine their own market demand q_{R1}^M, decided to the next stage carries strategic stockpiles $I^M(I^M \geq 0)$. In the second phase, manufacturers to determine their own demand w_2^M wholesale price of q_{M2}^M and direct channel; According to the manufacturer's decision, the market demand of retailers determine their q_{R2}^M. Manufacturer and retailer's profit function is expressed as the following form.

$$\underset{q_{R2}^M}{MAX}\,\pi_{R2}^M = (a - (q_{R2}^M + q_{M2}^M) + ke^M)q_{R2}^M - w_2^M(q_{R2}^M - I^M) \tag{7}$$

$$\begin{aligned}\underset{q_{M2}^M, w_2^M}{MAX}\,\pi_{M2}^M =& (w_2^M - l(e^M)^2)(q_{R2}^M - I^M) + (a - (q_{R2}^M + q_{M2}^M) \\ &+ ke^M - c - l(e^M)^2)q_{M2}^M\end{aligned} \tag{8}$$

$$\underset{q_{R1}^M}{MAX}\,\pi_{R1} = (a - (q_{R1}^M + q_{M1}^M) + ke^M)q_{R1}^M - w_1^M(q_{R1}^M + I^M) - hI^M + \pi_{R2}^{ME} \tag{9}$$

$$\begin{aligned}&\underset{q_{M1}^M, w_1^M}{MAX}\,\pi_{M1} = (w_1^M - l(e^M)^2)(q_{R1}^M + I^M) + \\ &(a - (q_{R1}^M + q_{M1}^M) + ke^M - c - l(e^M)^2)q_{M1}^M + \pi_{M2}^{ME}\end{aligned} \tag{10}$$

For manufacturers dominate the game model, we use backward induction is analyzed. First of all, the formula (8) of q_{M2}^M first derivative $\frac{\partial \pi_{M2}^M}{\partial q_{M2}^M}$,

$$\frac{\partial \pi_{M2}^M}{\partial q_{M2}^M} = -l(e^M)^2 + ke^M - q_{R2}^M + a - c - 2q_{M2}^M \tag{11}$$

Due to the manufacturer's profit in the q_{M2}^E for concave function, make $\frac{\partial \pi_{M2}^M}{\partial q_{M2}^M} = 0$, manufacturer can be in the second stage of the optimum ∂ q M argument Direct market demand of q_{M2}^{ME},

$$q_{M2}^{ME} = \frac{-l(e^M)^2 + ke^M - q_{R2}^M - c + a}{2} \tag{12}$$

Retailers predict manufacturers in the second phase of the wholesale price of w_2, as well as the response to the manufacturer's optimal direct market demand q_{M2}^{ME}, The formula (12) to replace into the formula (7), formula (7) to the first order derivative of qR2, choose the second phase of the optimal retail market demand q_{R2}^{ME},

$$q_{R2}^{ME}=\frac{a+l(e^M)^2+ke^M+c-2w_2^M}{2} \tag{13}$$

The formula (12) and formula (13) to replace into the formula (8), formula (8) for w_2, for the first order derivative, manufacturers in the second order. The optimal wholesale price of w_2^{ME}, w_2^{ME} replacement into the formula (12) and formula (13) can be retailers optimal retail market in the second stage q_{R2}^{ME} and the optimal demand of direct channel q_{M2}^{ME}:

$$\begin{aligned} w_2^{ME} &= \frac{3l(e^M)^2+3ke^M-4I^M+3a+c}{6}, \quad q_{R2}^{ME}=\frac{2I^M+c}{3} \text{和} \\ q_{M2}^{ME} &= \frac{3a-2I^M-4c+3ke^M-3l(e^M)^2}{6} \end{aligned} \tag{14}$$

We will w_2^{ME}, q_{R2}^{ME} and q_{M2}^{ME} substitution into the formula (7) and formula (8) can get Ma retailer's optimal profits in the second stage π_{R2}^{ME} and the manufacturer's optimal profit π_{M2}^{ME},

$$\pi_{R2}^{ME} = \frac{c^2+7cI^M+9lI^M(e^M)^2+9kI^Me^M+9aI^M-8(I^M)^2}{18} \tag{15}$$

$$\begin{aligned} \pi_{M2}^{ME} &= \frac{3(3l(e^M)^2-3ke^M+2I^M-3a+4c)^2}{18} - \\ &\frac{(I^M-c)(3a-4I^M+c+3ke^M-3l(e^M)^2)}{18} \end{aligned} \tag{16}$$

In the first stage, the first turn on the formula (16) to replace into the formula (10), formula (10) for partial derivatives can get q_{M1}^{M} manufacturers in the first Phase of the optimal market demand directly q_{M1}^{ME},

$$q_{M1}^{ME}=\frac{-l(e^M)^2+ke^M-q_{R1}^M-c+a}{2} \tag{17}$$

Retailers predict manufacturers in the first stage of the wholesale price of w_1^M and direct market demand response to the manufacturer's optimal q_{M1}^{ME}. The formula (17) to replace into the formula (9), formula (9) to the first order derivative of q_{R1}^M, choose the first phase of the optimal retail market demand q_{R1}^{ME},

$$q_{R1}^{ME}=\frac{a+l(e^M)^2+ke^M+c-2w_1^M}{2} \tag{18}$$

The formulas (17) and (18) into the formula (10), formula (10) to a first order derivative of w_1^{ME}, get manufacturers in the first phase of the optimal wholesale price w_1^{ME}, have replaced w_1^{ME} into the formulas (17) and (18) can get the first phase of retailers' optimal retail city MMEField demand q_{R1}^{ME} and manufacturers optimal direct channel demand q_{M1}^{ME}:

$$w_1^{ME} = \frac{3l(e^M)^2 + 3ke^M + 4I^M + 3a - c}{6}, q_{R1}^{ME} = \frac{2c - 2I^M}{3} \text{和}$$
$$q_{M1}^{ME} = \frac{3a - 5c + 3ke^M - 3l(e^M)^2 + 2I^M}{6} \tag{19}$$

We will w_1^{ME}, q_{R1}^{ME} and q_{M1}^{ME} to replace into the formula (9) and formula (10) can get the first phase of retailer's optimal profit π_{R1}^{ME}. And the manufacturer's optimal profit π_{R1}^{ME}.

Eventually manufacturers dominate the game model of equilibrium results summary in the Table 2.

The Table 2 shows that manufacturers in the first phase of the optimal wholesale price w_1^{ME} with the increase of product green degree e^M down after rising first, manufacturers in the second phase of the optimal wholesale price w_2^{ME} the same with the increase of product green degree e^M first rise after falling. Manufacturers in the first phase of the optimal wholesale price w_1^{ME} as zero Retailers to maintain strategic stockpiles I^M "increases with the increasing of manufacturers in the second phase of the optimal wholesale price w_2^{ME} is increased with the increase of strategic stockpiles I^M fall. We can get the manufacturer in a dominant position of dual channel supply chain model, the retailer to keep strategic stockpiles will lower the manufacturer of the second stage of the wholesale price. We found that the manufacturer of the first phase of the optimal direct channel q_{M1}^{ME} will demand as zero. Retailer keep increased with increasing the number of strategic stockpiles, manufacturers of the second stage of the optimum direct channel q_{M2}^{ME} will demand as retailers keep the increase of the number of strategic stockpiles. For retailers, retailers in the first stage and the second stage of the retail market demand has nothing to do with the degree of green products. Retailers to maintain strategic stockpiles makes it in the first phase of market demand for smaller, in the second stage of the market demand will be bigger.

4 The Manufacturer is in the Dominant Position of the Game Model

4.1 Problem Description

In R-M game model, the retailer leaders play a stark Kerr's game. In order to maximize the profits of retailers and manufacturers, we use $Q_i (i = 1, 2)$ to represent the retailer in each phase of the actual purchases. The first stage, the actual purchases Q_1 retailers to set their own products and the strategy of inventory carried by the I^R, according to the retailer's decision makers to determine the product green degree e^R, the product of the wholesale price of w_1^R and q_{M1}^R demand direct channel. The second phase, actual purchases 2 retailers to set their own products Q_2, according to the retailer's

Table 2 Equilibrium results of the M-R

Variable	Balanced results
w_1^{ME}	$\frac{3l(e^M)^2+3ke^M+4I^M+3a-c}{6}$
q_{R1}^{ME}	$\frac{2c-2I^M}{3}$
q_{M1}^{ME}	$\frac{3a-5c+3ke^M-3l(e^M)^2+2I^M}{6}$
π_{R1}^{ME}	$\frac{5c^2+2cI^M-18\text{h}I^M-16(I^M)^2}{18}$
π_{M1}^{ME}	$\frac{(I^M+2c)(4I^M+3a-c+3ke^M-3l(e^M)^2)-(I^M-c)(-3l(e^M)^2+3ke^M-4I^M+3a+c)}{18}+$ $\frac{6(3l(e^M)^2-3ke^M+2I^M-3a+4c)^2+(2I^M+3a-5c+3ke^M-3l(e^M)^2)^2}{36}$

decisions, manufacturers determine product wholesale price w_2^R, AM demand and direct sales channels q_{M2}^R.

4.2 Retailers Dominate Game Model

Manufacturer and retailer's profit function is expressed as the following form.

$$\underset{Q_2}{MAX}\, \pi_{R2}^R = (a - (Q_2 + I^R + q_{M2}^R + ke^R)(Q_2 + I^R) - w_2^R Q_2 \tag{20}$$

$$\underset{q_{M2}^R, w_2^R}{MAX}\, \pi_{M2}^R = (w_2^R - l(e^R)^2)Q_2 + (a - (Q_2 + I^R + q_{M2}^R) + ke^R - c - l(e^R)^2)q_{M2}^R \tag{21}$$

$$\underset{Q_1}{MAX}\, \pi_{R1}^R = (a - (Q_1 - I^R + q_{M1}^R) + ke^R)(Q_1 - I^R) - w_1^R Q_1 - hI^R + \pi_{R2}^{RE} \tag{22}$$

$$\begin{aligned}\underset{q_{M1}^R, w_1^R}{MAX}\, \pi_{M1}^R =& (w_1^R - l(e^R)^2)Q_1 + (a - (Q_1 - I^R + q_{M1}^R) \\ &+ ke^R - c - l(e^R)^2)q_{M1}^R + \pi_{M2}^{RE}\end{aligned} \tag{23}$$

For retailers in a dominant position of the double channel model of supply chain, we are also using backward induction method to analysis. In the second stage ,, first analyze the retailers' sales channels, namely formula (20) to Q_2, please first derivative $\frac{\partial \pi_{R2}^R}{\partial Q_2}$

$$\frac{\partial \pi_{R2}^R}{\partial Q_2} = a - q_{M2}^R - 2I^R - w_2^R + ke^R - 2Q_2 \tag{24}$$

Due to the profits of retailers in 2 place for concave function, make $\frac{\partial \pi_{M2}^M}{\partial q_{M2}^M} = 0$, manufacturers can get in the second stage of the optimum M the market demand is Q_2^E,

$$Q_2^E = \frac{a - q_{M2}^R - 2I^R - w_2^R + ke^R}{2} \tag{25}$$

Manufacturers actual purchases of Q_2^E forecast retailers, determine their wholesale prices w_2^R and direct channel demand q_{M2}^R, put Formula (25) into the formula (21), formula (21) of w_2^R and q_{M2}^R derivation is respectively:

$$w_2^{RE} = \frac{l(e^R)^2 + ke^R - 2I^R + a}{2} \tag{26}$$

$$q_{M2}^{RE}=\frac{a-2c+ke^R-l(e^R)^2}{2} \tag{27}$$

Through formula (26) and formula (27), Q_2^E after reduction is:

$$Q_2^E=\frac{c-I^R}{2} \tag{28}$$

By the formula (26), formula (27) and formula (28) respectively to replace into the formula (20) and formula (21), you can get the retailer's profits in the second stage π_{R2}^{RE} and manufacturer's profits π_{M2}^{RE},

$$\pi_{R2}^{RE}=\frac{c^2+2cI^R+2lI^R(e^R)^2+2kI^Re^R+2aI^R-3(I^R)^2}{4} \tag{29}$$

$$\pi_{M2}^{RE}=\frac{(I^R-c)(l(e^R)^2-ke^R+2I^R-a)}{4}-\frac{(a-2c+ke^R-l(e^R)^2)(l(e^R)^2-ke^R+I^R-a+c)}{4} \tag{30}$$

In the first stage, the maker of the actual purchases of Q_1 forecast retailers, set the product green degree of e^R, the wholesale price of w_1^R Demand for q_{M1}^R and direct marketing channels. The formula (29) to replace into the formula (22), formula (22) a derivative of Q_1,

$$\frac{\partial\pi_{R1}^R}{\partial Q_1}=a-2Q_1-q_{M1}^R-2I^R-w_1^R+ke^R \tag{31}$$

So, we can get the retailers in the first stage of the optimum purchases Q_1^E,

$$Q_1^E=\frac{a-q_{M1}^R-2I^R-w_1^R+ke^R}{2} \tag{32}$$

The formula (32) to replace into the formula (23), formula (23) of q_{M1}^R for first order partial derivative can be obtained $\frac{\partial\pi_{R1}^R}{\partial q_{M1}^R}$,

$$\frac{\partial\pi_{R1}^R}{\partial q_{M1}^R}=\frac{a-2q_{M1}^R-2c+ke^R-l(e^R)^2}{2} \tag{33}$$

As a result, we get the first phase of the manufacturer's optimal q_{M1}^{RE} demand direct channel,

$$q_{M1}^{RE}=\frac{a-2c+ke^R-l(e^R)^2}{2} \tag{34}$$

So, we have replaced formula (34) into the formula (32) can get Q_1^E.

$$Q_1^E = \frac{l(e^R)^2 + ke^R + 4I^R + a + 2c - 2w_1^R}{4} \tag{35}$$

We put the formula (34) and formula (35) to replace into the formula (23), then the formula (23) on the first derivative can get $\frac{\partial \pi_{M1}^R}{\partial w_1^R}$,

$$\frac{\partial \pi_{M1}^R}{\partial w_1^R} = \frac{l(e^R)^2 + ke^R + 2I^R + a - 2w_1^R}{2} \tag{36}$$

Therefore, manufacturers in the first stage of the optimal wholesale price w_1^{RE} as follows:

$$w_1^{RE} = \frac{l(e^R)^2 + ke^R + 2I^R + a}{2} \tag{37}$$

We have replaced formula (37) into the formula (35) retailers will be given in the first stage of the optimum actual purchases Q_1^E.

$$Q_1^E = \frac{c + I^R}{2} \tag{38}$$

We according to the formula (34), formula (37) and formula (38) can get the retailer's optimal profit 1 π_{R1}^{RE} and manufacturers the most Optimal profit π_{M1}^{RE},

$$\pi_{R1}^{RE} = \frac{c^2 - 2hI^R - 3(I^R)^2}{2} \tag{39}$$

$$\pi_{M1}^{RE} = (I^R)^2 + \frac{a^2}{2} - ac - al(e^R)^2 + ake^R + c^2 + cl(e^R)^2 - cke^R + \frac{l^2(e^R)^4}{2} - lk(e^R)^3 + \frac{k^2(e^R)^2}{2} \tag{40}$$

Final retailer dominated the game model of the equilibrium results summary in Table 3.

Known from the analysis of Table 3, manufacturers in the first phase of the optimal wholesale price w_1^{RE} with the increase of product green degree e^R increased after decreased first, the first phase of the manufacturer's optimal direct channel q_{M1}^{RE} demand with the increase of product green degree e^R first increases then decreases. Manufacturers in the first stage and the second phase of the direct channel sales have nothing to do with retailers to maintain strategic stockpiles. The first stage of the retailer's actual purchases Q_1 rises with the increase of strategic stockpiles, retailers the actual purchases of Q_2^E and vice.

Table 3 Retailers in a dominant position of equilibrium of game result

Variable	The equilibrium results
w_1^{RE}	$\frac{l(e^R)^2+ke^R+2I^R+a}{2}$
Q_1^E	$\frac{c+I^R}{2}$
q_{M1}^{RE}	$\frac{a-2c+ke^R-l(e^R)^2}{2}$
π_{R1}^{RE}	$\frac{c^2-2hI^R-3(I^R)^2}{2}$
π_{M1}^{RE}	$(I^R)^2+\frac{a^2}{2}-ac-al(e^R)^2+ake^R+c^2+cl(e^R)^2-cke^R+\frac{l^2(e^R)^4}{2}-lk(e^R)^3+\frac{k^2(e^R)^2}{2}$

5 Equal Status of Dual Channel Supply Chain Research

5.1 Problem Description

In dual channel supply chain model of equal status, members of the supply chain profit function with manufacturers dominate the game model of the same. Similar to the first two power structure, equal status of double channels in the supply chain profits of manufacturers and retailers also on the degree of green products, and retailers hold strategic stockpiles are sensitive. The first stage, the manufacturer to determine the product green degree e^N, wholesale prices w_1^N and demand for direct channel q_{M1}^N; At the same time retailers determine their retail market demand q_{R1}^N and strategic stockpiles I^N. The second phase, manufacturers to determine product wholesale price of w_2^N and direct channel demand q_{M2}^N, retailers q_{R2}^N demand determine product retail market.

5.2 Equal Status of Dual Channel Supply Chain Model

According to the backward induction, we first ask manufacturers to determine the products of the second stage of the wholesale price of w_2^N, and the demand of marketing channels q_{M2}^N, retailers q_{R2}^N demand to determine the product retail market. In the second phase of the profit function for the retailers.

$$\underset{q_{R2}^N}{MAX}\,\pi_{R2}^N=(a-(q_{R2}^N+q_{M2}^N)+ke^N)q_{R2}^N-w_2^N(q_{R2}^N-I^N) \tag{41}$$

Manufacturers in the second phase of the profit function for

$$\underset{q_{M2}^N, w_2^N}{MAX}\, \pi_{M2}^N = (w_2^N - le^2)(q_{R2}^N - I^N) + (a - (q_{R2}^N + q_{M2}^N) + ke^N - c - l(e^N)^2)q_{M2}^N \tag{42}$$

We need to make the π_{R2}^N for q_{R2}^N first derivative, then $\frac{\partial \pi_{R2}^N}{\partial q_{R2}^N}$,

$$\frac{\partial \pi_{R2}^N}{\partial q_{R2}^N} = a - q_{M2}^N - 2q_{R2}^N - w_2^N + ke^N \tag{43}$$

Because $\frac{\partial \pi_{R2}^N}{\partial q_{R2}^N}$ as convex function, so it is easy to calculate q_{R2}^{NE},

$$q_{R2}^{NE} = \frac{a - q_{M2}^N + ke^N - w_2^N}{2} \tag{44}$$

While retailers determine q_{R2}^{NE}, we need to π_{M2}^N for q_{M2}^N first order partial derivative, then $\frac{\partial \pi_{M2}^N}{\partial q_{M2}^N}$,

$$\frac{\partial \pi_{M2}^N}{\partial q_{M2}^N} = a - c - l(e^N)^2 + ke^N - q_{R2}^N - 2q_{M2}^N \tag{45}$$

Same as $\frac{\partial \pi_{M2}^N}{\partial q_{M2}^N}$ for convex function, then q_{M2}^{NE} for,

$$q_{M2}^{NE} = \frac{-l(e^N)^2 + ke^N - q_{R2}^N - c + a}{2} \tag{46}$$

We put the formula (44) into the formula (46), you can get q_{M2}^{NE},

$$q_{M2}^{NE} = \frac{a - 2c + w_2^N + ke^N - 2l(e^N)^2}{3} \tag{47}$$

So we can also get q_{R2}^{NE} about w_2^N

$$q_{R2}^{NE} = \frac{a + c - 2w_2^N + ke^N + l(e^N)^2}{3} \tag{48}$$

We put the formula (47) and formula (48) to replace into the formula (42), and make the formula (42) for w_2^N can get a first order partial derivatives $\frac{\partial \pi_{M2}^N}{\partial w_2^N}$,

$$\frac{\partial \pi_{M2}^N}{\partial w_2^N} = \frac{5l(e^N)^2 + 5ke^N - 9I^N + 5a - c - 10w_2^N}{9} \tag{49}$$

So we can get the manufacturer in the second phase of the optimal wholesale price w_2^{NE}:

$$w_2^{NE} = \frac{5l(e^N)^2 + 5ke^N + 5a - 9I^N - c}{10} \tag{50}$$

When we put the formula (50) to replace into the formula (47) and formula (48), you can get the second phase the manufacturer's optimal direct channel q_{M2}^{NE} and optimal retail market sales q_{R2}^{NE},

$$q_{M2}^{NE} = \frac{5a + 5ke^N - 5l(e^N)^2 - 3I^N + 7c}{10} \tag{51}$$

$$q_{R2}^{NE} = \frac{3I^N + 2c}{5} \tag{52}$$

So we put the formula (50), formula (51) and formula (52) to replace into the formula (41) can get the most of the second stage retailers optimal profit π_{R2}^{NE}:

$$\pi_{R2}^{NE} = \frac{(3I^N + 2c)(5l(e^N)^2 + 5ke^N - 3I^N + 5a + 3c)}{50} + \frac{(2I^N - 2c)(5l(e^N)^2 + 5ke^N + 5a - 9I^N - c)}{50} \tag{53}$$

Similarly, we can get the optimal profit in the second stage manufacturers π_{M2}^{NE},

$$\pi_{M2}^{NE} = \frac{(2I^N - 2c)(5l(e^N)^2 - 5ke^N - 5a + 9I^N + c)}{50} + \frac{(5l(e^N)^2 - 5ke^N - 5a + 7c)^2}{100} \tag{54}$$

In the first stage, the manufacturer to determine the product green degree of e^N, the wholesale price of w_1^N and direct sales channel q_{M1}^N, and The same time, retailers determine retail market sales, q_{R1}^N, and strategic inventory I^N. The retailer's profit function is shown as the following form.

$$\underset{q_{R1}^N}{MAX}\, \pi_{R1}^N = (a - (q_{R1}^N + q_{M1}^N) + ke^N)q_{R1}^N - w_1^N(q_{R1}^N + I^N) - hI^N + \pi_{R2}^{NE} \tag{55}$$

And manufacturers in the first stage of the profit function is shown as:

$$\underset{q_{M1}^N, w_1^N}{MAX}\,\pi_{M1}^N = (w_1^N - l(e^N)^2)(q_{R1} + I^N) + (a - (q_{R1}^N + q_{M1}^N) + ke^N - c - l(e^N)^2)q_{M1}^N + \pi_{M2}^{NE} \tag{56}$$

Similar to the second stage model, we make the retailer's profit function for retail market sales q_{R1}^N first derivative at the same time, The manufacturer's profit function to direct channel sales quantity for a first order partial derivatives. So we can get $\frac{\partial \pi_{R1}^N}{\partial q_{R1}^N}$,

$$\frac{\partial \pi_{R1}^N}{\partial q_{R1}^N} = a - q_{M1}^N - 2q_{R1}^N - w_1^N + ke^N \tag{57}$$

Because the $\frac{\partial \pi_{R1}^N}{\partial q_{R1}^N}$ obviously as convex function, therefore, we can obtain retailers retail market is like in the first phase of the best sales q_{R1}^{NE},

$$q_{R1}^{NE} = \frac{a - q_{M1}^N - w_1^N + ke^N}{2} \tag{58}$$

At the same time, we also can get $\frac{\partial \pi_{M1}^N}{\partial q_{M1}^N}$,

$$\frac{\partial \pi_{M1}^N}{\partial q_{M1}^N} = a - c - l(e^N)^2 + ke^N - q_{R1}^N - 2q_{M1}^N \tag{59}$$

In the same way, $\frac{\partial \pi_{M1}^N}{\partial q_{M1}^N}$ of the convex function, therefore, we get the first stage manufacturers optimal direct channel sales q_{M1}^{NE} is:

$$q_{M1}^{NE} = \frac{a - q_{R1}^N - c + ke^N - l(e^N)^2}{2} \tag{60}$$

We through formula (58) and formula (60) can only get the first phase of the best retail wholesale price w_1^N retailer Market sales q_{R1}^{NE} and makers of the first phase of the optimal direct channel sales q_{M1}^{NE}. They form is as follows.

$$q_{R1}^{NE} = \frac{a + c - 2w_1^N + ke^N + l(e^N)^2}{3} \tag{61}$$

$$q_{M1}^{NE} = \frac{a - 2c + w_1^N + ke^N - 2l(e^N)^2}{3} \tag{62}$$

We put the formula (61) and formula (62) to replace into the formula (56), and make the formula (56) to the manufacturer to determine the first phase of the wholesale price w_1^N for a first order partial derivatives, can get $\frac{\partial \pi_{M1}^N}{\partial w_1^N}$:

$$\frac{\partial \pi_{M1}^{N}}{\partial w_1^{N}} = \frac{5l(e^N)^2 + 5ke^N + 9I^N + 5a - c - 10w_1^N}{9} \tag{63}$$

Be determined by the formula (63), we can get the manufacturer as follows: the first stage of the wholesale price w_1^{NE}

$$w_1^{NE} = \frac{5l(e^N)^2 + 5ke^N + 5a + 9I^N - c}{10} \tag{64}$$

We have replaced formula (64) into the formula (61) and formula (62) can get retailers retail market is like in the first phase of the best sales q_{R1}^{NE} and makers of the first phase of the optimal direct channel sales q_{M1}^{NE}. They form is as follows:

$$q_{R1}^{NE} = \frac{2c - 3I}{5} \tag{65}$$

$$q_{M1}^{NE} = \frac{5ke^N - 5l(e^N)^2 + 5a + 3I^N - 7c}{10} \tag{66}$$

According to the formula (64), formula (65) and formula (66) we can get the best profit in the first stage of retailers π_{R1}^{NE} to,

$$\pi_{R1}^{NE} = \frac{8c^2 - 27(I^N)^2 - 25hI^N}{25} \tag{67}$$

Similarly, we can get the best profit in the first stage manufacturers π_{M1}^{NE} for

$$\pi_{M1}^{NE} = \frac{9(I^N)^2 + 5a^2 - 10ac - 10al(e^N)^2 + 10ake^N + 9c^2 + 10cl(e^N)^2}{10} - \frac{10cke^N + 5l^2(e^N)^4 - 10kl(e^N)^3 + 5k^2(e^N)^2}{10} \tag{68}$$

Final status equal game model of the equilibrium results summary in Table 4.

Known from the analysis of Table 4, manufacturers in the first phase of the optimal wholesale price w_1^{NE} with the increase of product green degree e^M rise after falling first, manufacturers in the second phase of the optimal wholesale price w_2^{NE} the same with the increase of product green degree e^M first rise after falling. Manufacturers in the first phase of the optimal wholesale price w_1^{NE} increased with the increase of retailers to maintain strategic stockpiles I^N rise gradually, manufacturers in the second phase of the optimal wholesale price w_2^{NE} is increased with the increase of strategic stockpiles I^N fall. The study found that in the equal status of dual channel supply chain model, retailers maintain strategic stockpiles will lower the manufacturer of the second stage of the wholesale price. For manufacturers, manufacturers of the first phase of the optimal demand for direct channel q_{M1}^{NE} will be increased with the increase of the number of retailers maintain strategic stockpiles to rise, demand

Table 4 The balanced Po running results of equal status

Variable	The equilibrium results
w_1^{NE}	$\frac{5l(e^N)^2+5ke^N+5a+9I^N-c}{10}$
q_{R1}^{NE}	$\frac{2c-3I}{5}$
q_{M1}^{NE}	$\frac{5ke^N-5l(e^N)^2+5a+3I^N-7c}{10}$
π_{R1}^{NE}	$\frac{8c^2-27(I^N)^2-25hI^N}{25}$
π_{M1}^{NE}	$\frac{9(I^N)^2+5a^2-10ac-10al(e^N)^2+10ake^N+9c^2+10cl(e^N)^2}{10}-\frac{10cke^N+5l^2(e^N)^4-10kl(e^N)^3+5k^2(e^N)^2}{10}$

for manufacturers of the second stage of the optimum direct channel q_{M2}^{NE} will be increased with the increase of the number of retailers maintain strategic stockpiles. For retailers, retailers in the first stage and the second stage of the retail market demand has nothing to do with the degree of green products. Retailers to maintain strategic stockpiles makes it in the first phase of market demand for smaller, in the second stage of the market demand will be bigger.

6 Conclusion and Prospect

As the environment has become a key factor of social and economic development and the improvement of people's living standards, people have higher and higher requirements for the company's products, and environmentally friendly products are more and more favored by consumers. The international community and various countries have also issued a variety of environmental protection laws and regulations to restrain the green degree of products in various industries. Enterprises will also invest in green technology for their own profit and corporate responsibility. Based on the green technology investment on products is conducted by manufacturers and retailers hold strategic supply chain inventory divided into manufacturers in a dominant position, retailers in a dominant position and equal status of three kinds of power structure, double channel based on the study of the supply chain in the past, the product green degree and strategic stockpiles considering the research of the article. On the basis of market sales price function, we divide the sales channels into retailer sales channels and manufacturer direct sales channels. Based on different power structures, we study the competition between manufacturers and retailers in the supply chain in order to obtain the maximum profit, and use the two-stage game method to obtain the equilibrium sales volume and the equilibrium profit under the three power structures. Through the research of the article, the following conclusions are obtained.

The manufacturer's optimal wholesale price in the first stage increased first and then decreased with the increase of the green degree of the product, and the manufacturer's optimal wholesale price in the second stage also increased first and then decreased with the increase of the green degree of the product. The optimal wholesale price of the manufacturer in the first stage increases gradually with the increase of the strategic inventory maintained by the retailer, while the optimal wholesale price of the manufacturer in the second stage decreases with the increase of the strategic inventory. Through the analysis of the first stage and the second stage, we can conclude that in the dual-channel supply chain model in which the manufacturer plays a dominant role, retailers keeping strategic inventory will make the manufacturer reduce the wholesale price of the second stage. We find that the optimal direct channel demand of manufacturers in the first stage will increase with the increase of the number of retailers maintaining strategic inventory, while the optimal direct channel demand of manufacturers in the second stage will decrease with the increase of the number of retailers maintaining strategic inventory. For retailers, the retail market demand in the first stage and the second stage has nothing to do with the green degree of the product. Retailers keep strategic inventory so that the market demand in the first stage will be smaller, but the market demand in the second stage will be larger.

In the first stage, the manufacturer's optimal wholesale price first decreases and then increases with the increase of the green degree of the product, and the manufacturer's optimal direct channel demand first increases and then decreases with the increase of the green degree of the product. Manufacturers' direct channel sales in the first and second stages are unrelated to the strategic inventory maintained by retailers. The actual purchases of stage 1 retailers increased with the increase of strategic inventory and vice versa.

The manufacturer's optimal wholesale price in the first stage decreased first and then increased with the increase of the green degree of the product, and the manufacturer's optimal wholesale price in the second stage also decreased first and then increased with the increase of the green degree of the product. The optimal wholesale price of the manufacturer in the first stage increases gradually with the increase of the strategic inventory maintained by the retailer, while the optimal wholesale price of the manufacturer in the second stage decreases with the increase of the strategic inventory. It is found that in a two-channel supply chain model with equal status, the retailer's strategic inventory will cause the manufacturer to lower the wholesale price of the second stage. For manufacturers, the optimal direct channel demand of manufacturers in the first stage will increase with the increase in the number of retailers maintaining strategic inventory, while the optimal direct channel demand of manufacturers in the second stage will decrease with the increase in the number of retailers maintaining strategic inventory. For retailers, the retail market demand in the first stage and the second stage has nothing to do with the green degree of the product. Retailers keep strategic inventory so that the market demand in the first stage will be smaller, but the market demand in the second stage will be larger. However, there are some shortcomings in this paper, mainly including the following two aspects: First, to simplify the problem, it is assumed that the sales price of the manufacturer's direct sales channel is the same as that of the retailer. In fact, the relationship between them often differs due to the speed of logistics, and future extensions will explore price discrimination in modeling. In addition, our model only discusses a market with constant customer demand, and uncertain random demand functions can be considered in the future.

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Contract and Mode Choices Under Demand and Price Volatility in a Shipping Supply Chain

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Abstract This paper studies a forwarder's mode choice and contract choice in a shipping supply chain. The forwarder canvasses shippers' orders and provides one-stop service to shippers. The forwarder needs to purchase ocean service from a carrier by a forward contract or spot market. Furthermore, the forwarder decides to offer inland service by insourcing mode or outsourcing mode. The market size, spot price and outsourcing cost is ex-uncertain. Moreover, the market size is correlates with the spot price and outsourcing cost. We find that the uncertainty of the market size, spot price and outsourcing cost have an important effect on the forwarder's choice. Firstly, the forwarder still chooses the forward contract to purchase the ocean service even when the contract price is slightly larger than the expected ocean service spot price. Secondly, the forwarder and carrier choose the forward contract when the market size is relatively small. Thirdly, we show that the forwarder's optimal mode choice. We find that the forwarder may choose insourcing mode although it faces high cost. Specially, the forwarder chooses the insourcing mode for the inland service even when the insourcing mode cost is slightly larger than the expected outsourcing cost. In summary, this paper analyzes the impact of the uncertainty on the mode choice and contract choice.

Keywords Shipping supply chain · Forward contract · Spot market · Outsourcing

1 Introduction

The export and import of cargoes include various services, including inland service, ocean service, customs clearance service, and so on. The complex service procurement process typically causes high service costs and inefficiencies for shippers. Therefore, it is optimal for the shippers that are not good at logistics service to purchase one-stop service. First, one-stop service can simplify logistics processes to prevent potential delays. Second, one-stop service gives shippers access to ensure

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cost-effective transit of cargos. On the other hand, the forwarder realizes value by offering the one-stop service to the shippers (Wang et al. 2020). For example, Sinotrans mainly provides shippers with multi-link services such as booking capacity, warehousing, gathering and clearing ports, customs clearance, distribution and delivery. Sinotrans has become the largest forwarder in China, handling more than 10 million TEUs of shipping containers annually, providing end to end supply chain logistics services between major ports in China and countries around the world. One-stop service makes the forwarder extend supply chain and offer more add-on services to entire more profits. Consequently, the one-stop service becomes the common choice of the shippers and forwarders.

The forwarder needs to purchase the ocean service from carrier. The forwarder previously focuses on backspread purchasing the ocean service through the forward contract and selling it in the spot market. However, affected by the epidemic, capacity shortage and high price make the forwarder mainly focuses on the ocean service price rather than capacity trading at present. Therefore, in shipping practice, the forwarder chooses whether to lock in the ocean service price by forward contract in advance or spot purchasing. In the former, the carrier determines the forward price which is locked in at the time of each order and the forwarder decides whether or not adopt. In the latter, the spot price is correlated with market size and is realized prior to the ship departure date. The pros and cons of the forward contract and spot market have been widely discussed in shipping market. A common view is that the forward contract enables the carrier to lock in capacity in advance and enables the forwarder to lock in service and price as well. In contrast, the spot market is flexible for both the carrier and forwarder. For the inland service, the forwarder offers it by insourcing mode or outsourcing mode. Under the insourcing mode, the forwarder needs to buy vehicles and build up warehouses to provide the inland service. On the contrary, under the outsourcing mode, the forwarder has not vehicles and warehouses and buys the inland service by spot market. For example, Sinotrans mainly adopts the outsourced vehicles and leases about three million square meters of warehouse resources.

Purchasing the ocean service and inland service has been an important topic in the shipping supply chain. However, few papers study service procurement combine the ocean service with inland service. Moreover, the volatility of ocean service and inland service spot price and the shipper potential demand market size has received little attention in the shipping supply chain literature. Therefore, the main purpose of this study is to address the above important issues. In particular, we seek to answer the following research questions: (1) Does the forwarder have an incentive to adopt the forward contract if the forward price is high? (2) When will the carrier and forwarder choose the forward contract? (3) Under what market situations should the forwarder adopt the insourcing mode or outsourcing mode?

We develop a model in which the forwarder purchases the ocean service from the carrier and offers the one-stop service to shippers. In the beginning, the forwarder decides to offer the inland service by insourcing mode or outsourcing mode. Next, the carrier offers a forward contract and the forwarder determines whether or not to sign the contract. If the contract is signed, the carrier determines the contract price, otherwise the forwarder purchases on the spot market. Then, the forwarder decides the one-stop service price to maximize its expected profit. Finally, the uncertain market size, the spot price and the outsourcing cost are realized.

In this model setting, purchasing the ocean service or inland service by spot price enables the forwarder to face cost uncertainty. We find that the forwarder still chooses the forward contract to buy the ocean service even when the contract price is slightly larger than the expected spot price because the forwarder intends to lock in the ocean service price to avoid the negative effect of the volatility of the ocean service spot price and shipper market size. We also find that the forwarder and carrier choose the forward contract when the market size is relatively small. In this case, the carrier sets a low contract price to make both the carrier and forwarder better. Finally, we show that when the forwarder adopts the insourcing mode or outsourcing mode. Interestingly, the forwarder adopts the insourcing mode for the inland service even when the insourcing mode cost is slightly larger than the expected outsourcing cost. The reason is that the forwarder intends to lock in the inland service price to avoid the negative effect of the volatility of inland service spot price and market size.

This paper contributes to the literature by revealing the effect of correlation of market size and spot price on service procurement. It also deepens our understanding of the effect of correlation by considering the ocean service and inland service procurement rather than single service (i.e., ocean service or inland service) procurement.

2 Literature Review

Purchasing transportation services is considered to be a key part of the shipping supply chain and has been extensively studied in the literature. Lafkihi et al. (2019) provided a comprehensive literature review of transportation service procurement and described the future prospects in new freight transportation markets. There is a group of papers that focus on procurement mechanisms including mechanism type, mechanism ownership and terms of agreement (e.g., Xu and Huang 2017, Lindsey and Mahmassani 2017, Kuyzu 2017 and Hu et al. 2016). Lim et al. (2008) studied a shipper's transportation procurement model in which the shipper negotiates with transportation companies through volume guarantees. Fransoo and Lee (2013) provide an excellent comprehensive review for contracting, pricing, and risk management of purchasing ocean container transportation. Wang et al. (2017) concentrated on a vertical integration problem in which the ocean shipping company competes with the inland shipping company to canvass the cargoes. Tan et al. (2018) investigated the competition and alliance strategies between one ocean carrier and one inland shipping company in a vertical container shipping chain. Liu and Wang (2019) investigate two competing carriers' incentives of horizontal alliance and values of vertical cooperation in a one-to-two shipping service competition model, where two carriers may form an alliance. Wang et al. (2020) investigate the incentive of forwarder's service purchasing and ocean company's market-entry problems in a shipping supply chain.

However, different from the existing works, we contribute by considering ocean and inland shipping service procurement under market size and spot price uncertainty.

This paper involves procurement contract issues, which includes commodity procurement contract and shipping service procurement contract. Purchasing commodity by forward contract or spot market has been extensively studied in the literature (e.g., Ai and Xu 2021, Etzion and Pinker 2008; Popescu and Seshadri 2013). However, we focus on contracts of ocean shipping service. Kavussanos et al. (2004) investigates the impact of Forward Freight Agreement trading on spot market price volatility. Lee et al. (2015) provide a fractional price-matching contract where shippers can purchase ocean services by forward contract or in spot market. Yang et al. (2017) propose a floating price contract to study contract default issue caused by spot market. There is also a group of papers that explore service purchase strategy by forward contract and spot market. Kelly et al. (2020) studies carrier-shipper risk management and coordination in the presence of spot freight market by three basic shipping structures. Our work differs from the aforementioned studies in that we take both ocean service and inland service into consideration. The correlation between ocean service and inland service influences the decisions of the ocean carrier significantly.

This study is also related to the literature on insourcing and outsourcing. There is a group of papers that study outsourcing of production. Cachon and Harker (2002), Liu and Tyagi (2011), and Feng and Lu (2012) study the advantage of outsourcing production in competitive background. In these papers, two firms compete in the same market, and each firm may choose to either insource or outsource the production of the product. There is also a group of papers that study outsourcing logistics. We mainly focus on insourcing logistics and outsourcing logistics. Cai et al. (2013) and Wu et al. (2015) introduce a 3pl provider into a fresh-product supply chain, and study supply chain equilibrium decisions and coordination. Two factors distinguish our work from the aforementioned studies. First, we focus on outsourcing logistics of the forwarder rather than producer or manufacturer. Second, we combine inland service mode choice with contract choice of ocean service. We also contribute to the literature by revealing how the price volatility affects contract or mode selection.

3 Model

Consider a shipping supply chain consisting of a carrier and a forwarder. The forwarder canvasses shippers' orders and provides one-stop service to shippers. The one-stop service includes ocean service and inland service. The forwarder needs to purchase the ocean service from the carrier through a forward contract or spot market and offers the inland service by the insourcing mode or the outsourcing mode.

The demand function for the forwarder is given by $q = a - p$, where p is the one-stop service price, and a represents market size with $a \sim N\left[\mu_a, \sigma_a^2\right]$. The spot price of ocean service denoted by s with $s \sim N\left[\mu_s, \sigma_s^2\right]$, where μ_s is expected spot price and σ_s is spot price volatility. The forward contract price is $(1-\theta)\mu_s$, where θ measures price adjustment rate. The forwarder's outsourcing cost is z with $z \sim N\left[\mu_z, \sigma_z^2\right]$. Correspondingly, we use $(1+\lambda)\mu_z$ to measure the forwarder's insourcing cost, where λ represents exogenous cost premium.

The market size a and the spot price s are positively correlated with coefficient ρ. That is, $Cov(a, s) = \rho\sigma_a\sigma_s$. When the market size increases, the spot price correspondingly increases (e.g., Yang et al. 2017). Moreover, the market size a and the outsourcing cost z are positively correlated with coefficient τ. That is $Cov(a, z) = \tau\sigma_a\sigma_z$. For simplify, we use v denote the forwarder's inland service cost and w measure the price of the ocean service. The carrier's service cost is a constant which is not affect the analysis, so we assume that the service cost of the carrier is zero. Correspondingly, the forwarder's profit is $\pi_F = (p - v - w)q$ and the carrier's profit is $\pi_C = wq$.

The sequence of events between the carrier and the forwarder are as follows. First, the forwarder decides to offer the inland service by insourcing mode or outsourcing mode. Second, the carrier offers a forward contract and the forwarder determines whether or not to sign the contract. If the contract is signed, the carrier determines the contract price, otherwise the forwarder purchases on the spot market. Third, the forwarder decides the one-stop service price to maximize its expected profit. Finally, the uncertain market size, the spot price and the outsourcing cost are realized.

4 Forward Contract Choice

Depending on the forwarder and carrier's choices forms four situations. Let IF, IS, OF and OS denote the four situations, with the first (second) letter representing the forwarder's inland service mode (ocean service) choice. In this section, we analyze if the carrier and forwarder can sign a forward contract.

4.1 Under Insourcing Mode

In the IF situation, the forwarder's inland service cost is $v = (1+\lambda)\mu_z$ and ocean service price is $w = (1-\theta)\mu_s$. The forwarder decides the one-stop service price to maximize its expected profit. The optimal one-stop price is given by

$$p^{IF} = \frac{1}{2}\left[\mu_a + (1-\theta)\mu_s + (1+\lambda)\mu_z\right]. \tag{1}$$

The expected profit of the forwarder and the carrier are computed as

$$\Pi_F^{IF} = \frac{1}{4}\left[\mu_a - (1-\theta)\mu_s - (1+\lambda)\mu_z\right]^2, \tag{2}$$

$$\Pi_C^{IF} = \frac{1}{2}(1-\theta)\mu_s\big[\mu_a - (1-\theta)\mu_s - (1+\lambda)\mu_z\big]. \tag{3}$$

In the IS situation, the forwarder's inland service cost is $v = (1+\lambda)\mu_z$ and ocean service price is $w = s$. The forwarder decides the one-stop service price to maximize its expected profit. The optimal one-stop price is given by

$$p^{IS} = \frac{1}{2}\big[\mu_a + \mu_s + (1+\lambda)\mu_z\big]. \tag{4}$$

The expected profit of the forwarder and the carrier are computed as

$$\Pi_F^{IS} = \frac{1}{4}\big[\mu_a - \mu_s - (1+\lambda)\mu_z\big]^2 - \rho\sigma_a\sigma_s, \tag{5}$$

$$\Pi_C^{IS} = \frac{1}{2}\mu_s\big[\mu_a - \mu_s - (1+\lambda)\mu_z\big] + \rho\sigma_a\sigma_s. \tag{6}$$

The forwarder's expected profit is negatively impacted by the volatility of market size and (or) ocean service spot market. However, the carrier's expected profit is positively impacted by them.

Comparing Eqs. (2) and (5), we analyze when the forwarder signs the forward contract with the carrier. Let $\theta_1 = \frac{1}{\mu_s}\left[\mu_s + (1+\lambda)\mu_z - \mu_a + \sqrt{\big[\mu_a - \mu_s - (1+\lambda)\mu_z\big]^2 - 4\rho\sigma_a\sigma_s}\right]$.

Lemma 1 In the insourcing mode, when $\theta \geq \theta_1$, the forwarder signs the forward contract with the carrier, on the contrary, when $\theta < \theta_1$, the forwarder chooses purchases the ocean service on the spot market. Moreover, $d\theta_1/d\lambda < 0$,$d\theta_1/d\sigma_a < 0$, and $d\theta_1/d\sigma_s < 0$.

Lemma 1 shows that the forwarder chooses the forward contract to purchase ocean service when the price adjustment rate is high. Interestingly, when the expected ocean service spot price is slightly smaller than the contract price, the forwarder still chooses the forward contract to purchase the ocean service. Furthermore, with the insourcing cost, the volatility of market size, or the volatility of ocean service spot price increases, the forwarder intends to choose forward contract.

We next analyze the optimal contract price decided by the carrier. The carrier's optimal price decision is $\max_\theta \Pi_C^{IF}$, conditional on $\theta \geq \theta_1$ and $\Pi_C^{IF} \geq \Pi_C^{IS}$. Let $\mu_1 = 2\mu_s + (1+\lambda)\mu_z - 2\sqrt{2\rho\sigma_a\sigma_s}$.

Proposition 1 In the insourcing mode. (a) When $\mu_a \leq \mu_1$, the carrier and forwarder choose the forward contract, in this case, the price adjustment rate is given by

$$\theta^{IF} = 1 - \frac{1}{2\mu_s}\big[\mu_a - (1+\lambda)\mu_z\big], \tag{7}$$

and the carrier and forwarder's expected profits are given by

$$\Pi_C^{IF} = \frac{1}{8}\left[\mu_a - (1+\lambda)\mu_z\right]^2, \tag{8}$$

$$\Pi_F^{IF} = \frac{1}{16}\left[\mu_a - (1+\lambda)\mu_z\right]^2. \tag{9}$$

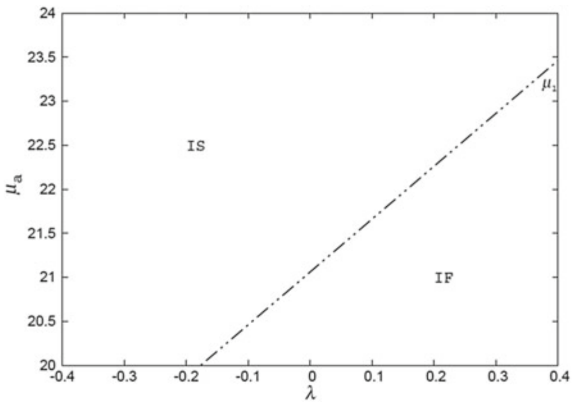
(b) When $\mu_a > \mu_1$, the carrier and forwarder choose the spot market, in this case, the carrier and forwarder's expected profits are given by

$$\Pi_C^{IS} = \frac{1}{2}\mu_s\left[\mu_a - \mu_s - (1+\lambda)\mu_z\right] + \rho\sigma_a\sigma_s, \tag{10}$$

$$\Pi_F^{IS} = \frac{1}{4}\left[\mu_a - \mu_s - (1+\lambda)\mu_z\right]^2 - \rho\sigma_a\sigma_s. \tag{11}$$

When the carrier and forwarder choose the forward contract, the forward contract price is not affected by the expected ocean service spot price and is lower than the expected ocean service spot price. However, it is negatively affected by insourcing cost. Plot Fig. 1 with $\mu_s = 9$, $\mu_z = 6$, $\rho = 0, 3$, $\sigma_a = 3$, and $\sigma_s = 1.2$. Figure 1 shows that when $\lambda \geq 0$, i.e., the insourcing mode cost is larger than the expected outsourcing mode cost, the carrier and forwarder choose the forward contract if the expected market size is relatively small; otherwise, the forwarder purchases the ocean service in spot market.

Fig. 1 Forward contract choice in insourcing mode



4.2 Under Outsourcing Mode

In the OF situation, the forwarder's inland service cost is $v = z$ and ocean service price is $w = (1-\theta)\mu_s$. The forwarder decides the one-stop service price to maximize its expected profit. The optimal one-stop price is given by

$$p^{OF} = \frac{1}{2}\left[\mu_a + (1-\theta)\mu_s + \mu_z\right]. \tag{12}$$

The expected profit of the forwarder and the carrier are computed as

$$\Pi_F^{OF} = \frac{1}{4}\left[\mu_a - (1-\theta)\mu_s - \mu_z\right]^2 - \tau\sigma_a\sigma_z, \tag{13}$$

$$\Pi_C^{OF} = \frac{1}{2}(1-\theta)\mu_s\left[\mu_a - (1-\theta)\mu_s - \mu_z\right]. \tag{14}$$

In the OS situation, the forwarder's inland service cost is $v = z$ and ocean service price is $w = s$. The forwarder decides the one-stop service price to maximize its expected profit. The optimal one-stop price is given by

$$p^{OS} = \frac{1}{2}(\mu_a + \mu_s + \mu_z). \tag{15}$$

The expected profit of the forwarder and the carrier are computed as

$$\Pi_F^{OS} = \frac{1}{4}(\mu_a - \mu_s - \mu_z)^2 - \rho\sigma_a\sigma_s - \tau\sigma_a\sigma_z, \tag{16}$$

$$\Pi_C^{OS} = \frac{1}{2}\mu_s(\mu_a - \mu_s - \mu_z) + \rho\sigma_a\sigma_s. \tag{17}$$

The forwarder's expected profit is negatively impacted by the volatility of market size, outsourcing cost and (or) ocean service spot market. However, the carrier's expected profit is positively impacted by the volatility of market size and (or) ocean service spot market.

Comparing Eqs. (13) and (16), we analyze when the forwarder signs the forward contract with the carrier. Let $\theta_2 = \frac{1}{\mu_s}\left[\mu_s + \mu_z - \mu_a + \sqrt{(\mu_a - \mu_s - \mu_z)^2 - 4\rho\sigma_a\sigma_s}\right]$.

Lemma 2 In the outsourcing mode, when $\theta \geq \theta_2$, the forwarder signs the forward contract with the carrier, on the contrary, when $\theta < \theta_2$, the forwarder chooses purchases the ocean service on the spot market. Moreover, $d\theta_2/d\sigma_a < 0$, and $d\theta_2/d\sigma_s < 0$.

Lemma 2 shows that the forwarder chooses the forward contract to purchase ocean service when the price adjustment rate is high. Interestingly, when the expected ocean service spot price is slightly smaller than the contract price, the forwarder still chooses the forward contract to purchase the ocean service. Furthermore, with the volatility of market size or the volatility of ocean service spot price increases, the forwarder intends to choose forward contract.

We next analyze the optimal contract price decided by the carrier. The carrier's optimal price decision is $\max_\theta \Pi_C^{OF}$, conditional on $\theta \geq \theta_2$ and $\Pi_C^{OF} \geq \Pi_C^{OS}$. Let $\mu_2 = 2\mu_s + \mu_z - 2\sqrt{2\rho\sigma_a\sigma_s}$.

Proposition 2 In the outsourcing mode. (a) When $\mu_a \leq \mu_2$, the carrier and forwarder choose the forward contract, in this case, the price adjustment rate is given by

$$\theta^{OF} = 1 - \frac{1}{2\mu_s}(\mu_a - \mu_z), \tag{18}$$

and the carrier and forwarder's expected profits are given by

$$\Pi_C^{OF} = \frac{1}{8}(\mu_a - \mu_z)^2, \tag{19}$$

$$\Pi_F^{OF} = \frac{1}{16}(\mu_a - \mu_z)^2 - \tau\sigma_a\sigma_z. \tag{20}$$

(b) When $\mu_a > \mu_2$, the carrier and forwarder choose the spot market, in this case, the carrier and forwarder's expected profits are given by

$$\Pi_C^{OS} = \frac{1}{2}\mu_s(\mu_a - \mu_s - \mu_z) + \rho\sigma_a\sigma_s, \tag{21}$$

$$\Pi_F^{OS} = \frac{1}{4}(\mu_a - \mu_s - \mu_z)^2 - \rho\sigma_a\sigma_s - \tau\sigma_a\sigma_z. \tag{22}$$

Clearly, the forward price under the outsourcing mode is higher than that under the insourcing mode. We further find that the forward price is not affected by expected ocean service spot price; however, it is negatively affected by the expected outsourcing mode cost. Moreover, the forward price is always lower than the expected ocean service spot price if the carrier and forwarder choose the forward contract.

5 Inland Service Mode Choice

In this section, we analyze the forwarder's optimal inland service mode choice and the impact of the forwarder's optimal choice on the carrier. Let $\psi_1 = \frac{1}{2\lambda\mu_z}\left[\lambda(2+\lambda)\mu_z^2 + 16\tau\sigma_a\sigma_z\right]$, $\psi_2 = \frac{1}{2\lambda\mu_z}\left[\lambda(2+\lambda)\mu_z^2 + 2\lambda\mu_s\mu_z + 4\tau\sigma_a\sigma_z\right]$, $\psi_3 = \frac{1}{3}\left[(3-\lambda)\mu_z + 4\mu_s + 2\sqrt{\mu_s^2 + \lambda^2\mu_z^2 - 2\lambda\mu_s\mu_z + 12\sigma_a(\rho\sigma_s + \tau\sigma_z)}\right]$,

$\psi_4 = \frac{1}{3}\left[4\mu_s + (3+4\lambda)\mu_z + 2\sqrt{\left(\mu_s^2 + \lambda^2\mu_z^2 + 2\lambda\mu_s\mu_z - 12(\tau\sigma_a\sigma_z - \rho\sigma_a\sigma_s)\right)}\right]$.
We first analyze the case where the insourcing cost is larger than the expected outsourcing cost.

Proposition 3 When $\lambda \geq 0$. (a) When $\mu_a \leq \min\{\mu_2, \psi_1\}$ or, $\mu_2 < \mu_s \leq \min\{\mu_1, \psi_3\}$, the forwarder chooses the insourcing mode and forward contract; (b) when $\psi_1 < \mu_a \leq \mu_2$, the forwarder chooses the outsourcing mode and forward contract; (c) when $\psi_3 < \mu_a \leq \mu_1$ or $\mu_a > \max\{\mu_1, \psi_2\}$, the forwarder chooses the outsourcing mode and spot market; (d) when $\mu_1 < \mu_a \leq \psi_2$, the forwarder chooses the insourcing mode and spot market.

Plot Fig. 2 to show Proposition 3 with $\mu_s = 9, \mu_z = 6, \sigma_a = 3, \sigma_s = 1.2, \sigma_z = 1, \rho = 0.3, \tau = 0.2$.We find that when the expected market size is relatively small, the forwarder chooses the forward contract regardless of the value of λ. This is because a higher shipper demand. Moreover, the forwarder typically chooses the insourcing mode to offer the inland service when the value of λ is sufficiently low. In this case, the forwarder intends to lock in the inland service cost in advance to avoid increased inland service cost caused by the volatility of market size and spot price. Interestingly, when the expected market size is moderate, the forwarder still adopts the insourcing mode when the value of λ is sufficiently large. In this case, the forwarder precludes the negative impact of the volatility of the spot price.

Proposition 4 When $\lambda < 0$. (a) When $\mu_a \leq \mu_1$, the forwarder chooses the insourcing mode and forward contract; (b) when $\mu_1 < \mu_a < \min\{\mu_2, \psi_4\}$, the forwarder chooses the outsourcing mode and forward contract; (c) when $\psi_4 \leq \mu_a < \mu_2$ or $\mu_a \geq \mu_2$, the forwarder chooses the insourcing mode and spot market.

Plot Fig. 3 to show Proposition 4 with $\mu_s = 9, \mu_z = 6, \sigma_a = 3, \sigma_s = 1.2, \sigma_z = 1, \rho = 0.3, \tau = 0.2$.When the expected market size is sufficiently small or large, the forwarder always chooses the insourcing mode because of lower insourcing cost. When the expected market size is moderate, the forwarder may choose outsourcing mode if λ is relatively large.

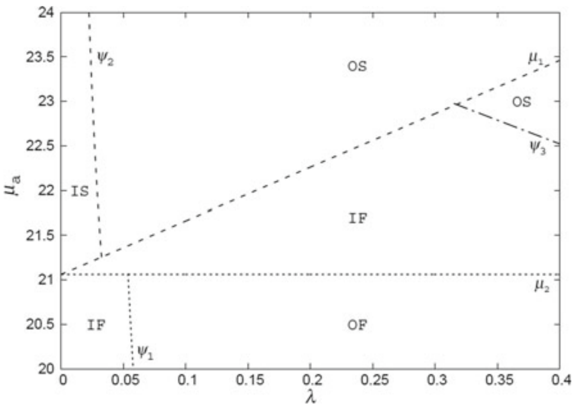


Fig. 2 The forwarder's inland mode choice for $\lambda \geq 0$

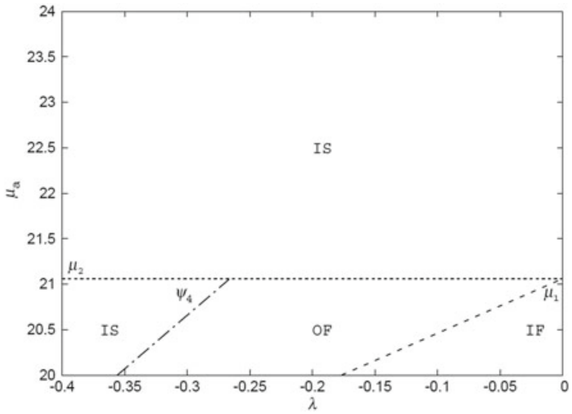


Fig. 3 The forwarder's inland mode choice for $\lambda < 0$

Proposition 5 When $\lambda \geq 0$,the forwarder chooses the insourcing mode which is always hurt the carrier, on the contrary, the carrier benefits from the outsourcing mode. When $\lambda < 0$, the forwarder chooses the outsourcing mode which is always hurt the carrier, on the contrary, the carrier benefits from the insourcing mode.

Proposition 5 shows that the optimal inland service mode choice for the carrier. When $\lambda \geq 0$, the carrier prefers the outsourcing mode. However, when $\lambda < 0$, the carrier prefers the insourcing mode.

6 Conclusions

Motivated by the popularity of the forwarder's end to end transportation. We develop a model to study the forwarder's inland service mode choice and ocean service forward contract choice. The main findings and managerial insights from this paper can be summarized as follows.

First, we find that the forwarder is more likely to choose the forward contract to purchase the ocean service if the forward price is relatively low. Interestingly, the forwarder still chooses the forward contract to purchase the ocean service even when the forward price is slightly larger than the expected ocean service spot price. This finding suggests that the forwarder intends to lock in ocean service cost to avoid the negative effect of the volatility of ocean service spot price and market size. Furthermore, we find that the forwarder is more likely to purchase the ocean service by the forward contract as the volatility of market size and/or ocean service spot price increases.

Second, we analyze the forwarder's forward contract choice. We find that the carrier and the forwarder choose the forward contract when the expected market size is relatively small. Interestingly, we find that the forwarder is more likely to purchase the ocean service by spot market as the volatility of ocean service spot price increases. Furthermore, in the insourcing mode, the carrier and forwarder are more likely to choose the forward contract as the insourcing mode cost increases.

Third, we explore the forwarder's optimal inland service mode choice between the insourcing and outsourcing modes. When the insourcing cost is larger than outsourcing cost, the forwarder chooses the insourcing mode which is always hurt the carrier, on the contrary, the carrier benefits from the outsourcing mode. Interestingly, the forwarder chooses the insourcing mode for the inland service even when the insourcing mode cost is slightly larger than the expected outsourcing cost. However, when the insourcing cost is smaller than outsourcing cost, the forwarder chooses the insourcing mode that benefits the carrier.

There are several promising directions for future research. First, how upstream and/or downstream competitions affect the mode choice and forward contract choice is an open question. Second, how the competition between the carrier and the forwarder affects the mode choice and forward contract choice is also an open question.

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Research on the Current Situation of Carbon Emissions and Emission Reduction Measures in Shandong Province

Yandong Li

Abstract With the rapid development of the times, the emission of greenhouse gases around the world is increasing day by day, which also intensifies the degree of the greenhouse effect. As the world's most populous country, China naturally shoulders extremely important responsibilities. Based on the "dual carbon" goals of "carbon neutrality" and "carbon peaking" proposed by General Secretary Xi, this paper selects Shandong Province as the research object, and analyzes the current status of its carbon emissions from the perspective of its economic structure and energy structure. On the basis of systematically analyzing the energy consumption and economic situation of Shandong Province, this paper puts forward the coping strategies of Shandong Province in terms of energy conservation and emission reduction in the future, in order to better implement the national strategic goal of "dual carbon".

Keywords Shandong Province · Dual carbon · Energy structure · Emission reduction measures

1 Introduction

In today's era, with the rapid development of social economy and modern technology, the phenomenon of global warming is becoming more and more serious, and all parts of the world are facing great security challenges. As the world's most populous country, China is naturally the world's largest carbon emitter, and its social responsibility is also extremely crucial. In September 2020, General Secretary Xi Jinping made a clear commitment at the 75th World United Nations General Assembly to strive to achieve the peak of CO_2 emissions in 2030, and achieve the goal of "carbon neutrality" in 2060. At the same time, which will definitely make a significant contribution for the global response to climate change. Based on the era background of modern low-carbon emission reduction, Shandong Province is also faced with the

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era task of carbon emission reduction. How to ensure the stable development of the province's economy while reducing the province's carbon emissions is a problem facing and urgently to be solved at this stage. Therefore, the research on the current situation of carbon emissions in Shandong Province and its influencing factors can provide a certain reference for the designation of emission reduction strategies in Shandong Province.

2 Research Review

2.1 Foreign Research Status

On the whole, foreign scholars have used the Diesel index method (LMDI) earlier to study the influencing factors of China's carbon emissions. Ang (2004) used this method to conduct a corresponding decomposition study on the amount of carbon dioxide emitted by various industrial energy sources in China (Ang 2004). Wu et al. (2005) decomposes China's carbon emissions into four factors through their research, including structural effect, intensity effect, sector-specific activity intensity effect and sector-specific activity scale effect (Wu et al. 2005). Ma and Stem (2008) decomposes the factors affecting my country's carbon emission changes into population scale effects, per capital GDP scale effects, biomass energy substitution effects, and fossil fuel substitution effects with the help of LMDI method (Ma and Stem 2008). Hermawan and Marzuki (2017) estimated the CO_2 emissions at each stage of the construction project supply chain based on the life cycle method, and constructed a carbon footprint model in line with Indonesia's sustainable infrastructure development accordingly (Hermawan et al. 2017).

2.2 Domestic Research Status

Compared with foreign carbon emission research, domestic research focuses more on the collection and analysis of influencing factor data, and then proposes effective emission reduction measures. Yu and Li (2017) analyzed the contribution of five types of energy to industrial carbon emissions in Hubei Province by using SPSS software, and put forward its existing problems and suggestions (Yu and Li 2017). Zhang (2019) studied and predicted the development mechanism of carbon emissions and carbon footprint of the domestic and provincial construction industry based on the carbon emission prediction model (Zhang 2019). Cui et al. (2019) used the ARMA model to estimate the carbon emissions of papermaking enterprises in the next five years, and based on this, they proposed that the impact of mandatory emission reduction measures on the carbon emission intensity of papermaking enterprises would be affected by the mandatory quota system (Cui et al. 2019). Guo and Xu (2020a) pointed out that factors such as population factors, social wealth, and per capital consumption of urban residents would have a positive impact on CO_2 emissions from forest industries based on the regression results of the STIRPAT model (Guo and Xu 2020b).

3 Analysis of Current Situation of Carbon Emissions in Shandong Province

The analysis about the current situation of carbon emissions in Shandong Province is mainly divided into two aspects: economic structure and energy consumption (Qin and Wu 2021; Guo and Xu 2020a).

3.1 Economic Structure of Shandong Province

Since 2010, the industrial structure of Shandong Province has generally stabilized. The contribution rate of the primary industry to the economic growth in the province is basically stable at the level of 3%-5%. The contribution rate of the secondary industry to economic growth has decreased year by year since 2012. In contrast, the contribution rate of the tertiary industry to the economic growth in the province Rising year by year, the highest can reach 76.9%.

According to the changes in the industrial structure of Shandong Province at this stage, it can be preliminarily judged that Shandong Province has gradually entered the middle and late stages of industrialization development, and the proportion of the tertiary industry is significantly higher than that of the secondary industry, indicating that the industrial structure has been gradually optimized (Fig. 1).

Judging from the current state of economic development in Shandong Province, the tertiary industry is developing rapidly. Compared with other European and American countries that have achieved carbon peaks, it still needs to be maintained. Similarly, judging from the data in 2020, the economic contribution rate of the tertiary industry has declined, accounting for only 55.1%. However, when developed countries such as the European Union and the United States achieved their carbon peaks, the added value of their tertiary industries accounted for 63.7% and 73.9% of the national GDP respectively. From this point of view, Shandong province only stayed within this range in 2018 and 2019. Considering that China and European and American countries have different types of industrial structures, it is necessary to actively seek alternative energy sources while maintaining the high-quality development of the industry and other manufacturing industries, and reduce the proportion of the secondary industry's top priority.

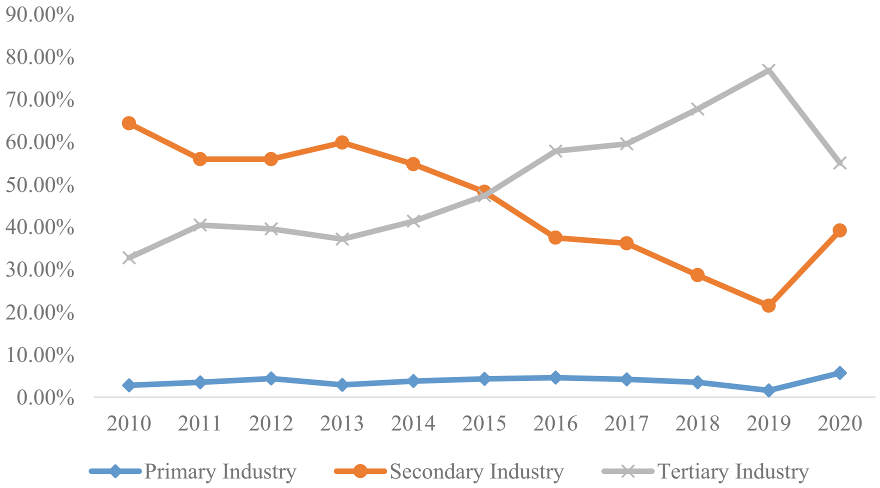

Fig. 1 Contribution rate of three industries to economic growth in Shandong Province from 2010 to 2020

3.2 Energy Consumption in Shandong Province

From the data in the table, it can be seen that from 2011 to 2020, the energy consumption of Shandong Province increased from 312.118 million tons to 418.268 million tons, and the total energy consumption increased by 3.4% on average. In contrast, during this period, the annual GDP of Shandong Province increased from 3,906.493 billion yuan to 7,312.900 billion yuan, with an average annual growth rate of 8.72%. It can be seen that the growth rate of Shandong's GDP is significantly higher than its energy consumption (Table 1).

Based on the data in the above table, it can calculate the energy consumption intensity of Shandong Province in each year, as shown in Fig. 2. It can be seen intuitively from the Fig. 2 that in 2011, the energy consumption per 10,000 yuan of GDP in Shandong Province was 0.799 tons of standard coal. The consumption was 0.636 tons of standard coal, 0.609 tons of standard coal, 0.587 tons of standard coal and 0.572 tons of standard coal. Compared with 2011, the energy consumption intensity per 10,000 yuan of GDP in Shandong Province has dropped by 28.4%, which also reflects from the side that the energy consumption intensity of Shandong Province has been decreasing year by year in the past ten years, and it also shows that the efficiency of energy consumption is increasing.

On this basis, the energy consumption of various industries in Shandong Province from 2015 to 2020 is analyzed, as shown in Fig. 3. Judging from the actual industrial energy consumption, the main energy consumption industries in Shandong Province are concentrated in industry, agriculture, forestry, animal husbandry and fishery, construction, transportation, storage and postal services, wholesale and retail, accommodation and catering, living consumption and other industries. Among them, the

Table 1 Energy consumption and GDP of Shandong Province from 2011 to 2020

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy Consumption(10,000 tons)	31,211.8	32,686.7	34,234.9	35,362.6	39,331.6	40,137.9	40,097.7	40,580.5	41,390.0	41,826.8
GDP(100 million yuan)	39,064.93	42,957.31	47,344.33	50,774.84	55,288.79	58,762.46	63,012.10	66,648.87	70,540.48	73,129.00

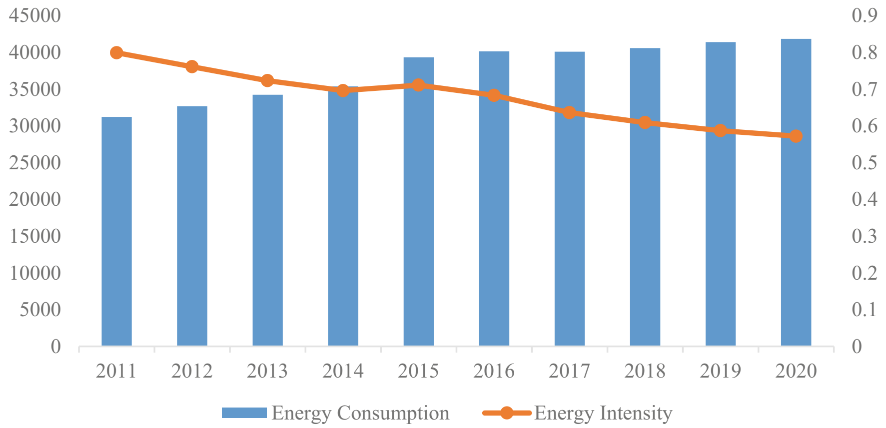

Fig. 2 Total energy consumption and energy intensity of Shandong Province from 2011 to 2020

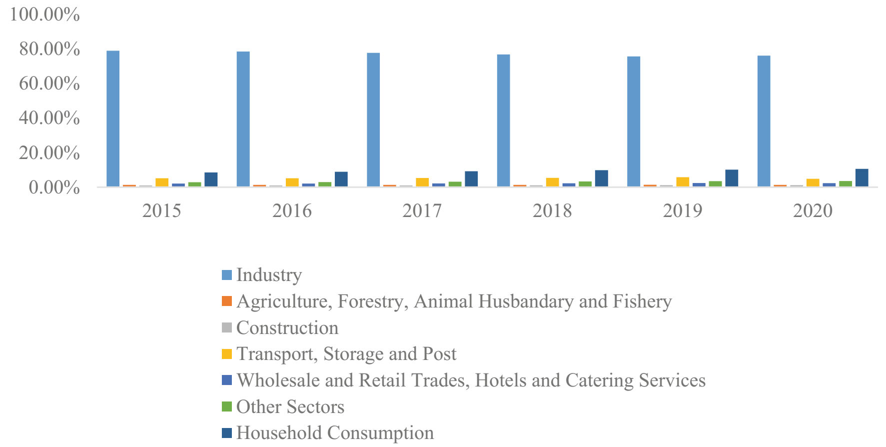

Fig. 3 The proportion of energy consumption in various industries in Shandong Province from 2015 to 2020

proportion of industrial energy consumption has always been far ahead, maintaining at about 76%–78%, followed by living consumption, delivery warehousing and transportation, which accounted for 8% and 5% respectively. The energy consumption of the above three items can account for more than 90% of the province's energy consumption. On the contrary, the energy consumption of wholesale and retail, accommodation and catering, agriculture, forestry, animal husbandry and fishery, construction and other industries is relatively small.

In addition to analyzing the energy consumption status of various industries in Shandong Province, to further understand the current status of carbon emissions in Shandong Province, it is necessary to analyze the total carbon emissions in Shandong

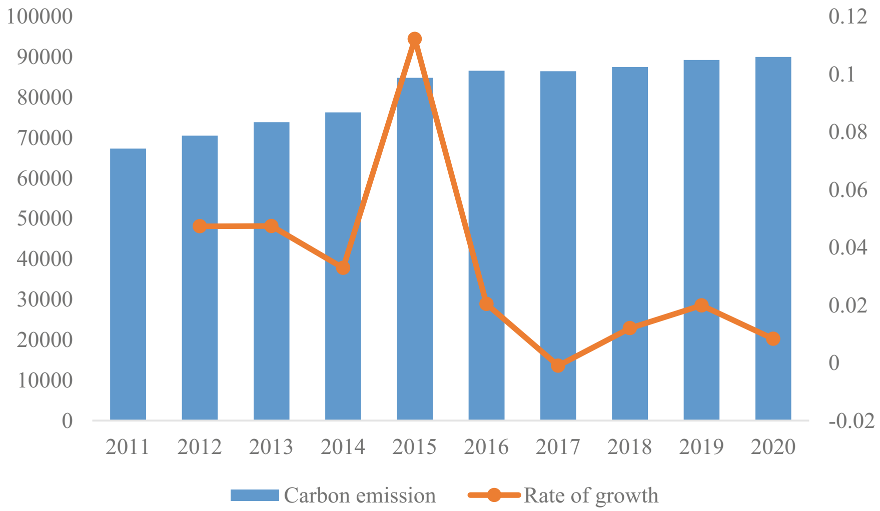

Fig. 4 The total carbon emissions and growth rate of Shandong Province from 2011 to 2020

Province in recent years and its growth rate in each year. The specific situation is shown in the Fig. 4.

From an overall energy perspective, Shandong Province's carbon emissions have the following characteristics:

(1) In recent years, the total carbon emissions in Shandong Province have increased year by year, but the growth has gradually slowed down after 2015. From the point of view of the growth rate of total carbon emissions, it showed a certain fluctuation state. Before 2015, the growth rate weakened year by year, but in 2015 there was another round of peaks. After that, the growth rate remained at a relatively stable level, with little overall fluctuation and change.

(2) The consumption of coal and coal products still occupies an indispensable position in the energy consumption of Shandong Province. Although the proportion has declined in recent years, it still accounts for about 70%. Secondly, the use of energy sources such as natural gas and electricity has an increasing trend year by year. In 2020, natural gas accounted for 5.83% of energy consumption, and electricity accounted for 4.36% of energy consumption, both of which were significantly higher than the proportions in 2015.

4 Shandong Province's Current Emission Reduction Suggestions

4.1 Adjust the Energy Structure Actively

According to the current energy situation in Shandong Province, the scale of renewable energy should be further expanded. At the same time, it should encourage the development of new energy storage technologies, actively promote the use of renewable clean energy such as wind energy, solar energy, water energy and biomass energy, and continuously promote the coordinated and orderly development of clean energy growth and consumption and energy storage technologies. On this basis, actively implement measures such as "coal to gas" and "coal to electricity" to reduce the coal consumption and consumption in the province, so as to realize the effective adjustment of the energy structure of Shandong Province.

4.2 Promote Technological Upgrading Vigorously

For energy conservation and emission reduction in Shandong Province, it is necessary to continuously increase the intensity of technological innovation, use high and new technologies to achieve effective energy conservation and consumption reduction, and gradually accelerate the research and development of low-carbon technologies. At the same time, we are supposed to continue to guide the standardized development of traditional industries dominated by fossil energy. Through active research and development of energy-saving and emission-reduction technologies, the utilization efficiency of energy itself will be improved, and the transformation and upgrading of enterprises will be realized. In addition, continuing to increase the promotion and demonstration of different types of new technologies and processes for energy conservation and carbon reduction can also provide effective reference and reference for the development of related industries (Song 2012; Jiang et al. 2021).

4.3 Focus on Improving Energy Efficiency in the Industry

The transformation and upgrading of energy enterprises will drive the development of emerging strategic enterprises and advanced equipment manufacturing industries, so as to promote the low-carbon transformation of high-energy-consuming enterprises, accelerate the construction of a modern economic system and the optimization of industrial structures, and achieve a industry with green, low-carbon and high quality development.

On the one hand, the government should comprehensively promote the optimization and adjustment of the industrial structure, focus on promoting knowledge-intensive, technology-intensive and productive service industries to become the dominant, play their due leading role, and realize the overall optimization and adjustment of the industrial structure and green and low-carbon transformation. On the other hand, it is also significant to actively promote the improvement of energy efficiency in power generation and terminal fields such as industry and construction, and accelerate the construction of a complete industrial chain of comprehensive energy utilization services, so as to form a green and intensive energy production and consumption model, and continuously promote the quality enhancement of energy in various fields.

4.4 Research and Introduce New Carbon Emission Policies

In order to effectively promote the implementation of carbon emission reduction in Shandong Province, it is necessary to continuously increase financial-related support to promote green and low-carbon development, which can encourage financial institutions to provide some credit services for emission reduction projects in traditional high-carbon industries. The relevant low-carbon emission reduction projects will focus on providing credit support. At the same time, based on the actual development situation in Shandong Province, relevant departments should study and formulate green investment and financing mechanisms that can promote industrial energy conservation and emission reduction, and guide more social funds to help the completion of carbon peaking and carbon neutrality projects. In addition, the carbon emission supervision and environmental protection departments of Shandong Province should also actively compare the relevant national regulations and standards for green products, promote the greening of industrial products and the construction of a standard system, and lay a solid foundation for the implementation of low-carbon emission reduction in the future.

4.5 Attempt to Introduce Carbon Capture and Storage Technology

The capture, storage and utilization technology of CO_2 refers to starting from the source of CO_2 emission and separating the CO_2 contained in it, so as to achieve carbon capture, storage and utilization. Among them, technologies mainly include carbon capture, transmission, storage and utilization, which are also of great benefit to the development of carbon emission reduction in the province (Ma and Cui 2020; Wu and Ma 2022; Wang and Bai 2022).

5 Conclusion

Combining the relevant economic and energy data of Shandong Province in recent years, this paper analyzes the current situation of carbon emissions in Shandong Province from the two aspects of economic structure and energy structure in Shandong Province. Combined with the "dual carbon" goal, it proposes corresponding countermeasures in terms of adjusting the energy structure, promoting technological upgrading, paying attention to energy efficiency improvement and promoting the introduction of policies for the existing problems of economic development and energy consumption in the province in order to improve the future carbon emissions of Shandong Province and achieve the aim of substantial improvement in emissions.

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A Study on the Influencing Factors of Carbon Emissions in Provincial Construction Industry Based on LMDI Model–Taking Shandong Province as an Example

Sun Ruihua and Yang Mengxuan

Abstract This paper takes the construction industry in Shandong Province as the research object and calculates the CO_2 emissions of the construction industry in Shandong Province for 15 years from 2005 to 2019 by using the IPCC carbon emission factor method, and analyzes the factors influencing the carbon emissions of the construction industry in Shandong Province from five aspects, such as carbon emission intensity, energy consumption structure, energy intensity, economic level, and population scale, by Logarithmic mean Divisia index (LMDI) decomposition method. The analysis result indicates that energy intensity and economic level are the critical factors influencing the change in carbon emission in Shandong Province's construction industry. Among them, the economic level is the major factor that promotes the positive growth of carbon emissions in Shandong Province's construction industry, with a contribution rate of 2329.39% of the total effect; energy intensity is an important factor that suppresses carbon emissions in Shandong Province's construction industry, with a contribution rate of −2739.81%.

Keywords Construction industry in Shandong Province · Carbon emission · LMDI model · Impact factor

1 Introduction

With the development of economic globalization, climate warming and environmental pollution have become issues of concern all over the world, and the high emission of CO_2 is the root cause of these problems. According to the latest data released by the International Energy Agency (IEA), the global energy sector CO_2 emissions in 2021 set a new history-breaking record, rising by 6% compared to 2020,

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with a total of 36.3 billion tons. Among them, China's CO_2 emissions exceed 11.9 billion tons, accounting for 33% of global CO_2 emissions [1]. At the 75th United Nations Conference held on September 22, 2020, General Secretary Xi Jinping put forward the "carbon peaking and carbon neutrality" goals, which are to strive to peak China's CO_2 emissions by 2030, and achieve "carbon neutrality" by 2060 [2]. The construction industry, as one of the three major sectors of global energy consumption and CO_2 emissions, will largely determine whether China will achieve "carbon neutrality" by 2060.

As a strong economic province and a large population province, Shandong Province, the gross value of the construction industry has been increasing year by year, and the total construction output value of the province reached 149.4730 billion CNY by 2020, a year-on-year increase of 4.75%. However, with the steady and rapid development of the construction economy, the energy consumption and greenhouse gas emissions of the construction industry in Shandong Province are also increasing. According to the latest data released by the National Bureau of Statistics, the total energy consumption of Shandong Province is as high as 423.9 million tons of standard coal, the first in the country, and the total emissions of major pollutants 193.3 million tons, ranking third in the country. In this regard, under the condition of stable economic growth, it is of great significance to study and analyze the carbon emission of the construction industry in Shandong province and identify the factors that affect the carbon emission of the construction industry scientifically and effectively to solve the ecological environment problems in Shandong province and achieve the goal of "carbon neutrality".

2 Literature Review

In recent years, as the importance of the construction industry in the field of energy-saving and emission reduction has been highlighted, the factors influencing carbon emission in the construction industry have become a research hotspot for scholars at home and abroad. However, most of the studies have been gathered from the macro perspective, and only a few scholars have focused on the study of carbon emission impact factors in specific regions.

The research scope of carbon emission influencing factors is divided into two categories: national and local. Shan decomposed the influencing factors of carbon emission changes in China from 2000–2017 based on Kaya's constant equation and LMDI model, and regressed them using the STIRPAT model [3]; Li decomposed the driving factors of carbon emission in China from 2001–2016 based on LMDI method, and obtained the structural effect, technological effect, economic effect[4]; Liu et al. used the STIRPAT model to quantitatively analyze the carbon emission impact factors of public and residential buildings in Guangzhou from 2006–2014 [5]; Jiang et al. focused on the study of the impact factors of the construction industry in Jiangsu Province, and used the LMDI model to decompose the carbon emission changes of the construction industry in Jiangsu Province from 2011–2017 [6]. A review of a large amount of relevant literature reveals that domestic research on the influencing factors of carbon emissions in the construction industry is mainly focused on the national level, but there is still a lot of research space to extend to specific provinces, except for Gansu [7] and Liaoning [8] where the research is relatively well developed. In addition, the current research on the influencing factors of carbon emissions in Shandong Province mainly focuses on the transportation industry [9], coal industry [10], agriculture [11] and other fields, and the research involving the construction industry is still insufficient.

Although scholars abroad and at home have studied the factors influencing carbon emissions in the construction industry, most of the studies are at the national macro level, the provincial studies are not mature, and the studies focusing on the construction industry in Shandong Province are still a vacancy. Therefore, this article takes the construction industry in Shandong Province as the starting point, and decomposes the carbon emissions of the construction industry in Shandong Province from 2005 to 2019 based on the LMDI decomposition method, to explore the focus of energy saving and emission reduction in the construction industry in Shandong Province, and provide a practical reference for China to achieve the goal of “carbon peaking and carbon neutrality”.

3 Analysis of Current Situation

As shown in Table 1, the overall energy consumption of the construction industry in Shandong Province shows a fluctuating trend, and the energy consumption in the four years from 2005 to 2008 was basically flat; In the four years from 2009 to 2011, the construction industry in Shandong Province was in a time of high-speed development, and the consumption of traditional energy sources such as coal and diesel reached a new high, peaking at 7.896 million tons of standard coal in 2011; after the 18th National Congress of the Communist Party of China, Shandong Province has stepped up efforts in energy conservation and environmental protection, so the energy consumption has fallen off a cliff in 2013–2014, although energy consumption has grown after 2016, there is still a big gap with the peak (Fig. 1). From the perspective of the proportion of energy consumption, the overall trend is more obvious. Except for the increase in the proportion in 2008, the proportion of energy consumption in the construction industry in Shandong Province showed a downward trend in the whole country, and in 2019 compared with 2005, it decreased by 10.69% (Fig. 2).

Table 1 The energy consumptions ratio of the construction industry in Shandong Province from 2005 to 2019

Year	Total energy consumption in Shandong Province	Total energy consumption of The construction industry in China	Proportion (%)
2005	556.2	3486	15.96
2006	547.8	3836	14.28
2007	554.0	4203	13.18
2008	563.0	3874	14.53
2009	665.0	4712	14.11
2010	725.8	5533	13.12
2011	789.6	6052	13.05
2012	715.6	6337	11.29
2013	755.4	7017	10.77
2014	470.2	7377	6.37
2015	416.4	7545	5.52
2016	426.8	7847	5.44
2017	430.0	8243	5.22
2018	437.3	8685	5.04
2019	481.4	9142	5.27

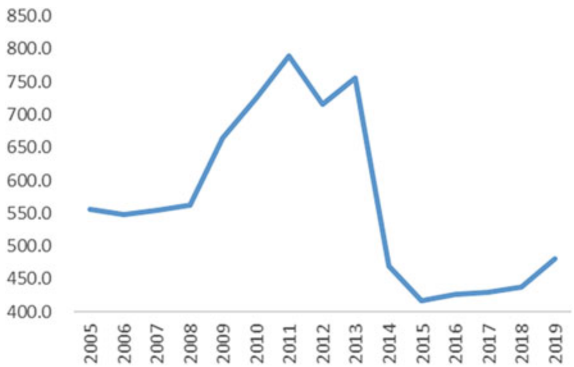

Fig. 1 Total energy consumption of the construction industry in Shandong Province from 2005 to 2019

4 Methodology

4.1 IPCC Carbon Emission Measurement Model

This paper uses the IPCC emission coefficient method to measure the carbon emissions of the construction industry in Shandong Province, which was proposed in the first "Guidelines for National Greenhouse Gas Inventories" issued by IPCC in 1996. Because of its simple, easy-to-understand, and high practicability, it is widely used to

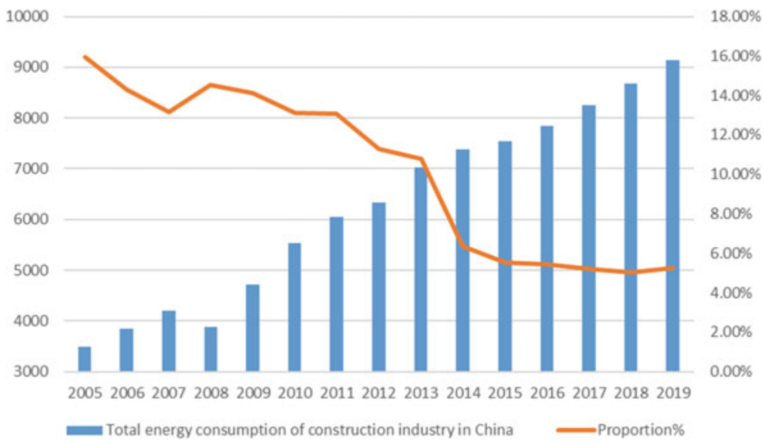

Fig. 2 Proportion of building energy consumption in Shandong Province from 2005 to 2019

calculate building carbon emissions [12]. The following models are used to measure the carbon emissions of buildings.

$$N = \sum_i C_i \times \alpha_i \tag{1}$$

$$C_i = c_i \times \beta_i \tag{2}$$

In formula (1), N represents the total amount of carbon emissions from buildings; C_i represents the consumption of various energy sources after converting to standard coal (10,000 tons); α_i represents the carbon emission coefficient of various energy sources (t carbon/t standard coal)). In formula (2), c_i represents the consumption of various energy sources before conversion (10,000 tons); β_i represents the standard coal coefficient of various energy conversions.

4.2 Decomposition Models

The LMDI decomposition method was proposed by Ang [13], which has the characteristics of adequate decomposition, ease to use, and wide range of use, and its biggest advantage is that it does not produce residual problems and allows the data to contain zero values. Therefore, the article adopts the "summation decomposition" form of the LMDI decomposition method to quantitatively analyze the factors influencing carbon emissions in the construction industry of Shandong Province, which combines the LMDI decomposition model with Kaya's constant equation proposed by Yoichi Kaya at the IPCC workshop, which relates CO_2 emissions to energy, economy, and population with the following equation.

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times P \tag{3}$$

In the article, the kaya constant is further extended to five influencing factors with the following equation.

$$E = \sum_i E_i = \sum_i \frac{E_i}{F_i} \times \frac{F_i}{Z} \times \frac{Z}{G} \times \frac{G}{P} \times P \tag{4}$$

In formula (4), E represents the total amount of carbon emissions from buildings in Shandong Province; i represents the type of energy (1–9 represent raw coal, coking coal, gasoline, kerosene, diesel, fuel oil, liquid petroleum gas, natural gas, and electricity, respectively); E_i represents the carbon emissions of the energy (10,000 tons); F_i represents the energy consumption (10,000 tons of standard coal); Z represents the total energy consumption of Shandong's construction industry (10,000 tons of standard coal); G Indicates the total production value of the construction industry in Shandong Province (100 million CNY); P represents the total population of Shandong Province (10,000 people).

In order to facilitate the calculation, let B $= \frac{E_i}{F_i}$ represent the carbon emission intensity of the energy source, that is, the carbon emission coefficient;

D $= \frac{i}{Z}$ represents the proportion of the energy consumption, that is, the energy consumption structure;

K $= \frac{Z}{G}$ represents the energy consumption per unit of construction GDP in Shandong Province, that is, energy intensity;

L $= \frac{G}{P}$ means GDP per capita, that is, the economic level;

So formula (4) can be written as

$$\mathrm{E} = \mathrm{K} \times \mathrm{L} \times \sum (B_i \times D_i) \times P \tag{5}$$

From formula (5), the article decomposes the influencing factors of carbon emission in the construction industry of Shandong province into 5 factors: carbon emission intensity, energy intensity, energy consumption structure, economic level, and population size.

Then the LMDI index method is used to decompose the carbon emission factors in Shandong Province, and the above five individual impact indicators are used to quantitatively analyze the degree of impact through the "additive form".

$$\begin{aligned} \Delta \mathrm{E} = E_t - E_0 &= \frac{E_t - E_0}{lnE_t - lnE_0} \times (lnE_t - lnE_0) \\ &= \Delta E_B + \Delta E_D + \Delta E_K + \Delta E_L + \Delta E_P \end{aligned} \tag{6}$$

ΔE represents the change in the target year T CO_2 emissions compared to the base year 0, ΔE_B, ΔE_P, ΔE_D, ΔE_K, ΔE_L represent the carbon emission coefficient factor, energy consumption structure factor, energy intensity factor, economic level factor, population size factor, and the formula for calculating the contribution value of each impact factor are:

$$\Delta E_B = \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \ln\left(\frac{B_{iT}}{B_{i0}}\right) \tag{7}$$

$$\Delta E_D = \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \ln(\frac{D_{iT}}{D_{i0}}) \tag{8}$$

$$\Delta E_K = \ln\left(\frac{K_T}{K_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{9}$$

$$\Delta E_L = \ln\left(\frac{L_T}{L_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{10}$$

$$\Delta E_P = \ln\left(\frac{P_T}{P_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{11}$$

Because the carbon emission coefficients of various building energy sources are fixed values, ΔE_B is 0, so the final calculation formula is as follows:

$$\Delta \mathrm{E} = E_t - E_0 = \Delta E_D + \Delta E_K + \Delta E_L + \Delta E_P \tag{12}$$

5 Results and Discussion

Based on the LMDI decomposition model, according to formulas (4)–(12), it can be obtained that the energy consumption structure effect E_D, the energy intensity effect E_K, the economic level effect E_L of the construction industry, and the population scale effect E_P in each stage from 2005 to 2019 the construction sector in Shandong Province Contribution to carbon emissions (Table 2).

5.1 Overall Effect

As shown in Table 2, if the contribution rate is >0, it means that the impact factor has a promoting effect on the positive change of carbon emissions, that is, the increase; if the contribution rate is less than 0, it means that the impact factor has an inhibitory effect on the increase of carbon emissions.

It can be seen that from 2005 to 2019, the overall carbon emissions of the construction industry in Shandong Province increased by 283,100 tons, with an average annual

Table 2 LMDI decomposition results of CO_2 emission change in the Shandong construction industry

	ΔEd	ΔEk	ΔEl	ΔEp	ΔE
2005–2006	26.03	−36.10	29.65	1.95	21.52
2006–2007	−11.00	−58.65	60.59	2.39	−6.67
2007–2008	−53.75	−48.73	52.50	1.86	−48.11
2008–2009	6.58	−3.28	62.78	2.08	68.15
2009–2010	−2.75	−40.12	72.20	4.83	34.16
2010–2011	6.29	−37.31	72.10	4.13	45.21
2011–2012	−31.19	−93.35	48.60	1.93	−74.00
2012–2013	−8.15	−38.81	58.93	1.57	13.54
2013–2014	228.59	−247.84	38.69	2.76	22.20
2014–2015	41.13	−56.57	0.47	2.60	−12.37
2015–2016	−2.84	−21.02	27.07	4.70	7.92
2016–2017	−3.19	−51.65	52.28	2.55	−0.01
2017–2018	−65.98	−40.32	45.35	1.77	−59.18
2018–2019	−21.50	−1.92	38.27	1.12	15.97
Average	7.73	−55.40	47.11	2.59	2.02
Total	108.29	−775.67	659.47	36.22	28.31
Contribution rate (%)	382.50	−2739.81	2329.39	127.92	100.00

increase of 20,200 tons. Among them, only the impact factor of energy intensity has an inhibitory effect on the increase of carbon emissions, which reduces the overall carbon emissions by 775.67 tons, an average annual reduction of 554,000 tons, and the contribution rate is as high as −2739.81%.

The other three influencing factors—poor energy consumption structure, improved economic level, and population growth—have contributed to the increase in carbon emissions, resulting in an overall increase of 8,039,800 tons of carbon emissions, with an average annual increase of 574,300 tons. In detail, the contributions of these three factors are far from each other: the economic level factor leads to an increase of 6,594,700 tons of carbon emissions, accounting for 2,329.39% of the total effect, becoming the main factor promoting the increase in carbon emissions; energy consumption structure The factor promotes an increase of 1.0829 million tons of carbon emissions, accounting for 382.50% of the total effect. The population scale factor leads to an increase of 362,200 tons of carbon emissions, an average annual increase of 25,900 tons, and the lowest contribution is only 9.32%.

5.2 The Effect of Energy Consumption Structure

According to formula (8), the specific energy consumption structure contribution value of various energy sources is calculated (Table 3). From Table 3, it can be seen that the overall effect of the energy consumption structure from 2005 to 2019 led to an increase of 1.0829 million tons of carbon emissions from the construction industry in Shandong Province. Among them, coke, kerosene, diesel, fuel oil, natural gas, and electricity are the positive factors for the increase of carbon emissions in the construction industry, and raw coal, gasoline, and liquefied gas are the negative factors for the increase of carbon emissions. It can be seen from Fig. 3 that diesel and raw coal have relatively prominent effects on the increase and decrease of carbon emissions, but their effects on the direction of carbon emissions change are positive and negative, and the contributions of the two are basically offset. Therefore, the impact of the energy consumption structure effect on the changes in carbon emissions of the construction industry in Shandong Province is not obvious.

5.3 The Effect of Energy Intensity

According to formula (9), the specific energy intensity contribution values of various energy sources are calculated (Table 4). From Table 4, it can be seen that from 2005 to 2019, the energy intensity effect inhibited the positive growth of carbon emissions from the construction industry in Shandong Province, and the overall reduction was 7.7567 million tons. It can be clearly seen from Fig. 4 that the energy intensity data in Shandong are all negative values, which further indicates that the energy intensity effect promotes the negative change in carbon emissions in the construction industry, but the change is not in a linear form, but fluctuates in stages. For example, the inhibitory effect of energy intensity on carbon emission reduction in 2012–2013 was smaller than that in the previous year, and the energy intensity in 2013–2014 had the largest inhibitory effect on carbon emissions in the construction industry in 15 years. The main reason for this phenomenon is that during the 10 years from 2003 to 2012, the economic construction of Shandong Province has developed vigorously, and energy consumption has entered the fastest growing stage. In 2012, the total energy consumption of Shandong Province was as high as 337.901 million tons of standard coal, ranking first in the country [14]. Since 2013, Shandong Province has implemented the concept of "Clear waters and green mountains are as good as mountains of gold and silver", the growth momentum of coal consumption has gradually slowed down, and the growth rate of energy consumption in the province has dropped significantly. Overall, the energy intensity effect is the most important factor restraining the growth of carbon emissions from the construction industry in Shandong Province.

Table 3 Calculation results of energy structure effect from 2005 to 2019

	Raw coal	Coke	Petrol	Kerosene	Diesel oil	Fuel oil	Liquid gas	Natural gas	Electricity	Total
2005–2006	2.66	0	0	0	21.45	0	0.98	0	0.94	26.03
2006–2007	−4.21	0	−0.1	0	1.75	0	−9.14	0	0.71	−11
2007–2008	29.94	0	−29.55	0.36	−71.32	11.6	3.56	0.08	1.59	−53.75
2008–2009	−11.34	0	2.67	0	16.31	−1.06	−0.01	0.01	−0.01	6.58
2009–2010	−9.18	0	0.58	0	4.99	−0.49	0.04	0	1.31	−2.75
2010–2011	−1.37	0	−1.76	0.01	8.1	−0.24	0.07	0.02	1.46	6.29
2011–2012	−31.11	0	−43.65	−0.4	56.77	−14.09	−1.74	0	3.03	−31.19
2012–2013	−63.46	0.64	31.22	1.12	4.14	17.12	0.3	0.04	0.73	−8.15
2013–2014	17.14	1.34	34.56	0.64	152.52	8.73	2.16	0.12	11.39	228.59
2014–2015	−0.97	−0.02	4.56	0	35.02	0.99	−0.66	0	2.22	41.13
2015–2016	−1.77	−1.31	0.32	−0.16	1.48	−0.27	−2.82	0.05	1.65	−2.84
2016–2017	−14.24	0	2.45	0.26	6.8	0	0	0.02	1.51	−3.19
2017–2018	−11.77	0	−18.3	23.66	−58.95	−3.42	0.43	−0.03	2.41	−65.98
2018–2019	−1.63	0	−4.27	−3.04	−14.09	−1.12	0.06	0.03	2.56	−21.5
Total	−101.3	0.65	−21.28	22.45	164.97	17.74	−6.76	0.33	31.49	108.29

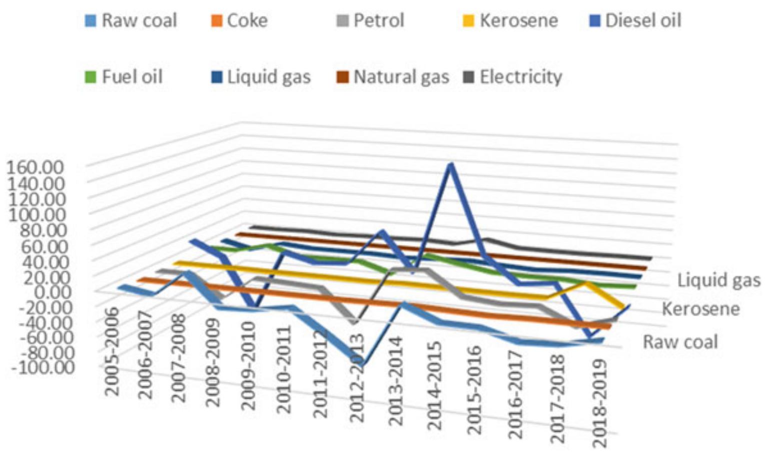

Fig. 3 A 2005–2019 energy consumption structure effect

5.4 The Effect of Economic Level

From Table 2, it can be seen that from 2005 to 2019, the economic horizontal structural effect has promoted a total of 6.5947 million tons of carbon emissions from the construction industry in Shandong Province. It can be seen from Fig. 5 that the contribution value of the economic level effect is all greater than 0, but the effect of this effect on the positive change of carbon emissions in the construction industry also fluctuates irregularly. Among them, the years with large fluctuations were 2005–2006, 2008–2009, 2014–2015,and 2015–2016; the effect of economic level effect on carbon emission reduction in 2013–2015 decreased year by year, and the contribution value as of 2015 reach the minimum is 0.47 million tons. Nevertheless, the economic level effect is still the main factor driving the growth of carbon emissions from the construction industry in Shandong.

5.5 The Effect of Population Size

The population scale effect is directly dependent on population growth. Table 2 visually shows that the population of Shandong Province increased from 92.48 million to 101.06 million from 2005 to 2019, the population scale effect increased the carbon emissions of the construction industry in Shandong Province by 362,200 tons, proving that carbon emissions The amount will increase as the population increases. It can be seen from Fig. 6 that, compared with other influencing factors, the effect of population size on the positive change of carbon emissions in the construction industry is relatively stable, with small changes, and a relatively low contribution rate.

Table 4 Calculation results of energy intensity effect from 2005 to 2019

	Raw coal	Coke	Petrol	Kerosene	Diesel oil	Fuel oil	Liquid gas	Natural gas	Electricity	Total
2005–2006	−10.41	0.00	0.00	0.00	−23.67	0.00	−1.06	0.00	−0.96	−36.10
2006–2007	−12.89	0.00	−13.07	0.00	−31.37	0.00	0.00	0.00	−1.32	−58.65
2007–2008	−13.62	0.00	−9.89	0.00	−23.83	0.00	0.00	0.00	−1.38	−48.73
2008–2009	−1.05	0.00	−0.57	0.00	−1.42	−0.11	−0.03	0.00	−0.10	−3.28
2009–2010	−11.75	0.00	−7.09	0.00	−18.31	−1.22	−0.42	0.00	−1.33	−40.12
2010–2011	−10.42	0.00	−6.51	−0.03	−17.49	−1.10	−0.39	−0.01	−1.35	−37.31
2011–2012	−23.92	0.00	−11.80	0.00	−52.76	0.00	−0.85	0.00	−4.02	−93.35
2012–2013	−5.45	0.00	−4.75	0.00	−26.32	0.00	−0.31	−0.01	−1.96	−38.81
2013–2014	−18.36	−0.57	−39.23	−0.66	−164.56	−9.89	−2.09	−0.11	−12.36	−247.84
2014–2015	−3.95	−0.18	−8.73	−0.15	−38.08	−2.19	−0.43	−0.02	−2.83	−56.57
2015–2016	−1.35	0.00	−3.24	−0.05	−14.47	−0.80	0.00	−0.01	−1.10	−21.02
2016–2017	−2.37	0.00	−8.47	−0.13	−37.63	0.00	0.00	−0.03	−3.02	−51.65
2017–2018	−0.56	0.00	−6.20	−0.78	−28.55	−1.50	0.00	−0.02	−2.71	−40.32
2018–2019	0.00	0.00	−0.27	−0.12	−1.31	−0.07	0.00	0.00	−0.15	−1.92
Total	−116.10	−0.75	−119.82	−1.92	−479.77	−16.88	−5.58	−0.23	−34.62	−775.67

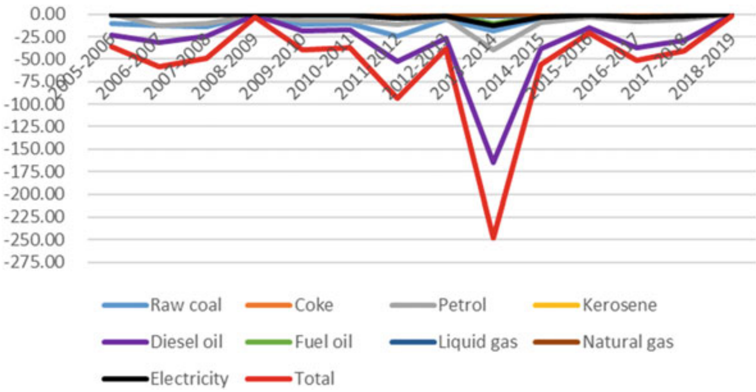

Fig. 4 The effect of energy efficiency on carbon emissions of the construction industry in Shandong Province from 2005 to 2019

Fig. 5 The effect of economic level on carbon emissions of the construction industry in Shandong Province from 2005 to 2019

6 Conclusion

This paper uses the LMDI decomposition method to decompose the factors affecting the carbon emissions of the construction industry in Shandong Province, and draws the following conclusions:

Energy consumption structure, economic level and population size are the driving factors for the increase in carbon emissions from the construction industry in Shandong. Among them, the economic level is the key factor to promote the positive increase of carbon emissions in the construction industry in Shandong, and its contribution value is as high as 6.5947 million tons, with a contribution rate of 2329.39%; the contribution of energy consumption structure to carbon emissions ranks second, with a contribution rate of 382.50%; The population size factor has the least driving

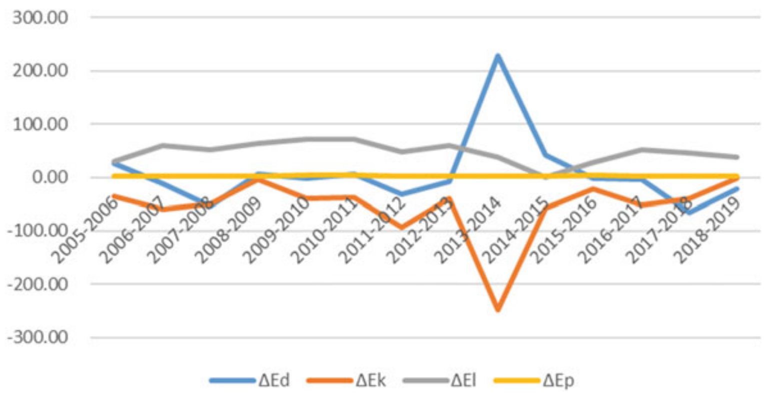

Fig. 6 The effect of various influencing factors on the carbon emissions of the construction industry in Shandong Province from 2005 to 2019

effect on the growth of carbon emissions, with a contribution value of only 362,200 tons, accounting for 127.92% of the total effect; (2) Energy intensity is the most important factor in restraining carbon emissions from the construction industry in Shandong. From 2005 to 2019, with the improvement of energy utilization rate and the advancement of energy conservation and emission reduction technologies, the energy intensity continued to decrease, and the macroscopically promoted carbon emission reduction of 7.7567 million tons, with a contribution rate of 2739.81%.

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Research on Technology Evolution Trend of Petrochemical Industry Based on Patent Perspective

Huang Changsheng and Wang Wenjie

Abstract In order to clarify the technology development trend in the domestic petrochemical field and promote the transformation, upgrading and high-quality development of the petrochemical industry, the study starts from the perspective of technology theme evolution, uses the incoPat patent search platform to obtain the relevant patent information of the petrochemical industry in the past ten years, conducts comprehensive mining of the themes in the petrochemical technology field in China with the help of LDA model, and after considering the dynamic evolution process of theme intensity and theme content, distills the development characteristics and future development trend of petrochemical industry. Research shows that: China's petrochemical industry technology research is mostly concentrated in the three major fields of oil extraction, refining and chemical, and oil pipelines. In the past decade, the petrochemical industry has shown the development trend of intelligence, automation and greening. In the future, China will enter a new era of intelligent petrochemicals and green petrochemicals based on the needs of high-quality development goals.

Keywords Petrochemicals · LDA topic model · Patent information · Technology evolution

1 Introduction

As an important pillar industry of China's national economy, the petrochemical industry, after decades of development, has built a modern industrial system with complete categories, advanced technology, supporting varieties and strong competitiveness, becoming one of the world's major petrochemical countries [1]. At present,

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China's economy has shifted from a high-speed growth stage to a high-quality development stage, the manufacturing industry needs to eliminate backward production capacity, improve the added value of products, the quantitative advantage into a quality advantage [2]. As an important part of the manufacturing industry, the petrochemical industry is undoubtedly needed to promote the high quality development of China's economy. At the same time, the emergence of the "emission peak and carbon neutrality" target has also put forward relevant requirements for petrochemicals, a high energy-consuming and high-emission industry [3]. The petrochemical industry needs to reduce excess capacity, reduce carbon emissions and reduce pollution on the one hand; on the other hand, it needs to start with technological innovation to achieve technological breakthroughs and find the direction of transformation.

At present, China's petrochemical industry is "big but not strong" dilemma, the overall in the global industrial chain and the low end of the value chain, there are a large number of low-technology level of backward production capacity [4]. Facing the dual pressure at home and abroad, the petrochemical industry needs to make breakthroughs at the technological level, clarify the trend of technological evolution, narrow the technological gap with petrochemical powerhouses, and achieve high-quality development of the petrochemical industry.

From the research on the technological development of the petrochemical industry, the existing research mostly focuses on the development of a certain field, and lacks the sorting out of the technological development of the whole industry. By analyzing the basic situation of oil pipelines in China, Qiuyang et al. [5] argue that the development of oil and gas pipeline networks in China still faces many problems, such as the layout structure of pipeline networks needs reasonable adjustment, the scale of pipeline networks cannot meet the actual domestic demand, and the system of pipeline networks restricts the current development, which requires further accelerating the construction related to oil and gas pipeline networks. Baoping [6] believes that the development of China's petrochemical engineering technology and equipment has made great progress, but there is still a large gap with the foreign advanced level, the need to increase research and development efforts to complete the breakthrough of key core technologies. Gensheng et al. [7] analyzed the development status of key technologies for intelligent drilling at home and abroad, and concluded that along with the rapid development of artificial intelligence technology in China, the field of drilling engineering needs to strengthen the integration with frontier theories and technologies represented by artificial intelligence, enhance multi-disciplinary collaborative innovation, and gradually build an intelligent drilling theory system and technology system. Youhao [8] has sorted out the development history of catalytic cracking process technology in China and made an outlook on the future development of this technology field.

From the perspective of patent research in the petrochemical industry, most of the existing researches have made simple statistics on the current situation and posture of petrochemical technology development by means of patent quantity statistics, patent applicants, IPC classification, etc., and lack further in-depth research. Although some of the studies can show certain development trends, they are generally macroscopic overviews, and the details about the development of petrochemical technologies are not well presented. By analyzing the patent results from 1985–2014, Lei et al. [9]. identified the technological research hotspots and the evolutionary direction of technological inventions in China's petroleum industry. Huiqun et al. [10] analyzed the patents of refining and chemical enterprises from four aspects: the trend of patent application and authorization, the characteristics of patent geographical distribution, the distribution of patent technology fields and patent intensity, and gave suggestions for the implementation of development strategies of refining and chemical enterprises by using patent information. Xiaoyan et al. [11] analyzed the current situation of CNPC's invention patents, pointing out that although CNPC is gradually increasing in the number of patents, the technology is relatively single and needs to strengthen the top-level design and strategic planning at the technology level in the future.

In view of the above shortcomings of practical and theoretical research, and the need for high-quality development of petrochemical industry in the context of new technological revolution, this study tries to introduce LDA model to identify the hidden theme information behind the patent data from the theme perspective, and use the patent text data to explore the evolution of petrochemical technology, analyze the changes in its evolution intensity and content, so as to refine the characteristics and future development direction of petrochemical industry technology development, provide inspiration and reference for promoting the high-quality development of petrochemical industry, and make up for the shortcomings of previous studies.

2 Research Methodology and Framework

2.1 LDA Topic Probability Model

LDA (Latent Dirichlet Allocation) model is a document topic (topic) generation model proposed by Blei et al. [12] in 2003, which is an unsupervised machine learning technique to achieve topic and vocabulary generation in documents with a three-layer Bayesian structure of text-topic-word, and can be effective for identifying topic information in large scale corpora [13]. Facing the petrochemical patent text with huge amount of data, this study adopts LDA model to analyze and combine with computer language to realize the theme modeling analysis of patent titles and abstracts, so as to achieve the purpose of mining the petrochemical industry technology theme in a more detailed way, and also to visualize the trend of petrochemical industry technology evolution and reveal the direction of petrochemical industry technology evolution. The LDA model uses the bag-of-words method to transform documents into word frequency vectors, after which documents are represented as a number of topics and composed with different probabilities, and topics are represented as a number of words composed with different probabilities, resulting in a document-topic matrix and a topic-word matrix [14]. The specific mathematization of the LDA model is described as follows.

(1) For each document based on d ∈ D, the polynomial distribution parameter θ_d of topics on document d is obtained according to $\theta_d \sim Dir(\alpha)$.
(2) For each topic z ∈ K, the polynomial distribution parameter φ_z of the vocabulary on topic z is obtained according to $\varphi_z \sim Dir(\beta)$.
(3) For the vocabulary $w_{d,j}$ in document d, the topic $Z_{d,j}$ is obtained according to the multinomial distribution $Z_{d,j} \sim Mult(\varphi_z)$, and the vocabulary $w_{d,j}$ is obtained according to the multinomial distribution $w_{d,j} \sim Mult(\varphi_z)$.

The parameters θ and φ cannot be obtained directly in the LDA model, so the parameter values are generally inferred by estimation methods, and the commonly used methods are Laplace approximation, Variational Inference, Gibbs sampling algorithm and Expectation Propagation. Among them, Gibbs sampling algorithm is simple to implement, fast to compute, and widely used in LDA probability generation model, so this paper adopts this method for parameter estimation [15]. The process of theme evolution analysis is shown in Fig. 1.

2.2 Research Framework

The purpose of this paper is to identify the technology themes in petrochemical industry and reveal their dynamic evolution process with the help of LDA theme model, so as to further refine the technology development characteristics and future development direction of petrochemical industry. The research covers the collection and pre-processing of patent data in the petrochemical industry, the presentation of technology theme mining and evolution results in the petrochemical industry, and the prediction of technology development trends in the petrochemical industry in China.

One of the core calculation steps is shown below.

(1) Determining the optimal number of topics. In LDA model training, whether the topic parameter K can be determined scientifically and accurately is the key of the study. In this paper, a combination of the evaluation function Perplexity [16] and manual screening [17] is used to determine the optimal number of topics, and the optimal number of topics is finally obtained as 30. The perplexity formula is shown in Eq. (1), where D_{test} is the test set; D is the number of texts; W_d is the sequence of observable words in document d; N_d is the number of words in document d [18].

$$\text{perplexity}(D_{test}) = exp\left\{-\frac{\sum_{d=1}^{D} logp(w_d)}{\sum_{d=1}^{D} N_d}\right\} \quad (1)$$

(2) Topic intensity metric. As an attribute of the topic itself, the topic intensity can express the degree of attention of petrochemical technology in the corresponding time period. The greater the intensity of the topic, the higher the degree

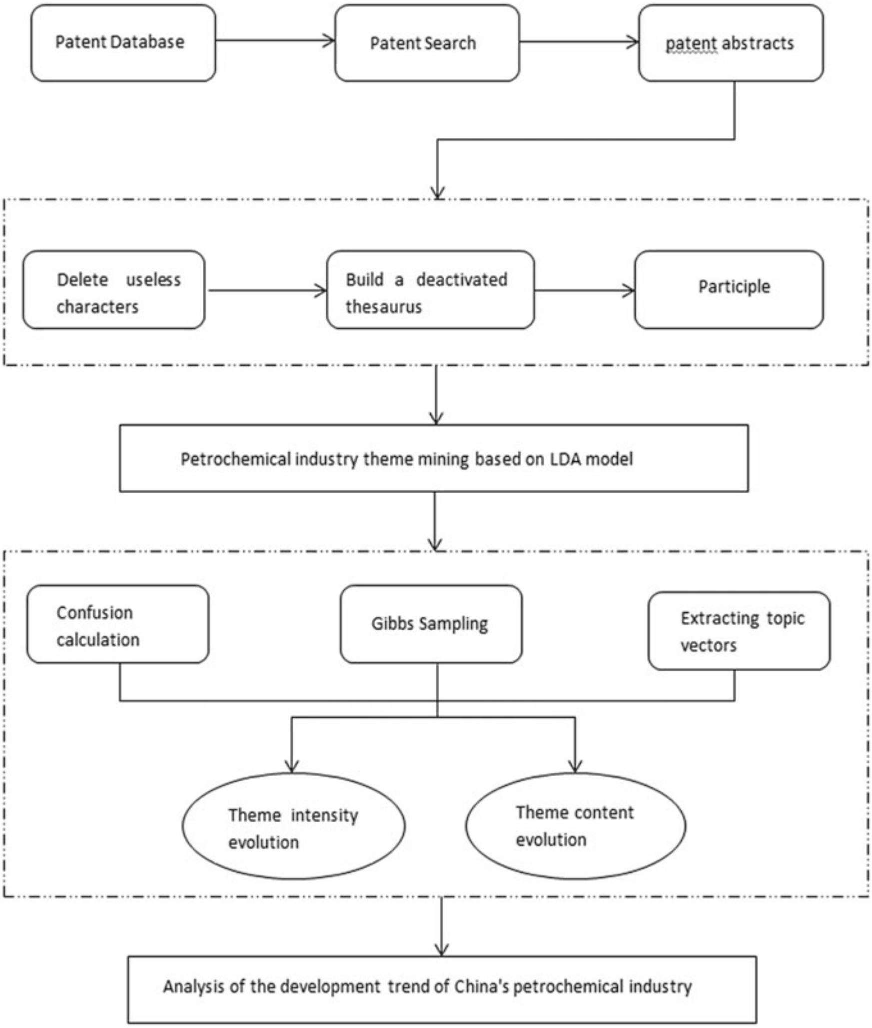


Fig. 1 Process for analyzing the evolution of technology themes in the petrochemical industry

of attention in the corresponding time period [19]. Therefore, the trend of hot technologies can be grasped by analyzing the change of petrochemical technology theme intensity on the time axis. The specific formula of topic intensity is shown in Eq. (2), where $Q(Z_{t,k})$ is the intensity of topic k in the current time slice t; $\theta_{d,k}$ is the probability of the k th topic in the d th patent document; D_t is the number of patents on time slice t [20].

$$Q(Z_{t,k}) = \frac{\sum_{d=1}^{D_t} \theta_{d,k}}{D_t} \tag{2}$$

(3) Topic similarity measure. Topic content evolution reflects the content change of a topic in each time period, and the results need to be obtained by filtering similar topics in the time slice sequence, and then analyzing the evolution of textual topic content [21]. In this paper, the cosine similarity is used to measure the topic similarity. The mathematical meaning of cosine similarity is the cosine of the angle between two vectors, and the maximum value of cosine is 1 when the angle between two vectors is 0, 0 when the angle between two vectors is 90 degrees, and the minimum value of cosine is −1 when the direction of two vectors is exactly opposite. The specific formula for calculating the theme similarity is shown in Eq. (3), where $\underset{A_i}{\rightarrow}$ and $\underset{B_i}{\rightarrow}$ denote each component A_i and B_i of vectors $\underset{A}{\rightarrow}$ and $\underset{B}{\rightarrow}$ [22].

$$\text{Similarity} = \cos(\theta) = \frac{\underset{A}{\rightarrow} \cdot \underset{B}{\rightarrow}}{\| \underset{A}{\rightarrow} \| \| \underset{B}{\rightarrow} \|} = \frac{\sum_{i=1}^{n} \underset{A}{\rightarrow}_i \times \underset{B}{\rightarrow}_i}{\sqrt{\sum_{i=1}^{n} (\underset{A}{\rightarrow}_i)^2} \times \sqrt{\sum_{i=1}^{n} (\underset{B}{\rightarrow}_i)^2}} \quad (3)$$

3 Experiment and Analysis of Results

3.1 Data Pre-processing

This study used incoPat patent database to search Chinese invention patents in the 10-year period of 2012–2021, using “refining, refining and chemicals, petroleum, petrochemical” as the search term ((TIAB = (refining OR refining and chemicals OR petroleum OR petrochemical)) AND (AD = [20120101 TO 20211231])), and 30,378 patents were retrieved. In order to ensure the scientificity and accuracy of the study, the retrieved data were standardized, and the patents that appeared repeatedly and those that were not related to the subject were eliminated, etc. Finally, 14,273 valid patent data were obtained, and the amount of patents in the calendar year is shown in Fig. 2.

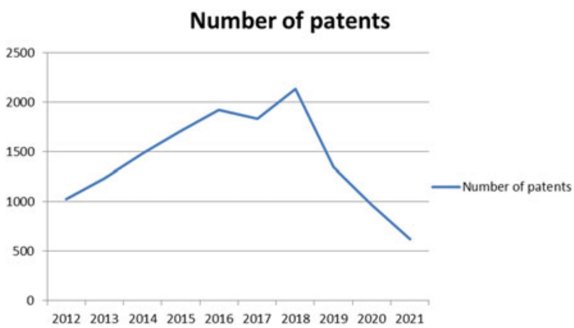


Fig. 2 Number of patents in China’s petrochemical industry over the years

The unprocessed patent text contains a large number of numbers, letters and meaningless high-frequency words as well as petrochemical-related words, such as "technology", "made", "stable", etc. "stable", etc. To ensure the effect of word separation, this study used python programming, combined with a special deactivation word list and a custom word bank to remove the interfering words, and used the jieba word separation package in python to separate the text.

3.2 Analysis of LDA Themes and Evolutionary Results

3.2.1 Theme Mining Results

After data pre-processing, perplexity calculation, Gibbs sampling and other calculations, the document-topic distribution and 30 topic-word distribution of 14,273 patent documents were finally obtained, and the specific meanings of 30 topics in petrochemical industry were summarized according to the high probability feature lexical items under each topic. Through categorization and summarization, the 30 topics were divided into three major fields of petroleum extraction, refining and chemical, and petroleum pipeline, as shown in Table 1.

As shown in the table, the field of oil extraction mainly involves oil drilling equipment, oil logging technology, oil exploration equipment, drilling fluid preparation, oil-contaminated soil treatment, etc.; the field of oil refining and chemical industry mainly involves catalyst preparation, refining wastewater and waste gas treatment, hydrogenation technology, catalytic cracking technology, asphalt, petroleum resin preparation and refining production systems; the field of oil pipelines mainly involves the manufacture of oil pipelines, oil pipeline inspection, cleaning and sealing technology of oil pipelines.

3.2.2 Theme Intensity Evolution Results

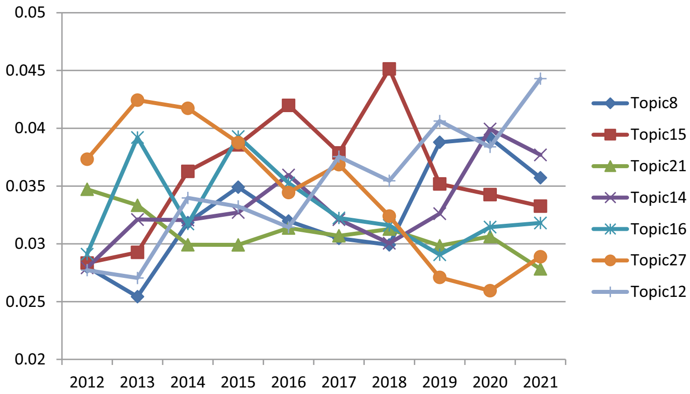
The theme intensity evolution can reflect the dynamic development trend of the theme to a certain extent. In this paper, the 10 years from 2012 to 2021 are divided into 10 time windows, and the theme intensity of each theme in each time window is calculated, and the line graphs of the theme intensity of oil extraction field, refining chemical field and oil pipeline field are plotted over time respectively, and some theme intensity evolution trends are shown in Fig. 3.

In terms of the evolution of the intensity of the themes in the oil extraction sector, the themes show a certain pattern of evolution. Combined with the theme development trend, it can be seen that oil drilling bits (Topic8) and pumping units (Topic14) were not very strong in the early stage of the theme, but the rising trend in recent years is obvious, indicating that they are receiving increasing attention. The rising trend of the topic intensity of drilling fluid preparation (Topic15) declined significantly after

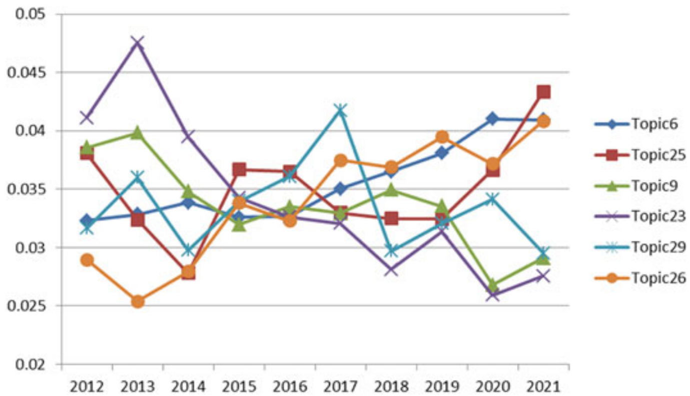
Table 1 LDA theme meanings

Fields of affiliation	Topic number	Topic content
Oil extraction field	Topic8	Oil drilling bits
	Topic15	Drilling fluid preparation
	Topic21	Oil drilling rigs
	Topic28	Oil drilling data transmission system
	Topic14	Oil Pumping Machine
	Topic16	Oil logging instruments
	Topic27	Oil exploration equipment
	Topic1	Oil seismic exploration
	Topic19	Reservoir core analysis techniques
	Topic11	Oil logging model construction
	Topic2	Oil Cementing Technology
	Topic12	Oil contaminated soil treatment
Oil refining and chemical field	Topic6	Refinery Exhaust Gas Treatment
	Topic25	Refinery wastewater treatment
	Topic9	Catalyst Preparation
	Topic10	Hydrogenation refining technology
	Topic23	Catalytic Cracking Technology
	Topic0	Oil fractionation technology
	Topic13	Oil–water separation technology
	Topic5	Asphalt preparation
	Topic29	Petroleum resin preparation
	Topic24	Petrochemical equipment fault diagnosis technology
	Topic7	Oilfield production data processing system
	Topic26	Petrochemical production monitoring system
Oil pipeline field	Topic20	Oil pipeline manufacturing
	Topic3	Oil pipeline cleaning equipment
	Topic22	Oil pipeline support device
	Topic4	Oil pipeline sealing technology
	Topic18	Oil pipeline cleaning robot
	Topic17	Oil pipeline inspection technology

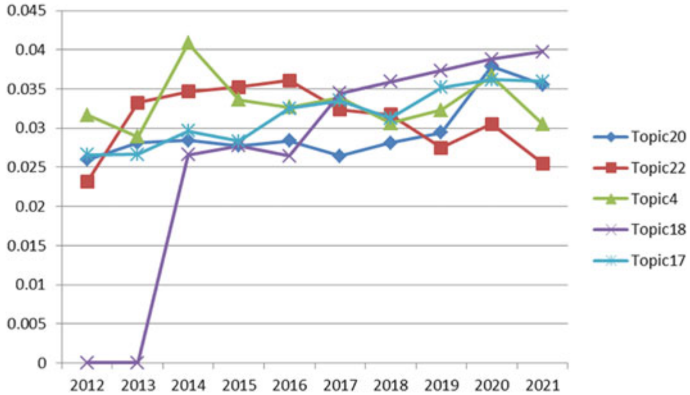
reaching a peak in 2018, indicating that the topic is maturing after a period of development and has little development potential. The topic intensity for Oil Drilling Rigs (Topic21) has remained low and flat, indicating that there is less research related to this topic. The theme intensity of Oil Logging Instruments (Topic16) fluctuates a lot in the early stage but gradually stabilizes in the later stage, indicating that the theme



(a) Oil extraction field



(b) Refining and chemical field



(c) Oil pipeline field

Fig. 3 Evolution of the intensity of research themes in China's petrochemical industry has formed a more stable content. Oil exploration equipment (Topic27) has shown a significant decline in theme intensity, indicating that the theme has continued to receive less attention and is no longer a hot topic of interest. The theme intensity development of oil-contaminated soil treatment (Topic12) has a large change and is in a rising state, which indicates that the theme has a high degree of attention and good development momentum, and will continue to receive attention.

In terms of the evolution of the intensity of topics in the refining chemical field, the research focus has shifted from refining technology processes to pollution treatment and refining monitoring equipment. It can be seen that the theme intensity of refining waste gas treatment (Topic6) and petrochemical production monitoring system (Topic26) has been on a steady rise, indicating that these two themes have received continuous attention and are the future direction of development. Refinery wastewater treatment (Topic25) theme intensity has experienced a period of fluctuation, the last 3 years is a steady upward trend, will be a hot spot for future attention. The topic strength of catalyst preparation (Topic9) and catalytic cracking technology (Topic23) has been decreasing year by year, indicating that the research related to these two topics has become more mature and is no longer the focus of research. The topic intensity of petroleum resin preparation (Topic29) shows a downward trend after a period of increase, indicating that the field had been concerned for a period of time and then gradually decreased in attention.

From the evolution of the intensity of the subject in the field of oil pipelines, the research direction is gradually moving toward intelligence and automation. It can be seen that the topic intensity of oil pipeline manufacturing (Topic20) has grown rapidly, especially the topic intensity of oil pipeline cleaning robot (Topic18) was still 0 in 2012 and 2013, indicating that there was no relevant research in this area in that period, but the related research has grown rapidly in the following years and has become a research hotspot. The momentum for oil pipeline support devices (Topic22) peaked in 2016 and has received less attention since then. The intensity of the topic of oil pipeline sealing technology (Topic4) fluctuates considerably, but remains generally unchanged. The topic intensity of Oil Pipeline Inspection Technology (Topic17) is steadily increasing, indicating that there is always a researchable value in this field.

In general, traditional refining fields such as catalytic cracking technology and catalyst preparation are experiencing relatively low momentum, while technology fields that benefit environmental protection such as waste gas and wastewater treatment and petroleum soil pollution treatment are receiving more and more attention. The oil extraction and oil pipeline fields are generally receiving increasing attention and are developing in the direction of intelligence and automation.

3.2.3 Results of the Evolution of Thematic Content

In order to further reflect the trend of technology evolution in the petrochemical industry, the data from 2012–2021 are divided into three time slices from 2012–2015 (the first time period), 2016–2018 (the second time period) and 2019–2021 (the third time period) according to the trend of changes in the number of patent applications, corresponding to the period of rapid growth, stable period and declining period of the number of patents in the petrochemical industry. After that, the LDA model was trained on the data of each period to obtain the topic mining results and determine the technical topic contents of each period, and the topic contents of each period are shown in Table 2.

After deriving the thematic contents of different time periods, the similarity of each thematic content between the first time period and the second time period, and the second time period and the third time period was calculated to construct a similarity matrix, which was used to reflect the evolution trend of thematic contents, as shown in Table 3.

In order to improve the accuracy of topic association, it is necessary to set the threshold T. If the threshold between two topics is less than T, the association between two topics is considered insufficient [23]. According to the actual situation of topic similarity in petrochemical industry, it is considered that $T = 0.26$, i.e., the topic association is invalid if the similarity is less than 0.26. Combined with the above, a content evolution diagram of the technical topics in the petrochemical industry is drawn, and the numbers on the arrows represent the similarity between the two topics, as shown in Fig. 4.

In terms of the evolution of the subject matter, the research directions are changing significantly, and the breadth of research is decreasing, but the depth of research will continue to increase. Greening, intelligence and automation have become the trend of petrochemical industry in recent years.

From the field of oil extraction, the research related to oil logging technology has evolved from logging sensors to fine logging instruments and finally to integrated logging instruments, which can be seen that the level of intelligence and informationization in the field of oil logging is constantly improving. The research related to oil drilling bits has evolved from differential pressure bits to combined PDC bits, and the quality and performance of the bits have been significantly improved. Research related to petroleum reservoir exploration has gradually evolved from measurement and prediction to reservoir model construction, which has improved the efficiency of exploration work. The research related to oil drill pipe evolved from oil drill pipe joints to oil drill pipe cleaning devices. In the field of petroleum-contaminated soil remediation, soil remediation agents are also evolving into more efficient and environmentally friendly soil degrading bacteria.

From the refining chemical field, the research related to catalyst preparation has evolved from catalytic cracking catalysts to hydrocracking catalysts, which can be seen that China's refining field is paying more and more attention to the quality of oil products and the refining process is being continuously improved. Heater energy monitoring technology has gradually evolved into a refinery process fault monitoring device, improving detection accuracy and efficiency. Refinery wastewater treatment equipment has also evolved into intelligent chemical wastewater treatment equipment to reduce wastewater pollution as much as possible. It can be seen that greening and intelligence are the focus of attention in the refining field in the near future, as well as the direction of development in the future. From the oil pipeline field, the

Table 2 Content of research topics in China's petrochemical industry at different time periods

Time period	Topic	Content
2012–2015 (the first time period)	Topic0(T_{a0})	Hydrocracking technology
	Topic1(T_{a1})	Oil pipeline sealing technology
	Topic2(T_{a2})	Heavy oil processing technology
	Topic3(T_{a3})	Heating furnace energy consumption monitoring
	Topic4(T_{a4})	Oil casing manufacturing
	Topic5(T_{a5})	Catalytic cracking catalysts
	Topic6(T_{a6})	Petroleum resin preparation
	Topic7(T_{a7})	Oil fractionation technology
	Topic8(T_{a8})	Oil pipeline support device
	Topic9(T_{a9})	Oil Drill Pipe Joints
	Topic10(T_{a10})	Petroleum reservoir exploration estimation
	Topic11(T_{a11})	Asphalt preparation
	Topic12(T_{a12})	Logging sensor
	Topic13(T_{a13})	Wastewater treatment equipment
	Topic14(T_{a14})	Petrochemical equipment corrosion monitoring
2016–2018 (the second time period)	Topic0(T_{b0})	Oil pipeline inner wall cleaning machine
	Topic1(T_{b1})	Oil reservoir forecasting
	Topic2(T_{b2})	Hydrocracking catalyst
	Topic3(T_{b3})	Contaminated soil remediation agent
	Topic4(T_{b4})	Drilling fluid preparation
	Topic5(T_{b5})	Refining process fault monitoring device
	Topic6(T_{b6})	Oil pipeline inspection device
	Topic7(T_{b7})	Differential pressure drill bits
	Topic8(T_{b8})	Oil pipeline pressure measurement technology
	Topic9(T_{b9})	Intelligent chemical wastewater treatment equipment
	Topic10(T_{b10})	Fine logging instruments
	Topic11(T_{b11})	Oil drill pipe cleaning device
	Topic12 (T_{b12}	Oil pipeline installation equipment
2019–2021 (the third time period)	Topic0(T_{c0})	Oil pipeline cleaning robot
	Topic1(T_{c1})	Thick oil viscosity reducer
	Topic2(T_{c2})	Pipeline inspection drones

(continued)

Table 2 (continued)

Time period	Topic	Content
	Topic3(T_{c3})	Leak-proof oil wellhead device
	Topic4(T_{c4})	Remediation of contaminated soil with degrading bacteria
	Topic5(T_{c5})	Combination PDC drill bits
	Topic6(T_{c6})	Oil pipeline sealing valve
	Topic7(T_{c7})	Reservoir model construction
	Topic8(T_{c8})	Oil pipeline internal pressure automatic detection device
	Topic9(T_{c9})	Oil and gas separation and recovery device
	Topic10(T_{c10})	Offshore Oil Production Troubleshooting System
	Topic11(T_{c11})	All-in-one logging instrument

Note T_a denotes the topic of the first period; T_b denotes the topic of the second period; T_c denotes the topic of the third period

oil pipeline inner wall cleaning machine technology gradually evolved into the oil pipeline cleaning robot, the pipeline cleaning effect has been significantly improved. Pipeline inspection drones, as an extension of oil pipeline inspection devices, have been effective in improving the efficiency of pipeline inspection. Oil pipeline pressure measurement technology has gradually evolved into an automatic oil pipeline internal pressure detection device, which improves the automation of oil pipeline inspection and reduces the waste of human resources. It can be seen that the field of oil pipelines is constantly developing towards the field of intelligence and automation, and certain breakthroughs have been made and practical applications are carried out.

Table 3 Theme similarity matrix

(a) The similarity matrix between the first time period and the second time period

	T_{a0}	T_{a1}	T_{a2}	T_{a3}	T_{a4}	T_{a5}	T_{a6}	T_{a7}	T_{a8}	T_{a9}	T_{a10}	T_{a11}	T_{a12}	T_{a13}	T_{a14}
T_{b0}	0.214	0.210	0.222	0.201	0.211	0.191	0.175	0.195	0.246	0.245	0.212	0.212	0.239	0.182	0.212
T_{b1}	0.228	0.214	0.232	0.228	0.227	0.220	0.207	0.243	0.222	0.225	0.264	0.228	0.226	0.205	0.241
T_{b2}	0.228	0.259	0.213	0.207	0.203	0.266	0.221	0.239	0.201	0.216	0.217	0.212	0.191	0.222	0.206
T_{b3}	0.176	0.228	0.222	0.186	0.178	0.231	0.185	0.251	0.182	0.225	0.231	0.225	0.182	0.202	0.180
T_{b4}	0.227	0.246	0.244	0.235	0.223	0.231	0.238	0.247	0.206	0.197	0.229	0.227	0.224	0.225	0.210
T_{b5}	0.227	0.249	0.223	0.263	0.244	0.219	0.257	0.239	0.217	0.220	0.216	0.232	0.223	0.259	0.234
T_{b6}	0.233	0.207	0.199	0.218	0.219	0.195	0.183	0.204	0.244	0.251	0.257	0.224	0.251	0.179	0.238
T_{b7}	0.212	0.249	0.211	0.213	0.193	0.199	0.257	0.224	0.209	0.208	0.221	0.208	0.197	0.218	0.201
T_{b8}	0.242	0.198	0.216	0.219	0.223	0.228	0.165	0.217	0.236	0.241	0.254	0.235	0.239	0.183	0.252
T_{b9}	0.211	0.257	0.222	0.198	0.218	0.218	0.237	0.252	0.167	0.178	0.207	0.210	0.187	0.262	0.183
T_{b10}	0.233	0.198	0.209	0.253	0.193	0.196	0.195	0.212	0.218	0.179	0.258	0.254	0.262	0.197	0.201
T_{b11}	0.222	0.189	0.217	0.202	0.215	0.200	0.172	0.198	0.235	0.275	0.189	0.208	0.220	0.180	0.232
T_{b12}	0.238	0.222	0.245	0.241	0.229	0.224	0.213	0.227	0.246	0.239	0.234	0.244	0.248	0.197	0.243

(b) Similarity matrix between the second and third time periods

	T_{b0}	T_{b1}	T_{b2}	T_{b3}	T_{b4}	T_{b5}	T_{b6}	T_{b7}	T_{b8}	T_{b9}	T_{b10}	T_{b11}	T_{b12}
T_{c0}	0.273	0.231	0.203	0.190	0.203	0.250	0.252	0.202	0.282	0.196	0.196	0.232	0.257
T_{c1}	0.222	0.216	0.266	0.231	0.245	0.253	0.204	0.230	0.210	0.254	0.209	0.213	0.220
T_{c2}	0.254	0.257	0.211	0.192	0.202	0.250	0.264	0.218	0.252	0.200	0.206	0.251	0.243
T_{c3}	0.228	0.254	0.213	0.173	0.203	0.231	0.250	0.205	0.236	0.182	0.186	0.258	0.248
T_{c4}	0.221	0.228	0.213	0.285	0.234	0.221	0.225	0.207	0.224	0.199	0.207	0.204	0.246

(continued)

Table 3 (continued)

(b) Similarity matrix between the second and third time periods

	T_{b0}	T_{b1}	T_{b2}	T_{b3}	T_{b4}	T_{b5}	T_{b6}	T_{b7}	T_{b8}	T_{b9}	T_{b10}	T_{b11}	T_{b12}
T_{c5}	0.213	0.226	0.218	0.185	0.214	0.221	0.215	0.268	0.213	0.188	0.199	0.243	0.227
T_{c6}	0.213	0.233	0.188	0.175	0.214	0.216	0.235	0.178	0.247	0.190	0.257	0.221	0.245
T_{c7}	0.200	0.269	0.196	0.173	0.221	0.190	0.215	0.201	0.212	0.165	0.242	0.217	0.234
T_{c8}	0.249	0.245	0.204	0.179	0.205	0.247	0.258	0.200	0.266	0.195	0.216	0.251	0.240
T_{c9}	0.172	0.200	0.227	0.204	0.224	0.238	0.189	0.217	0.178	0.251	0.217	0.167	0.184
T_{c10}	0.214	0.246	0.232	0.214	0.244	0.246	0.222	0.204	0.228	0.218	0.200	0.218	0.232
T_{c11}	0.241	0.255	0.214	0.190	0.205	0.242	0.252	0.211	0.258	0.201	0.266	0.241	0.249

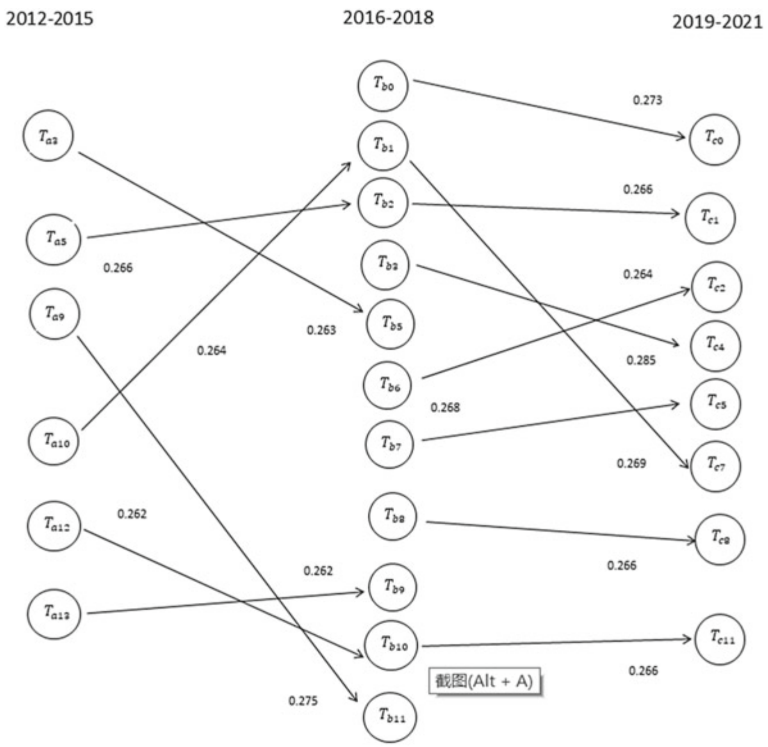


Fig. 4 Trends in the evolution of technical subject matter content in China's petrochemical industry

4 Conclusion

Based on the LDA subject probability model, this study conducted a technical subject evolution analysis of the research field of China's petrochemical industry using patent text information, and on this basis extracted the development characteristics and development direction of China's petrochemical industry, and the study found that:

(1) The number of patents in the petrochemical industry as a whole was in the growth period from 2012 to 2016 and achieved significant development, but the growth slowed down in 2016–2018, especially after 2018, which may be due to overheated investment and overcapacity in the petrochemical industry on the one hand [24]; on the other hand, it may be related to the development concept of "new and old kinetic energy conversion" and "high-quality development" proposed by the state. As a polluting traditional industry, the petrochemical industry in the face of national policy adjustments, may also be actively looking for the direction of transformation efforts.

(2) Technology research in petrochemical industry is mainly concentrated in three major fields: oil extraction field (including oil drilling equipment, oil logging

instruments and technology, drilling fluid preparation, etc.), refining chemical field (including catalytic cracking process, crude oil cracking process, waste gas and wastewater treatment, refining monitoring system, etc.), and oil pipeline field (including oil pipeline manufacturing, oil pipeline sealing, oil pipeline cleaning, etc.). In terms of the evolution of the intensity and content of the topics, the attention paid to technologies related to the refining and chemical fields has been decreasing year by year, replaced by the oil pipeline field and the oil extraction field. Some traditional fields such as catalyst preparation, drilling fluid preparation and asphalt preparation are receiving less and less attention, while some emerging fields such as automatic oil pipeline inspection, oil pipeline cleaning and intelligent extraction equipment are receiving more and more attention.

(3) The future technological development of China's petrochemical industry shows the trend of intelligence, greening, automation and integration, and these aspects will be the hot spots for future research. In oil extraction, intelligent logging and drilling equipment will be the focus of future research, and is also a key area where China needs to make breakthroughs, while oil-contaminated soil management will also receive more attention. In refining and chemical industry, refining and chemical integration, green refining and intelligent refining will be the future development trend and the transformation direction of traditional refining and chemical plants. In oil pipelines, the use of intelligent equipment such as robots and drones will become the focus of attention and receive more and more attention.

In summary, China's petrochemical industry is developing in the direction of greening, automation and intelligence. The petrochemical industry has been the pillar industry of China, in the process of transformation, we should focus on the elimination of backward production capacity and the development of new technologies on the one hand, and on the other hand, we should also focus on meeting the needs of social development. The petrochemical industry should conscientiously implement national and industry policies, pay close attention to changes and developments in technology, dare to make breakthroughs, seek innovation, rationalize resources and strategic planning, and promote high-quality sustainable development.

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Research on the Coupling and Coordinated Development of Industrial Structure and Ecological Environment

Qiufang Fan and Mengjie Lin

Abstract Based on the relevant data of 30 provinces in China (except Tibet, Hong Kong, Macao, and Taiwan) from 2007 to 2019, this paper uses the global entropy method and TOPSIS method to calculate the weight of each index and comprehensive evaluation index of industrial structure and ecological environment in China, and uses the coupling coordination degree model and spatial autocorrelation model to measure the coupling coordination degree of industrial structure and ecological environment, and analyzes its spatial aggregation characteristics. The results show that: (1) The overall level of China's industrial structure and ecological environment is on the rise, among which, the overall level of ecological environment is low, and there are obvious differences in industrial structure between eastern, central, and western China; (2) The coupling degree of industrial structure and ecological environment in China is high, and the coupling coordination degree is in a slow-growth trend; At present, many provinces are in the initial and intermediate stage of coordination, and there is no high-quality coordination province; There is a big gap between the coupling coordination degree of industrial structure and ecological environment in eastern, central and western regions, but the gap is gradually narrowing. (3) There is a positive spatial correlation between the coupling coordination degree of industrial structure and ecological environment in China, and the correlation is increasing year by year; High-high aggregation is mainly distributed in Beijing, Tianjin, Hebei and Jiangsu, Zhejiang, and Shanghai, while low-low aggregation is mainly distributed in Guangxi, Yunnan and other western regions, with few high-low aggregations. Finally, some suggestions are put forward to promote the coordinated development of industrial structure and ecological environment.

Keywords Industrial structure · Ecological environment · Coupling coordination degree · Spatial autocorrelation

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1 Introduction

To achieve the strategic goal of sustainable development and accelerate high-quality economic development and high-level protection of the ecological environment, China is actively exploring the coordinated path of development and protection. As mentioned in the Opinions of the State Council of the CPC Central Committee on the Complete and Accurate Implementation of the New Development Concept to Achieve Carbon Neutrality, we should accelerate the formation of industrial structure and production methods that conserve resources and protect the environment, and unswervingly take the high-quality development path of ecological priority and green low-carbon, to ensure that carbon peaks and carbon neutrality can be achieved as scheduled. In the context of “double carbon”, adjusting and optimizing the industrial structure and promoting green industrial development is essential to improving the ecological environment, and it is necessary and urgent to accelerate the coordinated development of industrial structure and ecological environment. For a long time, China’s industrial structure and ecological environment contradictions, although the industrial structure has achieved a “three-two-one” pattern, compared with other countries, the proportion of the secondary industry is still 10% higher than the world average, and China’s secondary industry energy consumption accounted for 70% of the total national energy consumption, high-intensity energy consumption led to the atmosphere, water, soil, and other pollution. High-intensity energy consumption has led to increased pollution of the atmosphere, water, and soil, which seriously affects the quality of China’s ecological environment. At the same time, the deterioration of the ecological environment has caused a scarcity of talents and resources, which also restricts the development of the industrial structure. To this end, this paper studies the coupled and coordinated relationship between industrial structure and ecological environment in China, to provide reference and reference for promoting the coordinated development of industrial structure and ecological environment in China and achieving the strategic goal of green and sustainable development.

2 Literature Review

Grossman and Krucger [1] showed that industrial structure optimization can reduce pollutant emissions and improve environmental quality; Zhenyu et al. [2] and Li [3] took the Yangtze River Economic Zone as an example and used the spatial Durbin model and the systematic GMM method, respectively, and found that industrial structure upgrading has a significant contribution to ecological environment optimization; Cui [4] using the industrial structure entropy value and industrial structure characteristic bias index method, the analysis concluded that the evolution of industrial structure has a greater impact on the quality of the ecological environment; Li et al. [5] In studying the environmental effects of industrial structure evolution in Yulin City, it was similarly found that the secondary industry has the most obvious effect on the ecological environment and the tertiary industry has the weakest effect; carbon emission, is one of the important indexes to measure the ecological environment, is closely related to industrial structure, Yuan and Zhou [6] using the SAR model and PECM model, they found that the rationalization of industrial structure has a suppressive effect on carbon emissions, while the effect of heightening on carbon emissions has an inverted U-shape, i.e., it plays a role in promoting and then suppressing carbon emissions; Wang and Wang [7] constructed a joint cubic equation model with panel data and found that the effect of industrial structure upgrading on carbon emissions differs among regions, with the eastern region playing the most important role. The effect of industrial structure upgrading on carbon emissions differs among regions, with a suppressive effect on the eastern region but a boost to carbon emissions in the central and western regions; Yu et al. [8] found that increasing the level of industrial structure upgrading has a positive effect on the decrease of carbon emissions intensity in the region and its surrounding areas.

Zhang et al. [9], Yuan et al. [10], and Qin et al. [11] demonstrated that environmental regulations promote industrial structure upgrading by using the spatial panel regression model, three-stage least squares, and fixed-effects model, respectively; Wang and He [12] found that environmental regulations can drive green innovation and thus promote industrial structure upgrading; In their study of the relationship between air pollution prevention and control actions in resource-based cities, Wu and Yin [13] found that the prevention and control actions regulate air pollution in resource-based cities by improving the rationalization and advanced industrial structure; Chen and Luo [14] used the spatial Durbin model to analyze that environmental regulation enhances the promotion effect of industrial structure on the efficiency and effectiveness of factor replacement; Lin and Guan [15] further found that Gao and Xiao [16] classify environmental regulations into command, market, and autonomous types, and use the SBM-DEA model to measure that market and autonomous environmental regulations have positive promotion effect on industrial structure upgrading and optimization, while command type has a negative effect; in addition, some scholars also studied the role of limited resources on industrial structure; Wang et al. [17], analyzing the factors influencing industrial structure in the Yellow River Basin, confirmed that the rationalization level of industrial structure in resource-rich areas is lower than that in areas with poorer resource endowment; Yan et al. [18] argued that industrial ecological development is an inevitable choice for Hunan Province to break through resource and environmental constraints and achieve sustainable development.

Regarding the relationship between industrial structure and ecological development, scholars generally agree that there is a long-term dynamic equilibrium between the two [19]. Grossman et al. [1, 20] found that industrial restructuring and environmental pollution have an inverted "U" shaped relationship, and Cui [21] and Dongbo Zhu [22] also reached the same conclusion in their studies; while Brajer et al. [23] argued that estimating The different pollutants and measurement methods used for EKC can lead to different results. Most scholars choose to use the coupled coordination model to study the relationship between the two. Zou et al. [24] constructed the industrial structure and ecological environment index system, used the principal component analysis to measure the evaluation index, and used the coupled coordination model to study the coordination relationship between industrial structure and ecological environment in China during 2000–2013; Ren and Du [25] used the coupled coordination model and the spatial autocorrelation model to Wang et al. [26] chose the CRITIC empowerment method and coupled coordination degree model to analyze the coupling relationship between industrial structure and ecological environment in the Beijing-Tianjin-Hebei region; in addition, some scholars also study the relationship between specific industries and ecological environment, such as the tourism industry [27, 28] and high-tech industry [29].

In summary, scholars at home and abroad have conducted a large number of studies on the relationship between industrial structure and ecological environment, but they mostly start based on the one-way relationship between the two, or study the influence of industrial structure on ecological environment, or study the influence of ecological environment on industrial structure, and there are relatively few studies involving the two-way interaction between industrial structure and ecological environment, and there is almost no literature studying the coordinated relationship between the two from the national level. Based on this, the marginal contributions of this paper are mainly in the following two aspects: (1) constructing an index system of industrial structure and ecological environment, using the global entropy value method and TOPSIS method to evaluate and analyze the status of industrial structure and ecological environment from 2007 to 2019; (2) using the coupling coordination degree model to measure the coupling coordination degree of industrial structure and ecological environment and analyzing their spatial aggregation characteristics, aiming at improving the relationship between industrial structure and ecological environment in China and promote the coordinated development of the two to provide a reference basis.

3 Mechanism Analysis and Research Design

3.1 Analysis of the Coupling and Coordination Mechanism Between Industrial Structure and Ecological Environment

To explore the coupling relationship between industrial structure and ecological environment, this paper draws a diagram of the coupling mechanism between industrial structure and ecological environment based on the research of scholars Hu et al. [30] and Zou et al. [24], as shown in Fig. 1.

Industrial structure affects the ecological environment in five main aspects. First, industrial structure determines the type and quantity of resource consumption, and a good industrial structure can reduce the dependence on and consumption of nonrenewable resources and alleviate resource shortage; second, resource consumption

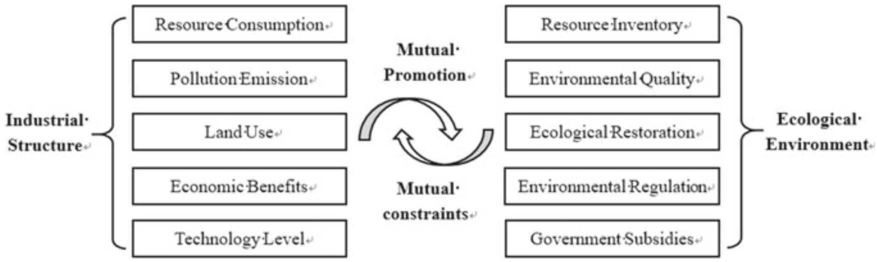

Fig. 1 Coupled coordination mechanism

directly determines the degree of pollution emission and affects the ecological environment level, and industrial structure optimization is conducive to reducing pollution emission and thus improving the ecological environment; third, industrial structure affects the way and layout of land use, and industrial structure development can improve the efficiency of land use and reduce spatial environmental constraints, while reducing environmental problems caused by overuse; fourth, industrial development can directly bring economic benefits, which on the one hand promotes ecological environmental protection and construction, and on the other hand enhances the height of industrial structure, promotes industrial green development and reduces ecological and environmental pressure; fifth, the improvement of technology level is conducive to improving resource utilization and pollution treatment capacity, and improving environmental quality.

The impact of the ecological environment on the industrial structure is also reflected in five aspects. First, the limited resource stock has a certain constraint on the current industrial development, but at the same time the role can promote the optimization of industrial structure; second, the current environmental pollution situation is still severe due to pollution emissions, land use, and other factors, and the decline in the level of environmental quality will weaken the attraction of high-quality enterprises and talents, affecting the development of local industrial structure; third, the ecological environment can self-healing, and a good environmental foundation Fourth, the government's environmental regulation policy eliminates the "three high" enterprises and accelerates the adjustment of industrial structure; Fifth, government subsidies help enterprises to establish environmental awareness, promote green development and optimize industrial structure.

It can be found that the industrial structure and ecological environment promote each other and constrain each other, the optimization and upgrading of the industrial structure needs a good ecological environment foundation, and the improvement of the ecological environment depends on the green development of industrial structure, therefore, it is important to study the coupling and coordination relationship between the two for green sustainable development.

3.2 Index System Construction and Data Sources

To comprehensively and objectively evaluate the industrial structure and ecological environment in China, this paper refers to the research of Zou et al. [24] and Zheng et al. [31], which establishes 13 indexes in four dimensions: industrial output value structure, industrial employment structure, industrial structure deviation, and industrial structure efficiency, among which, the industrial structure efficiency is mainly reflected in the economic aspect; in the ecological environment, this paper refers to the research of Cui et al. [32], Zhang and Huang [33] and Song [34]. Combining the current situation of the ecological environment in China, and according to the principle of data accessibility, the PSR model is used to construct the index system, and a total of 19 indexes are selected, which are shown in Table 1.

In this paper, 30 provinces in China are selected for the study (except Tibet, Hong Kong, Macao, and Taiwan), and the data are mainly obtained from China Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, and provincial statistical yearbooks from 2007 to 2019, and for individual missing data, the interpolation method is used to complete them.

3.3 Research Methodology

3.3.1 Global Entropy Method

The global entropy method is an objective weighting method, which determines the index weights by the amount of information contained in the index data itself; the global entropy method is also an improved entropy method, which can add time series to the cross-sectional data to form a three-dimensional time-series data table [35]. In this paper, we use the global entropy method to determine the weights of the index of industrial structure and ecological environment, and the specific steps are as follows.

(1) Standardization. In order to avoid the existence of different magnitudes and directions among the index, the data were standardized using the polarization normalization method. At the same time, to remove the effect of zero on the accuracy of the data, this paper performs data shifting.

The formula for calculating positive index:

$$x_{ij}^{t*} = \frac{x_{ij}^{t} - x_{\min}}{x_{\max} - x_{\min}} + 1, (\mathrm{i} = 1, 2, \ldots, \mathrm{m};\ \mathrm{t} = 1, 2, \ldots, \mathrm{T}) \tag{1}$$

The formula for calculating negative index:

Table 1 Evaluation index system

Target layer	Guideline layer	Index layer	Unit	Direction
Industrial structure system	Industry output structure	Primary industry value added as a proportion of GDP	%	Negative
		Secondary industry value added as a proportion of GDP	%	Positive
		Tertiary industry value added as a proportion of GDP	%	Positive
	Industry employment structure	The proportion of primary industry employees	%	Negative
		The proportion of secondary industry employees	%	Positive
		The proportion of tertiary industry employees	%	Positive
	Industrial structure deviation	Deviation of primary industry structure	%	0
		Deviation of secondary industry structure	%	0
		Deviation of tertiary industry structure	%	0
	Industry structure benefits	Gross regional product per capita	Yuan/person	Positive
		Farmers' per capita disposable income	Yuan/person	Positive
		Retail sales of social consumer goods per capita	Yuan/person	Positive
		Social labor productivity	Yuan/person	Positive
Ecological environment system	Pressure	Urban population density	People/km^2	Negative
		Natural population growth rate	‰	Negative
		Total water consumption	Billion cubic meters	Negative
		Total energy consumption	Million tons of standard coal	Negative
		Urban construction land area	Square kilometers	Negative

(continued)

Table 1 (continued)

Target layer	Guideline layer	Index layer	Unit	Direction
		Total chemical oxygen demand emissions	Ton	Negative
		Total ammonia nitrogen emissions	Ton	Negative
		Total sulfur dioxide emissions	Ton	Negative
		Agricultural fertilizer application amount	Million tons	Negative
	Status	Total arable land area	Thousands of hectares	Positive
		Water resources per capita	Cubic meter/person	Positive
		Direct economic losses from natural disasters	Billion	Negative
		Greening coverage of built-up areas	%	Positive
		Green space per capita	Square meter/person	Positive
	Response	Total afforestation area	Hectares	Positive
		Investment in environmental pollution control as a percentage of GDP	%	Positive
		General industrial solid waste comprehensive utilization rate	%	Positive
		Urban sewage treatment rate	%	Positive
		Harmless disposal rate of domestic waste	%	Positive

Industrial structure deviation = industry value added as a proportion of GDP/the proportion of industry employees-1, characterizing the balanced relationship between industry and employment

$$x_{ij}^{t^*} = \frac{x_{\max} - x_{ij}^{t}}{x_{\max} - x_{\min}} + 1, (\mathrm{i} = 1, 2, \ldots, \mathrm{m}; \mathrm{t} = 1, 2, \ldots, \mathrm{T}) \quad (2)$$

The formula for calculating adequacy index:

$$x_{ij}^{t^*} = 1 - \frac{\left| x_{ij}^{t} - x_{i}^{t^*} \right|}{\max\left| x_{ij}^{t} - x_{i}^{t^*} \right|} + 1, (\mathrm{i} = 1, 2, \ldots, \mathrm{m}; \mathrm{t} = 1, 2, \ldots, \mathrm{T}) \quad (3)$$

where $x_{ij}^{t^*}$ denotes the initial data normalized values, and x_{ij}^{t} denotes the initial value of the jth evaluation index of the ith province in the year t, and $x_{\max}$, $x_{\min}$ denotes the maximum and minimum values of this evaluation index, and $x_i^{t^*}$ denotes the optimal value of this evaluation index in province i in year t.

(2) Calculate the share of the ith province in year t under the jth index.

$$y_{ij}^{t} = \frac{x_{ij}^{t^*}}{\sum_{t=1}^{T}\sum_{i=1}^{m} x_{ij}^{t^*}} \tag{4}$$

(3) Calculation of the entropy of the index.

$$e_j = -K\sum_{t=1}^{T}\sum_{i=1}^{m} y_{ij}^{t}\ln y_{ij}^{t} \tag{5}$$

where e_j represents the entropy value of the jth index, $0 \leq e_j \leq 1$; $K = \frac{1}{lnmT}$, $K > 0$, and the value of K is determined by the number of provinces and years.

(4) Calculate the coefficient of variation of the index.

$$g_j = 1 - e_j \tag{6}$$

Coefficient of variation g_j is a coefficient that measures the importance of each index. For the jth index, its index value x_{ij}^{t}. The larger the variance, the more data information it contains, and the smaller its entropy value, when the g_j the larger it is, the more important the index is.

(5) Determination of index weights.

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{7}$$

where w_j is the index weight of the jth item, $0 \leq w_j \leq 1$, the $\sum_{j=1}^{n} w_j = 1$.

3.3.2 TOPSIS Method

The TOPSIS method, also known as the ranking method of approximating ideal solutions, evaluates the degree of merit of each program by determining the positive and negative ideal solutions of each index and finding the distance between each program and the ideal solution, with the following steps.

(1) Determine the decision matrix.

$$X = (X_{ij})_{m*n} = \begin{bmatrix} x_{11} & x_{21} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}, (i = 1, 2, \dots \text{m};\ j = 1, 2, \dots, \text{n}) \quad (8)$$

where X represents the decision matrix, i is the evaluation object, and j is the evaluation index.

(2) Construction of a normative decision matrix

$$P = (P_{ij})_{m*n} = \begin{bmatrix} P_{11} & P_{21} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{m1} & P_{m2} & \dots & P_{mn} \end{bmatrix}, (i = 1, 2, \dots, \text{m};\ j = 1, 2, \dots, \text{n}) \quad (9)$$

Since the data in the decision matrix X are not quantized and normalized, the data cannot be used for direct computational ranking, so this step normalizes the data.

(3) Determine the positive ideal solution and the negative ideal solution.

$$P^{+} = (p_{\max 1}, p_{\max 2}, \dots, p_{\max n}),\ \ P^{-} = (p_{\min 1}, p_{\min 2}, \dots, p_{\min n})$$

(4) Calculate the distance of each evaluation object from the ideal solution.

$$Sd_i^{+} = \sqrt{\sum_{j=1}^{n} w_j \left(p_{\max j} - p_{ij}\right)^2},\ Sd_i^{-} = \sqrt{\sum_{j=1}^{n} w_j \left(p_{\min j} - p_{ij}\right)^2} \quad (10)$$

where w_j is the weight of the jth index.

(5) Calculate the closeness of the evaluation object to the ideal solution.

$$C_i = \frac{sd_i^{-}}{\left(sd_i^{+} + sd_i^{-}\right)},\quad (i = 1, 2, \dots, \text{m}) \quad (11)$$

3.3.3 Coupling Coordination Degree Model

In order to prevent pseudo-coordination, this paper further defines the coupling coordination degree based on the coupling degree model to measure the degree of benign coupling between industrial structure and ecological environment, constructs the model is as follows.

Table 2 Classification of coupling coordination level

Coupling coordination degree (D)	Coupling coordination level
$0 < D \leq 0.3$	Severe disorder
$0.3 < D \leq 0.4$	Moderate disorder
$0.4 < D \leq 0.5$	Mild disorder
$0.5 < D \leq 0.6$	Primary coordination
$0.6 < D \leq 0.7$	Intermediate coordination
$0.7 < D \leq 0.8$	Good coordination
$0.8 < D \leq 1$	Quality coordination

(1) Industrial structure and ecological environment coupling degree model *C*.

$$C = 2\sqrt{\frac{(u \cdot v)}{(u + v)(u + v)}} \tag{12}$$

Among them, *u* represents the comprehensive evaluation index of industrial structure and *v* represents the comprehensive evaluation index of ecological environment.

(2) The coupling coordination degree model of industrial structure and ecological environment *D*.

$$D = \sqrt{C \times T} \tag{13}$$

where *C* is the coupling degree of industrial structure and ecological environment, *T* is the comprehensive evaluation index of coordinated development level, the $T = \alpha u + \beta v$, α and β represents the weight of industrial structure and ecological environment in the system respectively $\alpha = 0.5$, $\beta = 0.5$ [36]. Therefore, the value is taken as.

There are four main types of coordination degree levels: "four points", "six points", "seven points", and "ten points". This paper draws on the research results of related scholars [37] and classifies the coordination degree into seven levels, which are shown in Table 2.

3.3.4 Spatial Autocorrelation Method

This paper uses spatial autocorrelation to analyze the coupling coordination degree of industrial structure and ecological environment (hereinafter referred to as "two systems") in China by spatial aggregation characteristics. The global spatial autocorrelation is used to investigate whether there is a spatial correlation between the coupling coordination degree of the two systems, and the local spatial autocorrelation is used to analyze the regional spatial correlation characteristics.

(1) Global spatial autocorrelation

$$Moran'sI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{14}$$

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2 \tag{15}$$

where $Moran'sI$ is the global spatial autocorrelation index w_{ij} is the spatial weight matrix x_i, x_j represents the coupling coordination degree of two systems between region i and region j; $n = 30$ is the number of study objects. Provided that the Moran index passes the test, the value of the Moran index is between -1 and 1 when $Moran'sI > 0$, indicates that the data present a positive spatial correlation, when $Moran'sI < 0$, indicates that the data show a negative correlation.$Moran'sI$ The larger the absolute value, the stronger the correlation, and when $Moran'sI = 0$, the space presents randomness.

$Moran'sI$ Whether the test is passed or not depends on the Z-value, which is expressed as follows.

$$Z(d) = \frac{Moran'sI - E(I)}{\sqrt{VAR(I)}} \tag{16}$$

where $E(I)$ represents the expected value, and $VAR(I)$ represents the variance.

(2) Local spatial autocorrelation

$$I_i = \frac{n(x_i - \overline{x})\sum_{j=1}^{n} w_{ij}(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{17}$$

When $I_i > 0$, it means there is "high-high aggregation" or "low-low aggregation" between region i and its neighboring regions, when $I_i < 0$, it means there is "high-low aggregation" or "low–high aggregation" between region i and its neighboring regions, and when $I_i = 0$, means there is no correlation between regions.

4 Empirical Analysis

4.1 Comprehensive Evaluation Analysis of Industrial Structure and Ecological Environment

Based on the global entropy value method and TOPSIS method, the comprehensive evaluation indices of industrial structure and ecological environment of 30 provinces in China from 2007 to 2019 were measured, and due to the influence of space, only

Table 3 Comprehensive evaluation index

Province	Industrial Structure					Ecological Environment				
	2007	2011	2015	2019	Provincial average	2007	2011	2015	2019	Provincial average
Jiangsu	0.596	0.657	0.710	0.715	0.677	0.362	0.333	0.374	0.336	0.346
Shanghai	0.873	0.835	0.799	0.737	0.817	0.347	0.343	0.381	0.371	0.357
Zhejiang	0.630	0.708	0.743	0.726	0.707	0.348	0.346	0.402	0.387	0.368
Beijing	0.729	0.695	0.667	0.652	0.683	0.378	0.354	0.411	0.412	0.390
Tianjin	0.717	0.763	0.753	0.628	0.741	0.381	0.377	0.406	0.377	0.385
Guangdong	0.534	0.624	0.633	0.601	0.601	0.271	0.294	0.392	0.320	0.314
Fujian	0.492	0.559	0.591	0.592	0.562	0.348	0.359	0.409	0.345	0.361
Shandong	0.451	0.499	0.547	0.520	0.509	0.404	0.388	0.420	0.385	0.393
Hebei	0.398	0.447	0.468	0.449	0.443	0.379	0.359	0.405	0.425	0.398
Liaoning	0.423	0.476	0.492	0.394	0.454	0.319	0.374	0.383	0.368	0.368
Hainan	0.190	0.244	0.299	0.287	0.257	0.389	0.371	0.386	0.362	0.384
Jiangxi	0.333	0.403	0.453	0.470	0.417	0.326	0.331	0.394	0.331	0.345
AnHui	0.323	0.331	0.404	0.429	0.375	0.364	0.355	0.450	0.400	0.390
Henan	0.293	0.365	0.406	0.402	0.371	0.319	0.352	0.402	0.411	0.377
Hubei	0.356	0.294	0.361	0.415	0.367	0.372	0.371	0.412	0.410	0.388
Huanan	0.264	0.335	0.342	0.335	0.319	0.311	0.387	0.468	0.459	0.396
Heilongjiang	0.296	0.301	0.365	0.340	0.326	0.434	0.468	0.513	0.494	0.480
Jilin	0.301	0.306	0.370	0.339	0.335	0.374	0.381	0.444	0.420	0.411
Shanxi	0.339	0.360	0.402	0.288	0.360	0.387	0.374	0.379	0.363	0.379
Inner mongolia	0.259	0.306	0.303	0.222	0.284	0.577	0.568	0.551	0.477	0.547

(continued)

Table 3 (continued)

Province	Industrial Structure					Ecological Environment				
	2007	2011	2015	2019	Provincial average	2007	2011	2015	2019	Provincial average
Chongqing	0.358	0.359	0.486	0.487	0.432	0.395	0.428	0.446	0.420	0.419
Sichuan	0.283	0.328	0.379	0.403	0.347	0.458	0.385	0.463	0.400	0.424
Qinghai	0.258	0.300	0.323	0.317	0.298	0.450	0.492	0.465	0.494	0.478
Guangxi	0.252	0.203	0.184	0.216	0.206	0.363	0.362	0.443	0.386	0.386
Guizhou	0.118	0.081	0.141	0.211	0.132	0.362	0.355	0.496	0.419	0.409
Shaanxi	0.231	0.372	0.235	0.232	0.249	0.378	0.385	0.417	0.364	0.389
Xinjiang	0.177	0.192	0.214	0.222	0.190	0.346	0.347	0.421	0.394	0.373
Ningxia	0.285	0.193	0.223	0.217	0.245	0.393	0.361	0.382	0.319	0.369
Ganau	0.131	0.096	0.167	0.172	0.136	0.358	0.357	0.424	0.436	0.391
Yunnan	0.060	0.094	0.096	0.157	0.095	0.488	0.506	0.524	0.394	0.490
Annual average	0.365	0.391	0.419	0.406	–	0.379	0.382	0.429	0.396	–

the specific data of 2007, 2011, 2015 and 2019 are shown in this paper, and the results are shown in Table 3.

4.1.1 Analysis of Industrial Structure and Ecological Environment Evaluation Results Based on the Time Dimension

(1) Overall evaluation analysis

From 2007 to 2019, China's industrial structure and ecological environment level both improved, increasing by 0.041 and 0.017, respectively, with a slight decrease in the 2015–2019 period. The improvement in the overall level of industrial structure and ecological environment is mainly attributed to policy guidance, the continuous development of new manufacturing and modern service industries has pushed China's output value structure to gradually tilt toward secondary and tertiary industries, and the change of this tilt is especially obvious after 2013 under the influence of advanced manufacturing and specialized production service industries, and the industrial structure efficiency has increased substantially, meanwhile, the introduction of enterprise pollution reduction and ecological and environmental protection policies has reduced ecological and environmental pressure, making both the industrial structure and ecological environment improved; ecological and environmental level showed a decreasing trend in 2016–2018, which is mainly related to the change in the direction of environmental protection policy, which proposed to solve environmental problems from the source of development in 2016, with a significant decrease in environmental protection, coupled with the continuous increase in total energy consumption and urban construction land area, the ecological and environmental level dropped sharply, but with the source governance gradually comprehensive and in-depth, its advantages gradually emerge, that is, the ecological environment level began to rebound trend in 2019; at the same time, the source governance led to a large number of sewage enterprises face transformation and upgrading challenges and elimination crisis, the rate of industrial development declined, therefore, the level of industrial structure slightly reduced in 2019.

(2) Evaluation analysis of each system

In terms of industrial structure, the industrial structure level of the rest of China's provinces has improved during the study period, except for eight provinces, namely Shanghai, Beijing, Tianjin, Liaoning, Shanxi, Inner Mongolia, Guangxi and Ningxia; Yunnan and Guizhou grew faster, by 162% and 79% respectively, which is due to the substantial increase in the proportion of tertiary industries in the two provinces, with Yunnan rising by 14%, and at the same time, the proportion of the number of employees in the two provinces is tilted towards At the same time, the proportion of employees in both provinces is tilted toward the secondary industry, the deviation of the secondary industry structure is reduced, the industrial employment gradually develops in the direction of balance, and the efficiency of the industrial structure is obviously improved; at present, Jiangsu, Shanghai and Zhejiang provinces have a high level of industrial structure, mainly due to the good industrial structure foundation and rich talent resources in the region, while Yunnan only scores 0.157, and there are still problems of industrial structure and unbalanced employment structure, such as the high proportion of primary industry and the large proportion of employees in the primary industry. Yunnan still has the problems of unbalanced industrial structure and employment structure, such as a high proportion of primary industry and a large proportion of employees in primary industry.

In terms of ecological environment, only Heilongjiang, Inner Mongolia and Yunnan reached an ecological environment level of 0.5 or higher in some years during the study period, indicating that China's overall ecological environment is at a low level, and although local areas such as the Yellow River basin and the Yangtze River basin have been effectively improved, the overall ecological and environmental protection road is still a long way to go; Hunan has the fastest growth rate, up 47% from 2007, which is due to the province's air and water Environmental quality has improved, and the total area of reforestation has increased rapidly, promoting the quality of the ecological environment; the current top three are Heilongjiang, Inner Mongolia and Qinghai, which is mainly due to the superiority of the natural environment of the three provinces, Ningxia and Guangdong scored lower, which are both related to the pressure on the ecological environment, the rapid growth of urban population density in the two provinces, including Ningxia increased by 264%, coupled with the expansion of urban construction land area in the two provinces, energy consumption, resulting in a low level of ecological environment.

4.1.2 Analysis of Industrial Structure and Ecological Environment Evaluation Results Based on the Spatial Dimension

As seen in Table 3, the ecological environment level of 30 provinces in China is mainly concentrated in 0.3–0.5 with small regional differences, while the regional differences in industrial structure level are significant. From Fig. 2, it can be seen that the overall level of industrial structure in the eastern region of China is significantly higher than that in the central and western regions, and the provinces of Beijing, Tianjin and Jiangsu, Zhejiang and Shanghai are in the forefront, which is attributed to the rapid economic development and talent density in the eastern region, the high proportion of secondary and tertiary industry output value, and the high matching degree of industrial output value and employment, which provides a strong guarantee for the improvement of industrial structure level; the industrial structure level in the central region is slightly better than that in the western region, which This is because the central region has a smaller proportion of primary industries and a lower deviation of industrial structure than the western region, and the overall industrial level is higher than that of the western region, with good benefits of industrial structure; the western region, except for Sichuan and Chongqing, has a low overall level and a less reasonable industrial structure, while the high level of industrial structure in Sichuan and Chongqing is due to factors such as its higher level of industrial structure and perfect infrastructure.

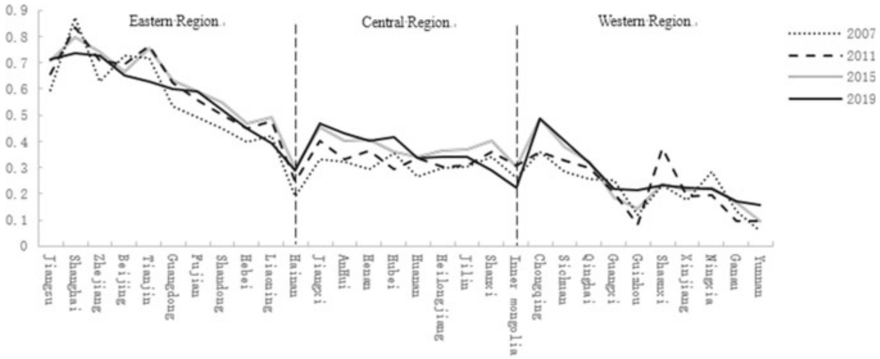

Fig. 2 Differences in the level of industrial structure between East, Central, and West

4.2 Coupling Coordination Degree Analysis of Industrial Structure and Ecological Environment

Based on the results of the comprehensive evaluation of industrial structure and ecological environment in China from 2007 to 2019, this paper measures the coupling degree and coupling coordination degree of the two systems. Due to the influence of space, this paper only shows the results of the coupling degree (Fig. 3) and coupling coordination degree (Table 4) of the two systems in 2007, 2011, 2015, and 2019.

4.2.1 Coupling Degree Measurement

According to Fig. 3, the coupling degree of the two systems in China is high during the study period, except for Guizhou, Yunnan, and Gansu in some years, the coupling degree of all the provinces reaches above 0.9, and all three provinces exceed 0.9 in

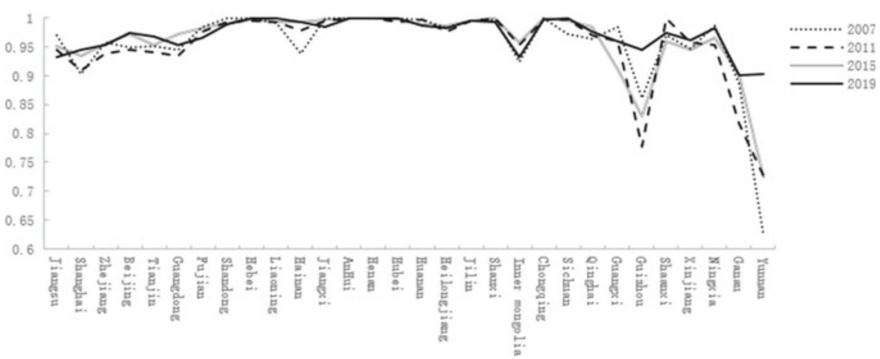

Fig. 3 Coupling degree

Table 4 Coupling coordination degree and grade classification

Province	2007	Level	2011	Level	2015	Level	2019	Level	Provincial average	Level
Jiangsu	0.681	Intermediate	0.684	Intermediate	0.718	Good	0.700	Good	0.695	Intermediate
Shanghai	0.742	Good	0.732	Good	0.743	Good	0.723	Good	0.735	Good
Zhejiang	0.684	Intermediate	0.704	Good	0.739	Good	0.728	Good	0.714	Good
Beijing	0.724	Good	0.704	Good	0.724	Good	0.720	Good	0.718	Good
Tianjin	0.723	Good	0.733	Good	0.744	Good	0.697	Intermediate	0.731	Good
Guangdong	0.617	Intermediate	0.655	Intermediate	0.706	Good	0.662	Intermediate	0.658	Intermediate
Fujian	0.643	Intermediate	0.670	Intermediate	0.701	Good	0.672	Intermediate	0.671	Intermediate
Shandong	0.653	Intermediate	0.663	Intermediate	0.692	Moderate	0.669	Intermediate	0.668	Intermediate
Hebei	0.623	Intermediate	0.633	Intermediate	0.660	Intermediate	0.661	Intermediate	0.647	Intermediate
Liaoning	0.606	Intermediate	0.650	Intermediate	0.659	Intermediate	0.617	Intermediate	0.639	Intermediate
Hainan	0.522	Primary	0.549	Primary	0.583	Primary	0.568	Primary	0.559	Primary
Jiangxi	0.574	Intermediate	0.604	Intermediate	0.650	Intermediate	0.628	Intermediate	0.615	Intermediate
AnHui	0.585	Primary	0.586	Primary	0.653	Intermediate	0.643	Intermediate	0.618	Intermediate
Henan	0.553	Primary	0.599	Primary	0.636	Intermediate	0.637	Intermediate	0.611	Intermediate
Hubei	0.603	Intermediate	0.575	Primary	0.621	Intermediate	0.642	Intermediate	0.613	Intermediate
Huanan	0.536	Primary	0.600	Intermediate	0.633	Intermediate	0.626	Intermediate	0.595	Primary
Heilongjiang	0.599	Primary	0.613	Intermediate	0.658	Intermediate	0.640	Intermediate	0.628	Intermediate
Jilin	0.579	Primary	0.585	Primary	0.637	Intermediate	0.614	Intermediate	0.609	Intermediate
Shanxi	0.602	Intermediate	0.606	Intermediate	0.625	Intermediate	0.568	Primary	0.607	Intermediate
Inner mongolia	0.622	Intermediate	0.646	Intermediate	0.639	Intermediate	0.571	Primary	0.627	Intermediate
Chongqing	0.613	Intermediate	0.626	Intermediate	0.682	Intermediate	0.673	Intermediate	0.651	Intermediate

(continued)

Table 4 (continued)

Province	2007	Level	2011	Level	2015	Level	2019	Level	Provincial average	Level
Sichuan	0.600	Intermediate	0.596	Primary	0.647	Intermediate	0.634	Intermediate	0.617	Intermediate
Qinghai	0.584	Primary	0.620	Intermediate	0.623	Intermediate	0.629	Intermediate	0.614	Intermediate
Guangxi	0.550	Primary	0.520	Primary	0.534	Primary	0.537	Primary	0.530	Primary
Guizhou	0.455	Mild	0.411	Mild	0.514	Primary	0.545	Primary	0.478	Mild
Shaanxi	0.544	Primary	0.615	Intermediate	0.559	Primary	0.539	Primary	0.556	Primary
Xinjiang	0.498	Mild	0.508	Primary	0.548	Primary	0.544	Primary	0.515	Primary
Ningxia	0.579	Primary	0.514	Primary	0.541	Primary	0.513	Primary	0.546	Primary
Ganau	0.465	Mild	0.430	Mild	0.515	Primary	0.523	Primary	0.479	Mild
Yunnan	0.414	Mild	0.467	Mild	0.474	Mild	0.500	Primary	0.461	Mild
Annual average	0.592	Primary	0.603	Intermediate	0.635	Intermediate	0.621	Intermediate	0.613	Intermediate

2019. it can be seen that there is a strong interaction between industrial structure and ecological environment in China, while Guizhou, Yunnan, and Gansu show low coupling degree in some years, mainly due to the local industrial structure level, and the unreasonable output value and employment structure of the three provinces cause the industrial structure to seriously lag behind the ecological environment level, resulting in the low coupling degree of the two systems in some years.

4.2.2 Coupling Coordination Degree Measurement

(1) Analysis of the coupling coordination degree between provincial industrial structure and ecological environment

As seen in Table 4, from 2007–2019, the two-system coupling coordination degree of 30 provinces in China was in the range of 0.4–0.8, and the coordination levels involved included mild dissonance, primary coordination, intermediate coordination, and good coordination. From an overall perspective, the level of two-system coupling coordination in China shows an upward trend, with an increase of 0.028 in 2019 compared with 2007, and the benign interaction between the two systems gradually increases; among them, the two-system coupling coordination in China increased by 7% from 2007 to 2015, and influenced by the new development concept and related policies, the coupling coordination started to slowly decline after 2015 until the rebound trend in 2019; in the study Although the coupling coordination degree fluctuated up and down during the period, the overall level always remained at the intermediate coordination stage except for 2007 and 2009 when it was at the primary coordination stage. This indicates that the overall level of coordination between the two systems in China is stable and improving, but there is still a gap between the good coordination and quality coordination stages.

From the perspective of each province, the two-system coupling coordination degree has increased from 2007 to 2019 except for eight provinces, namely Shanghai, Beijing, Tianjin, Shanxi, Inner Mongolia, Guangxi, Shaanxi, and Ningxia, among which Yunnan and Guizhou have the fastest growth rate, both of which have increased by 20%, achieving a shift from negative coupling to positive coupling, and the local two-system coordination and development relationship has entered a new stage; among the provinces with decreasing coupling coordination degree, Ningxia and Inner Mongolia two provinces fell more, respectively, 11% and 8%, but still in the original coordination stage; the current two-system coordination level, only Beijing, Zhejiang, Jiangsu, Shanghai for good coordination level, the rest of the provinces, there are 16 intermediate coordination stage provinces, 10 primary coordination stage provinces, no quality coordination stage provinces, in the primary coordination stage to Ningxia, Yunnan, Gansu for the lower level. It can be seen that there is a large room for upward movement in the coordination degree of the two systems in China, and there are obvious differences in the regional coordination degree, and the coupling coordination relationship between the two systems needs to be further improved.

(2) Analysis of the coupling coordination degree between regional industrial structure and ecological environment

There are obvious regional differences in the coupling coordination degree of the two systems in the eastern, central, and western regions of China. As can be seen from Fig. 4, the coupling coordination degree of the eastern region is above 0.65 during the study period, the central region is mainly concentrated between 0.6–0.65, and the annual average value basically overlaps with the central region, while the western region is between 0.5–0.6, and the gap between the eastern, central and western regions is obvious; the coupling coordination degree of the central and western regions grows faster, and both increase by 6% during the study period, while the eastern region only grows by 3%. It can be seen that the provinces in the eastern region have a good industrial structure foundation and low deviation, and with the transfer of emission enterprises and the development of new industries, the environmental pressure gradually decreases, so the coupling coordination degree of the two systems remains at a high level; the provinces in the central and western regions are both at the primary and secondary coordination stage, among which the overall coordination level in the central region is better than that in the western region due to factors such as resource endowment, urbanization level, and the speed of environmental improvement; the western region is still in the primary coordination stage, but with the rapid development of the tertiary industry, the efficiency of the industrial structure has grown significantly, which has contributed to the rise of the coupling coordination between the two systems. In conclusion, there are still large gaps in the coupling coordination relationship between the two systems in each region, and how to improve the level of coordination between the two systems is an important task at present.

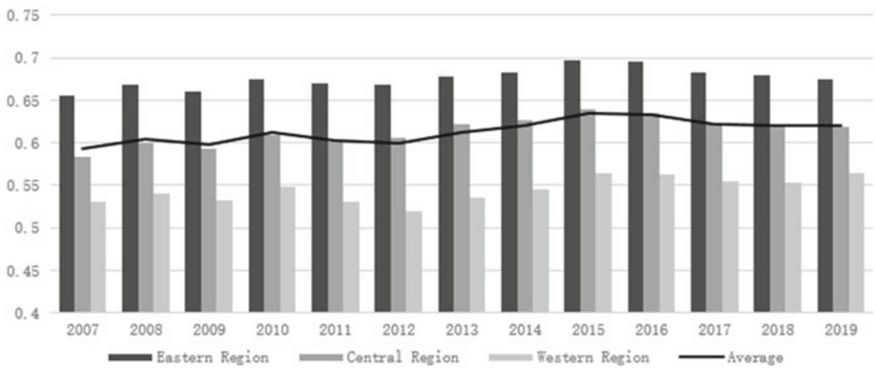

Fig. 4 Differences in the coupling coordination degree between the East, Central, and West systems

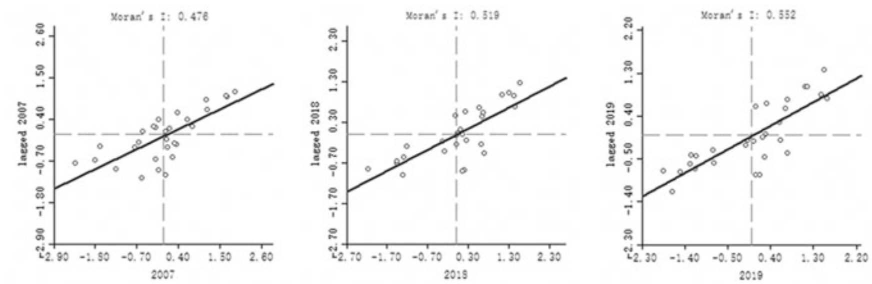

Fig. 5 Moran's I scatter plot of the coupling coordination degree

4.3 Spatial Characteristics Analysis of the Coupling Coordination Degree Between Industrial Structure and Ecological Environment

4.3.1 Global Spatial Autocorrelation Analysis

To further explore the spatial aggregation effect of two-system coupling coordination degree, this paper constructs a spatial weight matrix based on the results of the two-system coupling coordination degree using Geoda software, measures the global Moran's I index and draws a Moran's I scatter plot, which only shows the images of 2007, 2018 and 2019, in this paper as shown in Fig. 5.

It can be seen that China's two-system coupling coordination degree Moran's I am positive from 2007 to 2019, indicating that there is a significant positive spatial correlation between the two-system coupling coordination degree; the overall level of Moran's I index shows an increasing trend during the study period, from 0.476 to 0.552, with 2018- This indicates that the spatial aggregation characteristics of the two-system coupling coordination degree have gradually increased and the inter-regional links have become closer, with most provinces falling in the first and third quadrants during the sample period, indicating that the spatial aggregation of provinces is dominated by "high-high aggregation" and "low-low aggregation". The spatial clustering of provinces is dominated by "high-high clustering" and "low-low clustering", that is, provinces with high coupling coordination of the two systems have higher coupling coordination of their neighboring provinces, and provinces with low coupling coordination of the two systems have low coupling coordination of their neighboring provinces.

4.3.2 Local Spatial Autocorrelation Analysis

As shown in Table 5, China's "high-high aggregation" is mainly distributed in Beijing, Tianjin, Hebei and Jiangsu, Zhejiang and Shanghai regions, which is because the industrial structure in this region is of high level and good efficiency, and the ecological environment is improving faster, thus showing the aggregation phenomenon of high regional coupling coordination degree; “low-low aggregation “ is mainly distributed in Guangxi, Yunnan and other western regions, the reason is that the industrial structure of the region is relatively backward, but small anthropogenic pollution, ecological environment level is high, resulting in the aggregation phenomenon of low coupling coordination degree of the two systems; in addition, there are fewer “high–low aggregation”, mainly exist in some years in Sichuan, In addition, there are fewer “high-low clusters”, mainly in Sichuan, Qinghai, and Chongqing in some years, which are mainly attributed to the fact that the coupling coordination degree of these provinces is higher than that of other provinces around them and the difference is larger. In conclusion, the spatial coupling coordination degree of the two systems in China is mainly characterized by “high-high clustering” and “low-low clustering”, and these two clustering characteristics have some fluctuations but remain stable overall.

Table 5 Classification of spatial changes in the coupling coordination degree

Year	High-High	Low-Low	High–Low
2007	Jiangsu, Zhejiang, Shanghai, Hebei, Beijing, Tianjin	Guangxi, Guizhou	Sichuan
2008	Jiangsu, Zhejiang, Shanghai, Hebei	Guangxi, Qinghai	Sichuan
2009	Jiangsu, Zhejiang, Shanghai, Hebei	Guangxi, Yunnan, Sichuan, Qinghai, Guizhou	–
2010	Jiangsu, Zhejiang, Shanghai, Hebei	Guangxi, Yunnan, Sichuan, Qinghai, Guizhou	–
2011	Jiangsu, Zhejiang, Shanghai, Hebei, Beijing	Guangxi, Yunnan, Sichuan	Qinghai
2012	Jiangsu, Zhejiang, Shanghai, Hebei, Beijing	Guangxi, Yunnan, Sichuan	Qinghai, Chongqing
2013	Jiangsu, Zhejiang, Shanghai, Hebei, Beijing	Guangxi, Yunnan, Sichuan, Qinghai	Chongqing
2014	Jiangsu, Zhejiang, Shanghai, Hebei	Guangxi, Yunnan, Sichuan	Qinghai
2015	Jiangsu, Zhejiang, Shanghai	Guangxi, Yunnan	Sichuan
2016	Jiangsu, Zhejiang, Shanghai, Beijing	Guangxi, Yunnan	Sichuan
2017	Jiangsu, Zhejiang, Shanghai	Ningxia	Sichuan
2018	Jiangsu, Zhejiang, Shanghai, Beijing	Ningxia, Gansu	Sichuan
2019	Jiangsu, Zhejiang, Shanghai, Anhui	Ningxia, Gansu, Inner Mongolia	Sichuan

5 Research Conclusions and Policy Recommendations

In this paper, based on the panel data of 30 provinces in China from 2007 to 2019, the coupling and coordination relationship between industrial structure and ecological environment is studied. Firstly, the index systems of industrial structure and ecological environment were constructed separately, and the weights of each index and comprehensive evaluation index of the two systems were measured by using the global entropy weight method and TOPSIS method; secondly, the coupling degree and coupling coordination degree of the two systems were measured by the coupling degree and coupling coordination degree models respectively; finally, the spatial aggregation characteristics of the coupling coordination degree of the two systems were analyzed by using the spatial autocorrelation method. The following conclusions were obtained.

First, according to the evaluation results of industrial structure and ecological environment, it is found that (1) from 2007–2019, the overall level of industrial structure and ecological environment in China showed an upward trend, among which, the level of ecological environment showed a slight decrease in 2016–2018; (2) the overall level of ecological environment is low, only Heilongjiang, Inner Mongolia, and Yunnan reached above 0.5 in some years; (3) the level of industrial structure There is regional heterogeneity, and the level in the eastern region is significantly better than that in the central and western regions, while the difference between the central and western regions is small, except for Sichuan and Chongqing, the remaining provinces in the western region are slightly lower than that in the central region.

Second, according to the coordination degree of industrial structure and ecological environment, it is found that (1) the coupling degree of the two systems in China is high during the study period, and all provinces reach 0.9 by 2019; (2) the coupling coordination degree of the two systems as a whole shows a fluctuating growth trend, including a slow decline from 2016 to 2018; (3) the coupling coordination degree of Yunnan and Guizhou has the fastest growth rate during the study period, and the decline is large in Ningxia and Inner Mongolia, and by 2019 year, there are 4 good coordination stage provinces, 16 intermediate coordination stage provinces, and 10 primary coordination stage provinces; (4) the gap between the two systems' coordination degrees in the east, central and western regions is large, but is gradually narrowing.

Third, according to the spatial aggregation characteristics of the coupling coordination degree of the two systems, it is found that (1) during the study period, the coupling coordination degrees of both systems in China show positive spatial correlation, and the correlation increases year by year; (2) "high-high aggregation" is mainly distributed in Beijing, Tianjin, Hebei and Jiangsu, Zhejiang and Shanghai regions, "low-low aggregation (2) "High-high aggregation" is mainly distributed in Beijing, Tianjin, Hebei and Jiangsu, Zhejiang and Shanghai, "low-low aggregation" is mainly distributed in Guangxi, Yunnan, and other western regions, and there is less "high-low aggregation".

Based on the above findings, relevant suggestions to enhance the coupling coordination degree of industrial structure and ecological environment coupling in China are proposed.

First, according to local conditions, accelerate the transformation and upgrading of industrial structure and improve the current situation of environmental pollution. The ecological environment level in the eastern region is lower than that in the central and western regions, and the advanced construction of industrial structure needs to be strengthened; we should accelerate the development of technology-oriented and knowledge-intensive industries, improve the core competitiveness of tertiary industries, improve the structure of industrial output value and industrial structure efficiency, and reduce pollution emissions; among them, Guangdong, Fujian, and Jiangsu have a high proportion of secondary industries and poor ecological environment quality, and should realize the transfer of secondary industries to Guangdong, Fujian, and Jiangsu have a high proportion of secondary industries and poor ecological and environmental quality, so they should realize the partial transfer of secondary industries to tertiary industries to reduce energy consumption and improve land-use efficiency. In central and western regions, the rationalization and advanced level of industrial structure need to be improved, among which, the central region should speed up the adjustment of industrial employment structure and accelerate the transfer of employment in the primary industry to secondary and tertiary industries, meanwhile, the central region has outstanding advantages in the development of secondary industry, but most of them are mainly traditional manufacturing industries, so it is necessary to rely on the construction of "one belt and one road" to promote the flow of factors and accelerate the transfer to new industries. Therefore, we should rely on the "Belt and Road" construction, promote the flow of factors, accelerate the transformation and upgrading to new industrialized industries and technology-intensive industries, and achieve green and sustainable development; the western region should accelerate the improvement of infrastructure construction, reduce the deviation of the primary industry structure, do a good job of staff transformation, and strengthen the construction of talents to undertake the industrial transfer work in the eastern and central regions; Yunnan's industrial structure is developing rapidly but is still at the lowest level in the country, and should maintain the local characteristic advantages, accelerate the development of tertiary industry, extend the industrial chain, and promote ecological green development.

Secondly, the collaboration of multiple parties to strengthen ecological and environmental governance and protection, and promote the optimization of industrial structure. At present, China's ecological and environmental situation is severe, the government as the main body should respond positively to ecological and environmental restoration, improve environmental regulation policies, reduce enterprise emissions, and promote the transformation and upgrading of enterprises; at the same time, provinces should also strengthen cooperation and communication with neighboring provinces to achieve regional ecological and environmental management cost-sharing and benefit-sharing. Guangdong, Jiangxi, Jiangsu, and Ningxia's ecological environment level is low, should reduce the total energy consumption, control the area of urban construction land, and improve the comprehensive utilization rate of industrial solid waste, of which, Jiangsu also need to expand the total area of afforestation, improve the greening coverage; Ningxia, as the only province in the western region with low ecological environment quality, should accelerate the treatment of water pollution, improve water quality, improve the utilization rate of water resources, implement ecological compensation mechanism, and Repair the regional ecological environment.

Third, promote each other, accelerate the realization of industrial structure and ecological environment green coordinated development. Provinces should adhere to the ecological priority, green development strategy, on the one hand, to improve industrial technology innovation, improve the level of industrial level, to help achieve the "double carbon" goal, of which, the eastern region to promote industrial technology innovation, the central region due to the solid industrial foundation, should focus on improving industrial production technology, improve industrial clean productivity. On the other hand, each province should promote the formation of a lifestyle that conserves resources and protects the environment, create a beautiful and comfortable ecological environment, attract high-end enterprises and talents, accelerate the optimization and upgrading of industrial structure, and promote green and sustainable development.

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Evolutionary Game Research on Government Regulation and Enterprise Production Behavior Under Reward and Punishment Mechanism

Shuai Chen, Qiufang Fan, and Xiangxing Yan

Abstract In order to explore the influence of government regulation behavior on the production behavior of industrial enterprises in industrial pollution control, this paper constructs an evolutionary game model of local governments and enterprises based on static and dynamic reward and punishment mechanisms, and focuses on the stability of the equilibrium point of the system. The results are verified by example analysis. Finally, the influence of reward and punishment intensity and reporting probability on evolutionary stability strategy (ESS) is discussed. The results show that when the government adopts static subsidies and static punishment, dynamic subsidies and static punishment, there is no evolutionary stable strategy in the game system, but when the probability of reporting reaches a fixed value, both sides will reach stability at the same time; when static subsidies and dynamic penalties, dynamic subsidies and dynamic penalties are adopted, the system has evolutionary stability strategy, and dynamic subsidies and dynamic penalties are the optimal policies; the probability of government active supervision is negatively correlated with the upper limit of subsidy intensity, the probability of reporting and the upper limit of punishment intensity; the probability of cleaner production of industrial enterprises is negatively correlated with the upper limit of subsidy intensity and the probability of reporting, and is positively correlated with the upper limit of punishment intensity.

Keywords Government regulation · Dynamic reward and punishment mechanism · Evolutionary game · Evolutionary stability strategy

1 Introduction

In September 2020, President Xi Jinping made a solemn commitment to the world at the 75th United Nations General Assembly that China will reach its carbon peak by 2030 and carbon neutrality target by 2060. In order to strengthen the control

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of carbon emissions and further improve the requirements and quality of environmental pollution management, the Chinese government released the Action Plan for Carbon Peaking by 2030 in October 2021, which focuses on requiring energy to transition to green and low-carbon, and industry to move towards clean and low-carbon development, guiding industrial enterprises to upgrade their green innovation and accelerate the pace of cleaner industrial production. However, at present, most industrial enterprises have not completed the transition from traditional production to cleaner production [1], which adds to the difficulty of reaching the double carbon target and achieving green and sustainable development. The reason for this is that the profit maximisation nature of enterprises makes them opportunistic in their decision to choose cleaner production [2]. It is clear that the government, as the main body of environmental governance, is the key to achieving China's dual carbon goals and green sustainable development by formulating a scientific and effective reward and punishment mechanism and choosing a reasonable regulatory strategy to guide and regulate the production behaviors of enterprises in the face of conflicting interests.

At present, there has been a great deal of academic research on the relationship between government regulation and the production behaviors of enterprises. Government regulation is divided into two main areas: policy subsidies and the implementation of reward and punishment mechanisms. In terms of government policy subsidies, Liao Xinlin et al. [3] found that government policy subsidies have a significant leverage effect on the development of enterprises themselves, and the effect becomes more and more obvious as the degree of industrialisation increases. Some scholars have found that appropriate government subsidies can stimulate green technology innovation, but too high a subsidy can have a dampening effect on firms' innovation behaviors [4, 5], which shows that the effect of government subsidies is closely related to the amount of subsidies, i.e., there is an optimal range in which government subsidies can better promote firms' innovation without creating a dampening effect. Later, Wang and Xiaohua [6] found that when the intensity of government subsidies was in the range of 75–100%, the internal R&D investment of enterprises increased significantly and the efficiency of industrial enterprises in transitioning to cleaner production was enhanced accordingly. This view has also been verified in the study of Hui et al. [7] on enterprise R&D investment. However, some scholars argue that government subsidies show a crowding-out effect on industrial firms' innovation investment [8–10], i.e., when firms themselves plan and have the ability to invest in green technology innovation, if the government subsidises them, they will invest their own R&D funds in other highly profitable projects, creating a substitution effect. Yu [11] and Xu et al. [12] also found that over-reliance on government subsidies can lead to this effect.

In terms of government incentives and penalties, Chen et al. [13] compared the dynamic evolution of firms' decision making process in choosing traditional production versus green and low-carbon production before and after the introduction of government incentives and penalties. Zhaogun et al. [14] discussed the impact of rewards and punishments on enterprises' low-carbon transition decisions from the perspectives of both endogenous and exogenous dynamics. Zhu et al. [15] investigated the impact of government incentives and penalties on the performance of their own regulatory duties and enterprise production through a three-way evolutionary game model. Xue et al. [16] constructed a two-tier planning model with both incentives and penalties and carbon emission quotas, and empirically analysed the effect of incentives and penalties on promoting clean emissions reduction in enterprises. Wiguo et al. [17] studied the impact of government adoption of incentive subsidies and punitive taxes on the decision of emission reduction behavior of enterprise clusters under low carbon policies. Zhu et al. [18] constructed an evolutionary game model between the government and enterprises based on system dynamics and introduced a reward and punishment mechanism to analyse the interaction mechanism of their strategies. Jiao et al. [19] further studied the evolutionary path of the behaviors of both parties under the reward and punishment mechanism by correlating important indicators with carbon emissions on the basis of Zhu Qinghua et al. and dissected the influencing factors.

Game theory has also been widely used to study the conflict and cooperation relationship between government and enterprises in environmental governance. In 2003, Moledina [20] used a dynamic game model to analyze firms' coping strategies in the face of different government policies, and Duan et al. [21] investigated the choice between government environmental regulation strategies and firms' production behaviors under the implementation of tax and penalty measures. However, most scholars in related types of studies assume that the participants are perfectly rational [22], but this is not actually the case; local governments have asymmetric information between the two parties when governing industrial enterprises, and are basically limitedly rational. This problem is perfectly solved by evolutionary games, in which the participants are finitely rational [23] and the information between them is not perfectly symmetric [24]. Sun [25] and Wang [26] studied the evolutionary game between the central government and the local government on the regulatory strategy from the subject side of governance, and Wu et al. [27] investigated the impact of government incentives on the implementation of low-carbon behaviors by constructing an evolutionary game model between government and enterprises et al. [28] analyzed the interaction and influencing factors of pollution control, government regulation and public participation in industrial enterprises through a tripartite evolutionary game model, providing a theoretical basis for the government to establish an effective environmental governance system and improve the efficiency of environmental governance and public satisfaction.

In summary, most of the current literature uses evolutionary games to study the evolutionary stabilization strategies of government and enterprises under a static reward and punishment mechanism, whereas in practice, government subsidies and penalties are not static and discussing only static mechanisms cannot reflect the dynamic nature of governmental reward and punishment policies. In addition, most studies do not take third-party reporting into account when analysing the government's decision-making behaviors. In fact, due to the existence of self-media and social organisations, even if the government adopts passive regulation, there is still the possibility that industrial enterprises' irregularities will be reported and thus punished, and once the reporting behaviors occurs, the effect will be the same as if the government adopts active regulation. (1) Using the evolutionary game approach, we focus on the evolutionary stabilization strategy between government and enterprises and the influence mechanism on the clean production behaviors of industrial enterprises under four policy combinations of local government's dynamic reward and punishment mechanism (static subsidy and static penalty, dynamic subsidy and static penalty, static subsidy and dynamic penalty, and dynamic subsidy and dynamic penalty). (2) A third-party reporting factor other than the two game subjects is considered to further supplement and improve the absence of third-party influencing factors in similar studies. (3) Through simulation, the evolutionary stabilization strategies of industrial enterprises' production behaviors under different reward and punishment mechanisms are analyzed and compared, and the optimal subsidy and punishment mechanisms are selected to provide some theoretical reference for the government to promote cleaner production and control industrial pollution in industrial enterprises.

2 Construction and Analysis of an Evolutionary Game Model Under Static Reward and Punishment Mechanism

2.1 Description of the Problem

This paper investigates the evolutionary game between local governments and industrial enterprises under the incentive and punishment mechanism, where the main players are local governments and industrial enterprises. The local government has two strategic choices after formulating a policy of incentives and penalties to guide industrial enterprises to adopt cleaner production, to actively regulate the production behaviours of the enterprises or to passively regulate them, where passive regulation refers to the government's action of regulating only after third-party reports. Industrial enterprises also have two strategic options, either to respond to the national environmental policy and engage in cleaner production, or to ignore the national environmental policy and continue to adopt the traditional non-clean production model. If the local government, as the supervisor, adopts active supervision, the government will give certain subsidies as incentives when the enterprises choose cleaner production, such as lower interest rates on loans, reduced tax payments, when the enterprises choose traditional non-clean production, the government will give corresponding penalties according to the enterprises' pollution emission status, such as fines, restrictions on production, suspension of production and rectification, etc.; when the government chooses passive supervision, no matter which production mode the enterprises adopt, they will not receive subsidies. When the government chooses passive regulation, no matter which production mode the enterprise adopts, it will not receive subsidies, and the enterprise's non-clean production behaviours have the probability of being reported by a third party, when the third party reports occur, it is equivalent to the government taking active supervision, and the enterprise will still be subject to supervision and punishment from the government.

2.2 Model and Assumptions

Hypothesis 1: During the game, both local governments and industrial enterprises are finite rational.

Hypothesis 2: In the group of industrial enterprises, the proportion of those who choose to carry out cleaner production strategy is x, then the proportion of those who choose the traditional no cleaner production strategy is $1-x$; in the group of local governments, the proportion of those who adopt active regulation strategy is y, then the proportion of those who adopt passive regulation strategy is $1-y$. where $x, y \in [0, 1]$ are satisfied.

Hypothesis 3: When the government carries out active regulation and the enterprise carries out cleaner production, the basic benefit of the enterprise is I1 and the cost is C1, the basic benefit of the government is I2, the cost of regulation is C3, and the subsidy given is S. At this time, the total benefit of the enterprise is $I1-C1+S$, and the total benefit of the government is I2-S-C3.

Hypothesis 4: When the government carries out active regulation and the enterprise carries out traditional production, the basic benefit to the enterprise is I1, the cost drops to C2 due to the lack of equipment upgrades and expenses such as source control, and the penalty P given by the government, while the damage caused to the environment leads to a lower reputation of the government, the basic benefit to the government drops to I3, and also the economic loss to society (e.g., pollution leading to respiratory diseases in the population and At this point, the total benefit to the firm is I1-C2-P and the total benefit to the government is $I3\text{-}C3 + P\text{-}D$. where $C1 > C2$ is satisfied.

Hypothesis 5: When the government carries out passive regulation and the enterprise carries out cleaner production, the total benefit to the enterprise is I1-C1 and the total benefit to the government is I2.

Hypothesis 6: When the government carries out passive regulation and the enterprise carries out traditional production, if the government receives reports from the public and reports anonymously, it will punish the enterprise similarly with probability β. At this time, the total return to the enterprise is I1-C2-βP and the total return to the government is $I3\text{-}D + \beta P$.

The relevant symbols in the hypothesis are shown in Table 1. Based on the above assumptions, the matrix of benefits for industrial enterprises and local governments is constructed as shown in Table 2.

Based on the above benefit matrix and game relationship between local governments and industrial enterprises, the replication dynamic equation between them is constructed and firstly solved to derive the adaptation degree and average adaptation degree of both parties under the two strategies.

For the local government, the adaptation degree of adopting the active regulatory strategy is as follows.

Table 1 Description of parameters and variables

Symbols	Description
I_1	Corporate fixed income
I_2	Government benefits when enterprises are cleaner
I_3	Government benefits when enterprises produce conventionally
C_1	Cost of cleaner production
C_2	Cost of traditional production for enterprises
C_3	Government monitoring costs
S	Government subsidies to enterprises for cleaner production
P	Government penalties for traditional production by enterprises
D	Socio-economic losses
β	Probability of government passively regulating enterprises being reported

Table 2 Benefits matrix for industrial enterprises and local governments

Industrial companies	Local government			
	Proactive regulation passive regulation		Proactive regulation passive regulation	
Clean production	I_1-$C_1 + S$	I_2-S-C_3	I_1-C_1	I_2
Traditional production	I_1-C_2-P	I_3-$C_3 + P$-D	I_1-C_2-βP	I_3-$D + \beta P$

$$E_{11} = x(I_2 - S - C_3) + (1 - x)(I_3 - C_3 + P - D)$$

Adaptability in adopting passive regulatory strategies:

$$E_{12} = xI_2 + (1 - x)(I_3 - D + \beta P)$$

Average adaptation:

$$\overline{E}_1 = yE_{11} + (1 - y)E_{12}$$

Based on the Malthusian equation, the replication dynamics sub-equation for local government is obtained as:

$$F_1(y) = \frac{dy}{dt} = y\left(E_{11} - \overline{E}_1\right) = y(1 - y)[P - C_3 - \beta P - x(S + P - \beta P)]$$

Similarly, the replication dynamics sub-equation for industrial firms can be obtained as:

$$F_1(x) = \frac{\mathrm{d}x}{\mathrm{d}t} = x\left(U_{11} - \overline{U}_1\right) = x(1 - x)[-C_1 + C_2 + \beta P + y(S + P - \beta P)]$$

A two-dimensional dynamical system (I) can be obtained from Eqs. (4) and (5)

$$\begin{cases} F_1(x) = \frac{dx}{dt} = x(1-x)[-C_1 + C_2 + \beta P + y(S + P - \beta P)] \\ F_1(y) = \frac{dy}{dt} = y(1-y)[P - C_3 - \beta P - x(S + P - \beta P)] \end{cases}$$

Proposition 1 *The equilibrium points in system (I) are (0, 0), (0, 1), (1, 0), (1, 1). When* $0 < C_1 - C_2 < S + P$, (x_1^*, y_1^*) *is likewise an equilibrium point of system (I).*

Proof In system (I), let $\frac{dy}{dt} = 0$, $\frac{dx}{dt} = 0$, respectively, and by solving the results we can get (0,0), (0,1), (1,0), (1,1) are the equilibrium points of the system, when $0 < C_1 - C_2 < S + P$, (x_1^*, y_1^*) is also the equilibrium point of the system. Of which $x_1^* = \frac{P - C_3 - \beta P}{S + P - \beta P}$, $y_1^* = \frac{C_1 - C_2 - \beta P}{S + P - \beta P}$, proof complete.

2.3 Stability Analysis of System Evolutionary Equilibrium Points

According to the idea proposed by Friedman [29], the stability of the equilibrium point of a system of differential equations can be obtained by analysing the local stability of the Jacobian matrix, so the Jacobian matrix can be used to explore the local stability of the system and thus to analyse the final evolutionary stability. The Jacobian matrix can be obtained by taking partial derivatives with respect to x and y for the replicated dynamic equations in the two-dimensional dynamical system (I).

$$J = \begin{bmatrix} \frac{\partial F_1(x)}{\partial x} & \frac{\partial F_1(x)}{\partial y} \\ \frac{\partial F_1(y)}{\partial x} & \frac{\partial F_1(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

$$= \begin{bmatrix} (1-2x)[-C_1 + C_2 + \beta P + y(S + P - \beta P)] & x(1-x)(S + P - \beta P) \\ y(1-y)(\beta P - S - P) & (1-2y)[P - C_3 - \beta P - x(S + P - \beta P)] \end{bmatrix}$$

where det(J) $= a_{11}a_{22}$ matrix determinant $det(J) = a_{11}a_{22} - a_{12}a_{21}$ matrix trace $tr(J) = a_{11} + a_{22}$, when the equilibrium point in the system satisfies the conditions $det(J) > 0$ and $tr(J) < 0$, then the equilibrium point in the system replicating the dynamic equations is stable, for the evolutionary stability strategy (ESS), the stability analysis results of the evolutionary equilibrium point in the two-dimensional dynamic system are shown in Table 3.

From the analysis in Table 3, it can be seen that the equilibrium points (0,0), (0,1), (1,0), (1,1) are all saddle points and the equilibrium point (x_1^*, y_1^*) is the central point. There is no evolutionary stabilization strategy (ESS) in system (I), and the behavioral strategies of both parties will make a cycle around the equilibrium point (x_1^*, y_1^*), and the game behavior in the system will not gradually stabilize to the equilibrium point.

Table 3 Two-dimensional dynamical system (I): stability analysis of equilibrium points

Balance point	det(J)	tr(J)	State
(0, 0)	–	N	Saddle point
(0, 1)	–	N	Saddle point
(1, 0)	–	N	Saddle point
(1, 1)	–	N	Saddle point
(x_1^*, y_1^*)	+	0	Centre point

Note "+ " is greater than 0, "−" is less than 0, "N" is not sure

2.4 Analysis of Algorithms

Under the premise of satisfying the model requirement $0 < C_1 - C_2 < S + P$, the initial parameters are assigned with the actual situation of the country. Assume that the cost of an industrial enterprise that ignores the national policy call to go against green and still carry out traditional production is 300,000, and if it responds positively to the national call to strengthen source control, establish an inter-enterprise waste utilisation chain, upgrade obsolete equipment and introduce new energy-saving and efficient technologies for cleaner production, the cost will increase to 550,000. Meanwhile the incentive subsidy given by the local government is 100,000. If an enterprise violates the law by not treating industrial by-products, etc., resulting in pollutant emissions exceeding the standard, it will be fined 500,000 by the government, the cost expenditure for the government to take active supervision is 100,000, and the initial value of the probability of an enterprise carrying out traditional production being reported is 0.1. In summary, the initial values of each variable parameter are as follows: $C_1 = 55$, $C_2 = 30$, $C_3 = 10$, $S = 10$, $P = 50$, $\beta = 0.1$. The above assignments are brought into the expression of (x_1^*, y_1^*) to find $x_1^* = 0.636$, $y_1^* = 0.364$, which will be used as the initial system strategy for Matlab simulation analysis respectively.

From Fig. 1, it can be seen that when the initial strategy $x_1^* = 0.636$ is chosen for the probability of cleaner production of industrial enterprises, and three fixed values $y_1^* = 0.2$, $y_1^* = 0.5$, $y_1^* = 0.8$ are chosen in [0,1] for the probability of active regulation by local government respectively, the probability of active regulation by government always oscillates up and down over time and the system cannot be stabilized. Similarly, in Fig. 2 when the local government's active regulation probability chooses the initial strategy $y_1^* = 0.364$ and the enterprise's cleaner production probability chooses three fixed values $x_1^* = 0.2$, $x_1^* = 0.5$, $x_1^* = 0.8$ in [0,1] respectively, the enterprise's cleaner production probability keeps oscillating up and down over time and the system cannot reach stability. This indicates that when x or y choose the equilibrium point as the initial strategy and the other side takes a fixed value, the evolutionary game curve of the system always oscillates up and down and cannot reach stability. When the initial values of x and y in the system are both the same fixed values, set the initial values of x and y to 0.1 and the running time to [0,5], the dynamic evolution process of the system is shown in Fig. 3, which is a closed

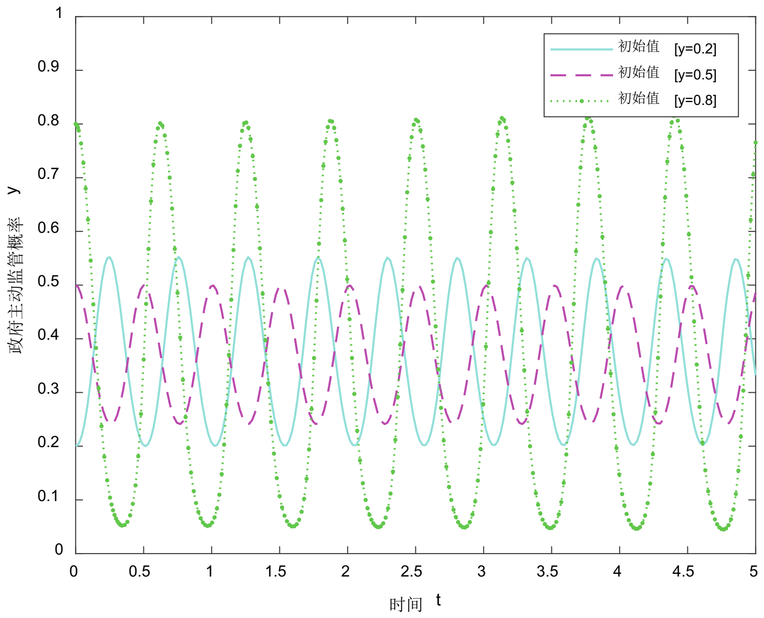


Fig. 1 Evolutionary path of proactive government regulation

loop with periodic motion around the central point (x_1^*, y_1^*) and cannot reach the equilibrium point automatically. It shows that the active regulation by local governments and cleaner production by industrial enterprises in this system show a cyclical pattern of behaviors. It is worth noting that the change in the reporting probability β has a more significant impact on the stability of the system evolution, as shown in Figs. 4 and 5. When the initial value of β is adjusted from 10 to 50%, it can be seen that the amplitude and period of the system oscillation also increases, and once it reaches 50%, the system will immediately stabilise. The specific reasons for this will be discussed later in this paper.

3 Construction and Analysis of Evolutionary Games Under Dynamic Reward and Punishment Mechanisms

3.1 *Dynamic Subsidies*

Assume that the local government's subsidy policy for cleaner production enterprises is related to the enterprises' own strategic choices. When the enterprises choose cleaner production and invest more in upgrading equipment or introducing new technologies, etc., the government gives equal proportional subsidies according to

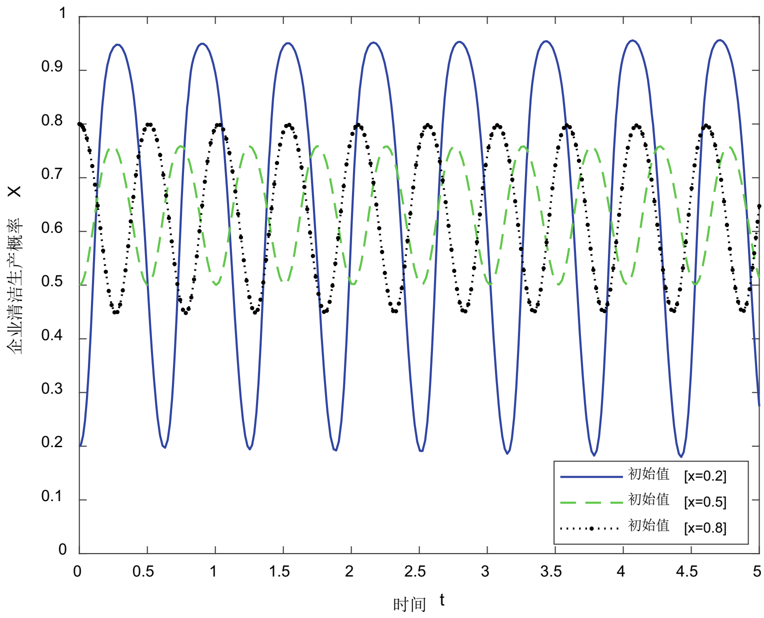


Fig. 2 Evolutionary path of cleaner production in enterprises

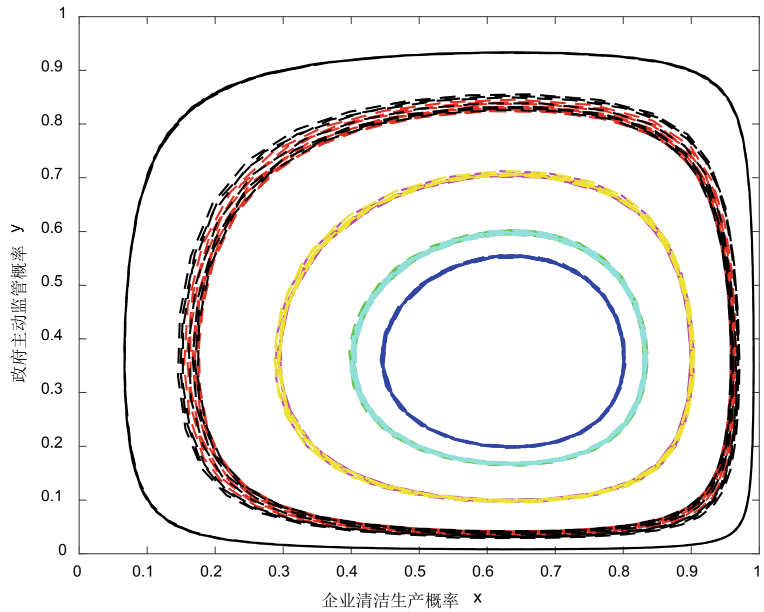


Fig. 3 Diagram of the dynamic evolutionary process of system (I)

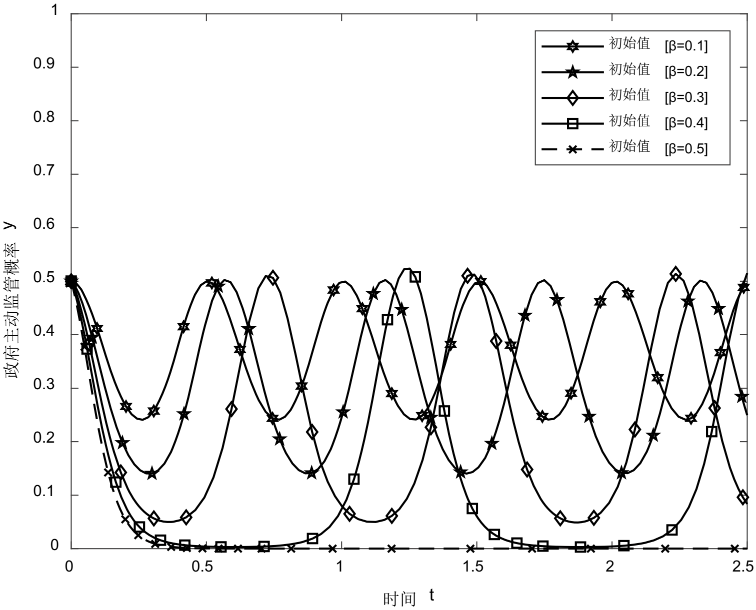


Fig. 4 Evolutionary path of government behaviors as the value of β cha

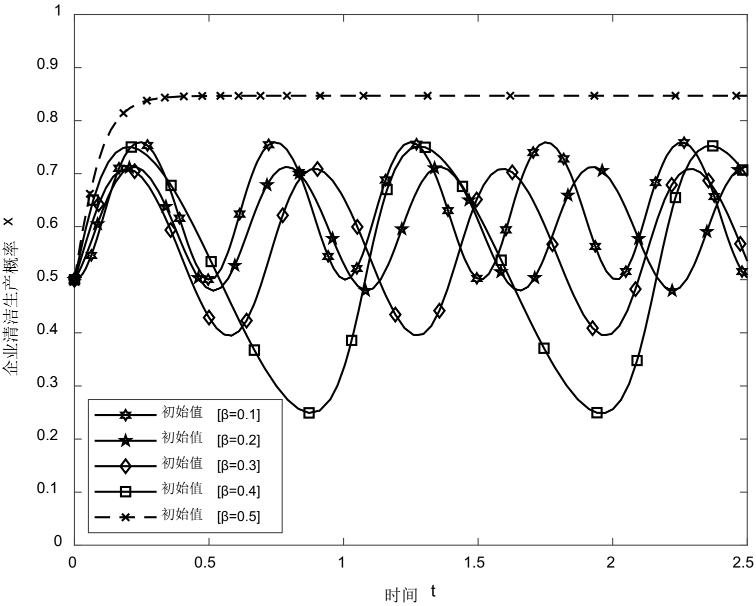


Fig. 5 Evolutionary path of enterprise behaviours as β varies

their input costs, the higher the input, the stronger the subsidy. Thus let the original government subsidy S be the maximum incentive, and under this mechanism the existing subsidy changes from the original S to $S(x) = xS$, which can be substituted into Eq. (6) to obtain the two-dimensional dynamical system (II).

$$\begin{cases} F_2(x) = \frac{\mathrm{d}x}{\mathrm{d}t} = x(1-x)[-C_1 + C_2 + \beta P + y(xS + P - \beta P)] \\ F_2(y) = \frac{\mathrm{d}y}{\mathrm{d}t} = y(1-y)[P - C_3 - \beta P - x(xS + P - \beta P)] \end{cases}$$

Proposition 2 *The equilibrium points in system (II) are (0,0), (0,1), (1,0), (1,1). If the following conditions are satisfied:*

$$\begin{cases} 0 < 2(C_1 - C_2 - \beta P) < (1-\beta)P + \sqrt{(1-\beta)^2 P^2 - 4S(C_3 + \beta P - P)} \\ 0 < (\beta - 1)P + \sqrt{(1-\beta)^2 P^2 - 4S(C_3 + \beta P - P)} < 2S \end{cases}$$

(x_2^*,y_2^*) *is likewise the equilibrium point of system (II).*

Proof In system (II), let $\frac{\mathrm{d}x}{\mathrm{d}t} = 0$, $\frac{dy}{dt} = 0$, respectively, and by solving the results we can get (0,0), (0,1), (1,0), (1,1) are the equilibrium points of the system, when Eq. (9) holds, (x_2^*, y_2^*) is also the equilibrium point of the system. where $x_2^* = \frac{2(C_1 - C_2 - \beta P)}{(1-\beta)P + \sqrt{(1-\beta)^2 P^2 - 4S(C_3 + \beta P - P)}}$, $y_2^* = \frac{(\beta - 1)P + \sqrt{(1-\beta)^2 P^2 - 4S(C_3 + \beta P - P)}}{2S}$, the proof is complete.

The Jacobian matrix expression for the two-dimensional dynamical system (II) is as follows:

$$J = \begin{bmatrix} \frac{\partial F_2(x)}{\partial x} & \frac{\partial F_2(x)}{\partial y} \\ \frac{\partial F_2(y)}{\partial x} & \frac{\partial F_2(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

The equilibrium points in system (II) were analysed in conjunction with the Jacobian matrix and the results are shown in Table 4.

From the analysis in Table 4, it can be seen that the equilibrium points (0,0), (0,1), (1,0), (1,1) are all saddle points and the equilibrium point (x_2^*,y_2^*) is the central point, there is also no evolutionary stabilization strategy (ESS) in system (II), and

Table 4 Two-dimensional dynamical system (II): stability analysis of the equilibrium point

Balance point	det(J)	tr(J)	State
(0, 0)	–	N	Saddle point
(0, 1)	–	N	Saddle point
(1, 0)	–	N	Saddle point
(1, 1)	–	N	Saddle point
(x_2^*, y_2^*)	+	0	Centre point

Note "+" is greater than 0, "–" is less than 0, "N" is not sure the behavioral strategies of both sides will make a cycle around the equilibrium point (x_2^*, y_2^*) The game behaviour in the system will not gradually stabilise to the equilibrium point. This means that the dynamic subsidy mechanism does not change the behavioural strategy evolution of both parties in system (I).

The results obtained are verified by Matlab simulation below.

As shown in Figs. 6 and 7, compared with the static subsidy mechanism, the evolutionary game curve between the government and enterprises in system (II) under the dynamic subsidy mechanism still keeps oscillating up and down over time, and the amplitude of the oscillation has increased significantly, making the whole game process more difficult to stabilize; the dynamic evolutionary process of the system, as shown in Fig. 8, is a spiral closed curve around the central point (x_2^*, y_2^*), which cannot automatically reach equilibrium. Figures 9 and 10 show that in system (II), the amplitude and period of the evolutionary game curves of the government's proactive regulatory behaviors and the enterprises' cleaner production behaviors still increase with the initial value of β, but the amplitude of the oscillations also increases significantly and is more difficult to stabilise than in system (I).

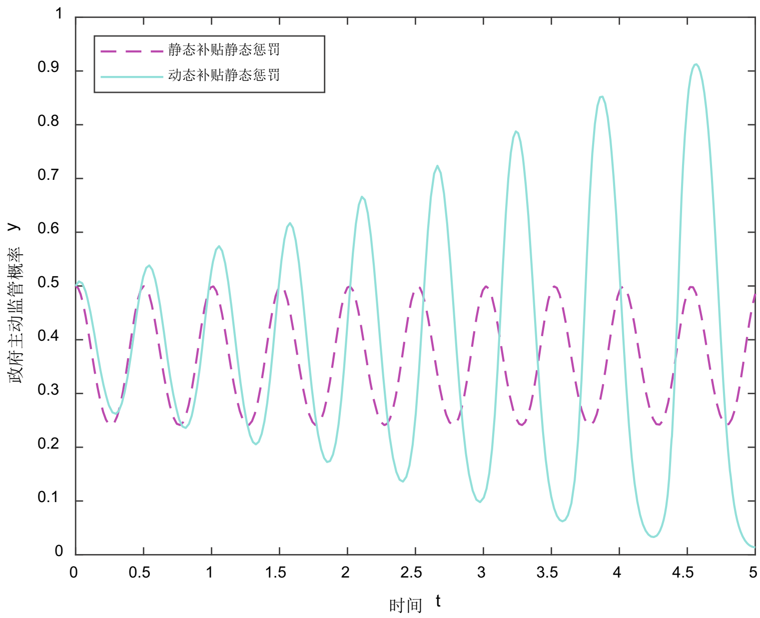


Fig. 6 Evolutionary path of proactive government regulation

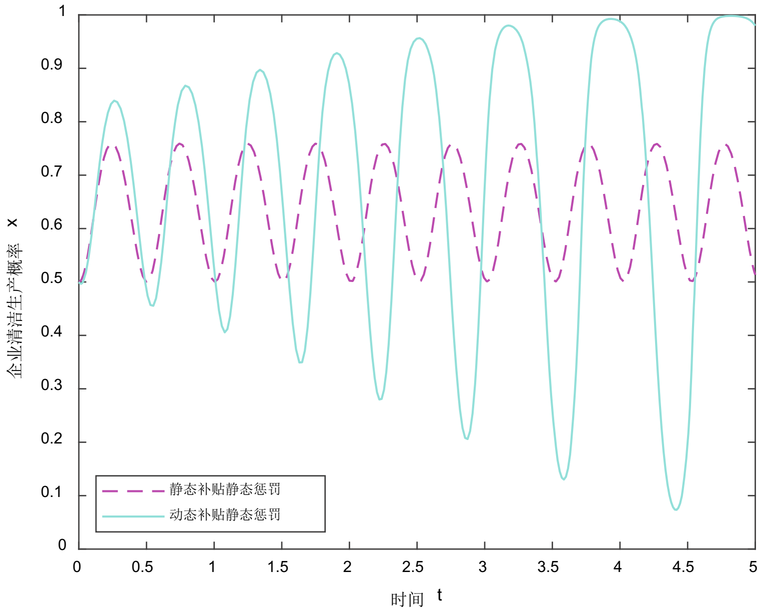


Fig. 7 Evolutionary path of cleaner production in enterprises

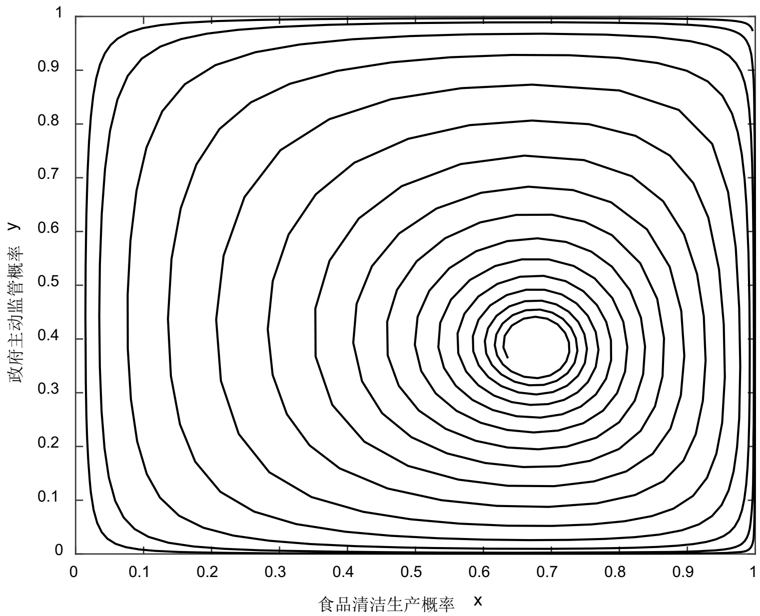


Fig. 8 Diagram of the dynamic evolutionary process of system (II)

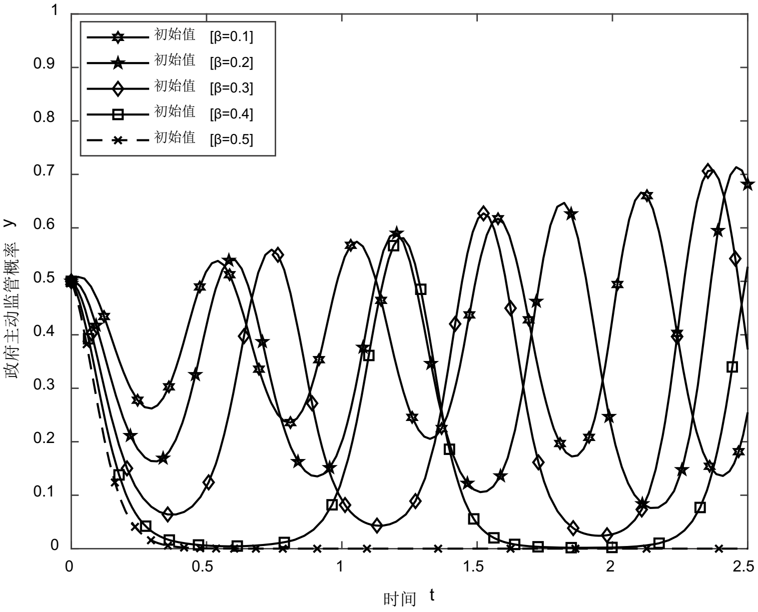


Fig. 9 Evolutionary path of government behaviors as the value of β changes

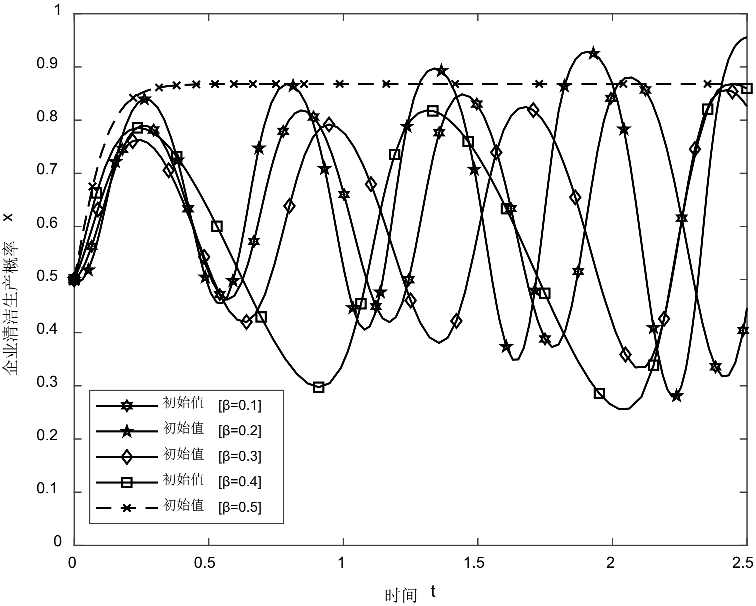


Fig. 10 Evolutionary path of enterprise behaviors as β varies

3.2 Dynamic Penalties

Under this mechanism, it is assumed that the level of punishment imposed by the local government on industrial enterprises is related to their cleaner production behaviors, and that when the probability of an enterprise choosing cleaner production behaviors is higher, the probability of the government punishing it is lower. That is, there is an inverse linear function relationship between the two, where the lower the probability of an enterprise's cleaner production input, the higher the probability of the government punishing it. Therefore let the original government penalty P be the upper bound of the penalty and the existing dynamic penalty $P(x) = (1 - x)P$, which is brought into Eq. (6) to obtain the two-dimensional dynamical system (III).

$$\begin{cases} F_3(x) = \frac{dx}{dt} = x(1-x)[-C_1 + C_2 + \beta(1-x)P + y[S + (1-x)(1-\beta)P]] \\ F_3(y) = \frac{dy}{dt} = y(1-y)\left[(1-x)^2(1-\beta)P - C_3 - Sx\right] \end{cases}$$

Proposition 3 *The equilibrium points of the evolutionary game in system (III) are (0,0), (0,1), (1,0), (1,1). If the following conditions are satisfied.*

$$\begin{cases} 0 < 2(1-\beta)P + S - K < 2(1-\beta)P \\ 0 < 2(C_1 - C_2)(1-\beta)\beta + S - K < (1-\beta)\beta(S+K) \end{cases}$$

Note: $K = \sqrt{S^2 + 4(1-\beta)PS - 4(1-\beta)PC_3}$.
(x_3^*, y_3^*) is likewise the equilibrium point of system (III).

Proof In system (III), let $\frac{\mathrm{d}x}{\mathrm{d}t} = 0$, $\frac{dy}{dt} = 0$, respectively, and by solving the result we get that (0,0), (0,1), (1,0), (1,1) are the equilibrium points of the system, and when Eq. (12) holds, (x_3^*, y_3^*) is also the equilibrium point of the system. $x_3^* = \frac{2(1-\beta)P + S - \sqrt{S^2+4(1-\beta)PS-4(1-\beta)PC_3}}{2(1-\beta)P}$, $y_3^* = \frac{2(C_1-C_2)}{S+\sqrt{S^2+4(1-\beta)PS-4(1-\beta)PC_3}} + \frac{S-\sqrt{S^2+4(1-\beta)PS-4(1-\beta)PC_3}}{(1-\beta)\beta\left(S+\sqrt{S^2+4(1-\beta)PS-4(1-\beta)PC_3}\right)}$, and the proof is complete.

The Jacobian matrix expression for the two-dimensional dynamical system (III) is as follows.

$$J = \begin{bmatrix} \frac{\partial F_3(x)}{\partial x} & \frac{\partial F_3(x)}{\partial y} \\ \frac{\partial F_3(y)}{\partial x} & \frac{\partial F_3(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

In Eq. (13):

$$a_{11} = (1-2x)\left[-C_1 + C_2 + \beta(1-x)P + y[S + (1-x)(1-\beta)P]\right] - x(1-x)[\beta P + (1-\beta)Py]$$
$$a_{12} = x(1-x)[S + (1-x)(1-\beta)P]$$
$$a_{21} = y(1-y)[-2(1-\beta)P(1-x) - S]$$
$$a_{22} = (1-2y)[(1-x)^2(1-\beta)P - C_3 - Sx]$$

Table 5 Two-dimensional dynamical system (III): stability analysis of equilibrium points

Balance point	det(J)	tr(J)	State
(0, 0)	–	N	Saddle point
(0, 1)	–	N	Saddle point
(1, 0)	–	N	Saddle point
(1, 1)	–	N	Saddle point
(x_3^*, y_3^*)	+	–	ESS

Note "+" is greater than 0, "–" is less than 0, "N" is not sure

The equilibrium points in system (III) were analysed in conjunction with the Jacobian matrix and the results are shown in Table 5.

From the analysis in Table 5, it can be seen that the equilibrium points (0,0), (0,1), (1,0), (1,1) are all saddle points, and the equilibrium point(x_3^*, y_3^*) is the stable evolution strategy (ESS), and the point (x_3^*, y_3^*) is brought into the Jacobian matrix for solution. Through the study of Jonker et al. [30], it can be seen that when the matrix of The system (III) is asymptotically stable when the eigenvalues all have negative real parts, and the evolutionary trajectory is a spiral curve and gradually converges to the evolutionary stability point(x_3^*, y_3^*). This indicates that there is a stable evolutionary strategy between the local government and industrial enterprises under the dynamic punishment mechanism, with the probability of cleaner production for enterprises being x_3^* and the probability of the government implementing active regulation being y_3^*, respectively.

The results obtained are verified by Matlab simulation below.

As shown in Figs. 11 and 12, compared with the static penalty mechanism, the evolution of the decision-making behaviors of the government and the firm in system (III) under the dynamic penalty mechanism no longer fluctuates up and down with time and the number of games, but transforms into a process that gradually converges until it eventually stabilises. The dynamic evolution of the system is shown in Fig. 13, where the curve continues to converge in a spiral fashion, gradually approaching and eventually stabilising at the equilibrium point(x_3^*, y_3^*), and the system has asymptotic stability. As can be seen in Figs. 14 and 15, when the initial value of the probability of reporting β is adjusted from 10 to 50%, the probability of government active regulation is gradually decreasing, and the rate of decrease is showing an increasing trend; while the probability of cleaner production of enterprises also shows a gradual decrease, but the rate is lower than the former. This suggests that the effect of a change in the probability of reporting β is the same for both parties under the dynamic penalty mechanism, but that firms are less sensitive to the change than the government.

3.3 Dynamic Subsidies Dynamic Penalties

It is assumed that the local government's subsidy and penalty policies for cleaner production enterprises are both related to the enterprises' own strategic choices, with

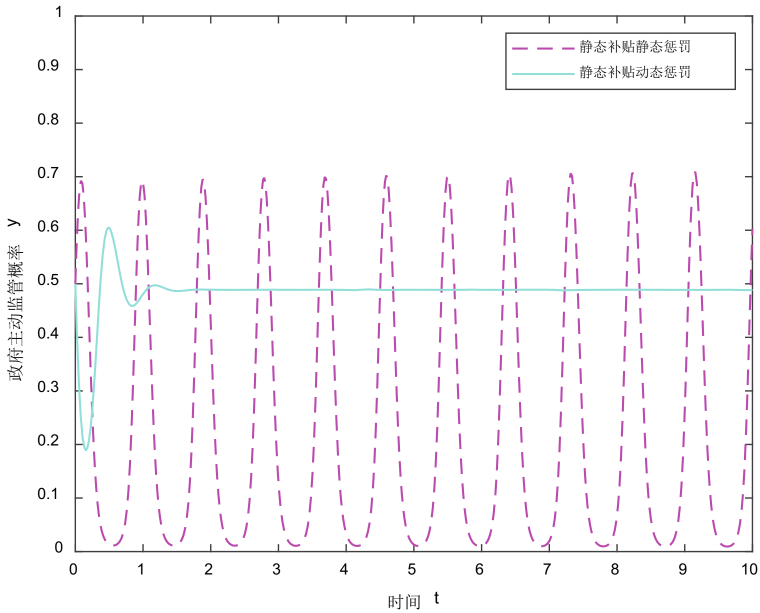


Fig. 11 Evolutionary path of proactive government regulation

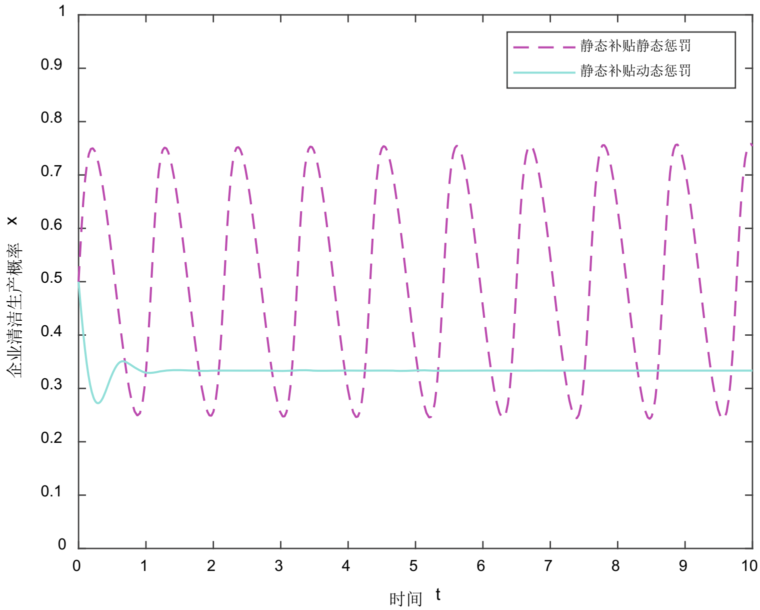


Fig. 12 Evolutionary path of cleaner production in enterprises

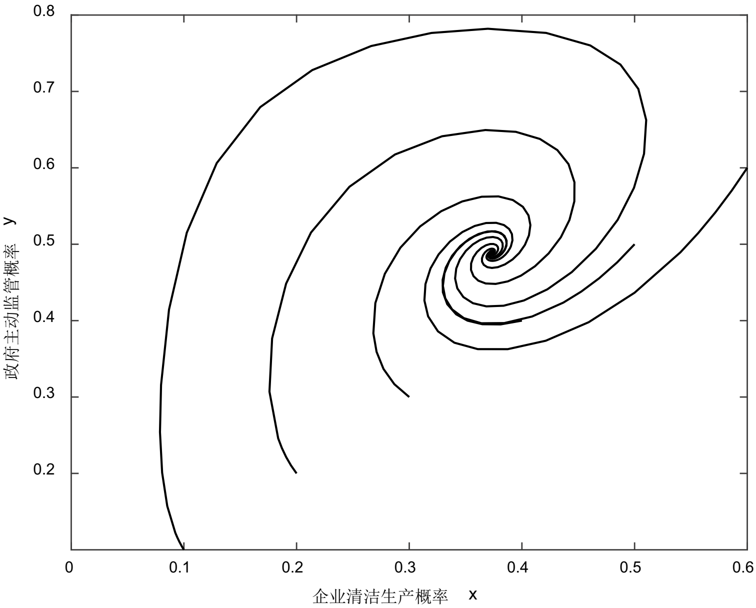


Fig. 13 Diagram of the dynamic evolutionary process of system (III)

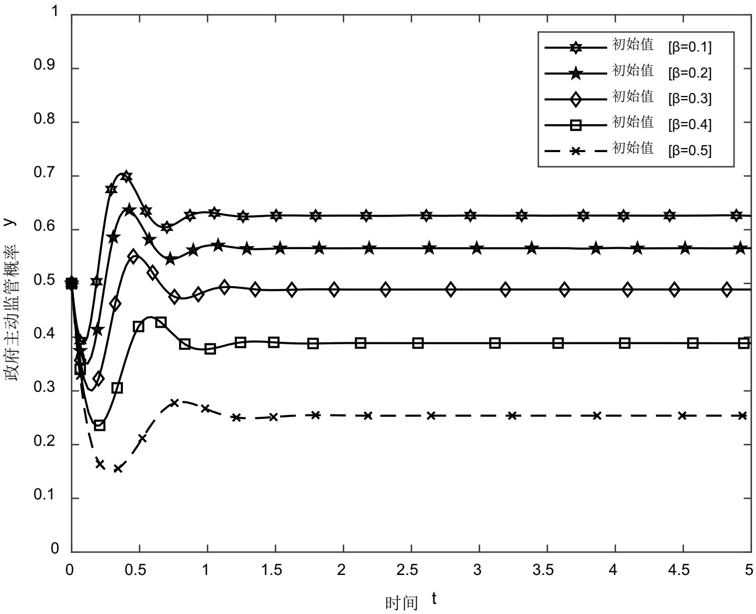


Fig. 14 Evolutionary path of government behaviors as the value of β changes

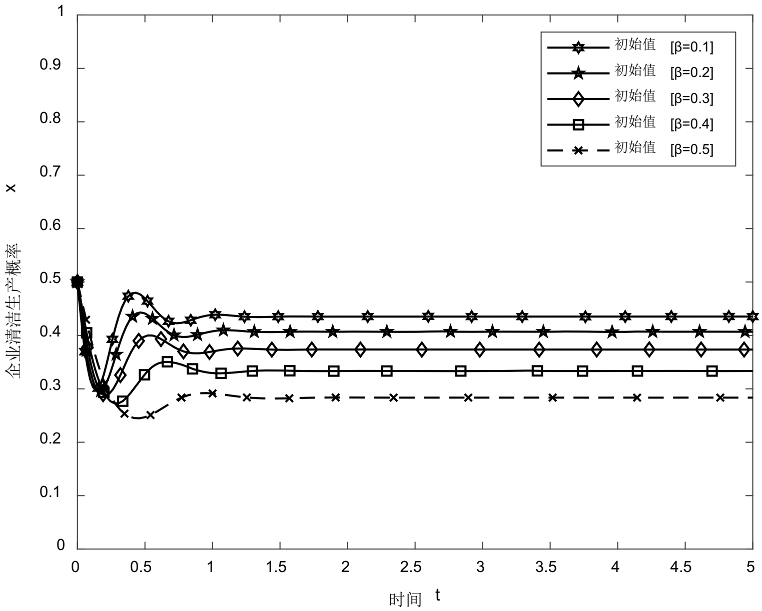


Fig. 15 Evolutionary path of enterprise behaviours as β varie

the government giving equal proportions of subsidies based on their cleaner production input costs while also having a higher probability of penalties for enterprises with a lower probability of cleaner production. The dynamic subsidy mechanism $S(x) = xS$ in system (II) and the dynamic penalty mechanism $P(x) = (1 - x)P$ in system (III) are simultaneously brought into system (I) to obtain a two-dimensional dynamical system (IV).

$$\begin{cases} F_4(x) = \frac{dx}{dt} = x(1-x)[-C_1 + C_2 + \beta(1-x)P + y[Sx + (1-x)(1-\beta)P]] \\ F_4(y) = \frac{dy}{dt} = y(1-y)\left[(1-x)^2(1-\beta)P - C_3 - Sx^2\right]\cdot \end{cases}$$

Proposition 4 *The equilibrium points of the evolutionary game in system (IV) are (0,0), (0,1), (1,0), (1,1). If the following conditions are satisfied.*

$$\begin{cases} 0 < 2(1-\beta)P - Q < 2[(1-\beta)P - S] \\ 0 < 2(C_1 - C_2)[(1-\beta)P - S] + 2S\beta P - \beta P Q < [(1-\beta)P - S]Q \end{cases}$$

Note: $Q = \sqrt{4(1-\beta)PC_3 + 4(1-\beta)PS - 4SC_3}$.
(x_4^*, y_4^*) is likewise the equilibrium point of system (III).

Proof In system (IV), let $\frac{\mathrm{d}x}{\mathrm{d}t} = 0$, $\frac{dy}{dt} = 0$, , respectively, by solving the result we can get (0,0), (0,1), (1,0), (1,1) is the equilibrium point of the system, when Eq. (15) holds, (x_4^*, y_4^*) is also the equilibrium point of the system. Solving for $x_4^* = \frac{2(1-\beta)P-\sqrt{4(1-\beta)PC_3+4(1-\beta)PS-4SC_3}}{2[(1-\beta)P-S]}$, $y_4^* = \frac{2(C_1-C_2)}{\sqrt{4(1-\beta)PC_3+4(1-\beta)PS-4SC_3}} + \frac{2S\beta P-\beta P\sqrt{4(1-\beta)PC_3+4(1-\beta)PS-4SC_3}}{[(1-\beta)P-S]\sqrt{4(1-\beta)PC_3+4(1-\beta)PS-4SC_3}}$, the proof is over.

The Jacobian matrix expression for the two-dimensional dynamical system (IV) is as follows:

$$J = \begin{bmatrix} \frac{\partial F_4(x)}{\partial x} & \frac{\partial F_3(x)}{\partial y} \\ \frac{\partial F_4(y)}{\partial x} & \frac{\partial F_4(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

In Eq. (16).

$$\begin{aligned} a_{11} &= (1-2x)[-C_1 + C_2 + \beta(1-x)P + y[Sx + (1-x)(1-\beta)P]] \\ &\quad - x(1-x)[Sy - \beta P - (1-\beta)Py] \\ a_{12} &= x(1-x)[Sx + (1-x)(1-\beta)P] \\ a_{21} &= y(1-y)[2x[(1-\beta)P - S] - 2(1-\beta)P] \\ a_{22} &= (1-2y)[(1-x)^2(1-\beta)P - C_3 - x^2 S] \end{aligned}$$

The equilibrium points in system (IV) were analysed in conjunction with the Jacobian matrix and the results are shown in Table 6.

From the analysis in Table 6, we can see that the equilibrium points (0,0), (0,1), (1,0), (1,1) are all saddle points, and the equilibrium point (x_4^*, y_4^*) is the stable evolutionary strategy (ESS), and the point (x_4^*, y_4^*) is brought into the Jacobian matrix for solution, and the characteristic roots of the matrix can be obtained as a pair of characteristic complex roots with negative real parts, system (IV) has asymptotic stability, so the point (x_4^*, y_4^*) is the evolutionary stability point of this system, and the evolutionary trajectory tends to the equilibrium point (x_4^*, y_4^*). It indicates that there is a stable evolutionary strategy between the local government and industrial enterprises under the dynamic subsidy dynamic punishment mechanism, respectively, the

Table 6 Two-dimensional dynamical system (IV): stability analysis of the equilibrium point

Balance point	det(J)	tr(J)	State
(0, 0)	–	N	Saddle point
(0, 1)	–	N	Saddle point
(1, 0)	–	N	Saddle point
(1, 1)	–	N	Saddle point
(x_4^*, y_4^*)	+	–	ESS

Note "+" is greater than 0, "–" is less than 0, "N" is not sure probability that the enterprises produce cleanly is x_4^* and the probability that the government implements active regulation is y_4^*.

The results obtained are verified by Matlab simulation below.

As shown in Figs. 16 and 17, it is easy to see that, compared with the static penalties in Systems (I) and (II), after the dynamic penalty mechanism is added, the evolution of the decision-making behaviors of both the government and the enterprises changes from continuous up-and-down oscillations to short oscillations before converging and eventually stabilizing. However, for both systems (III) and (IV), although both systems converge after a brief oscillation, the final results show that the probability of local governments choosing active regulation and industrial enterprises choosing cleaner production is higher under the dynamic subsidy and dynamic penalty mechanism than under the static subsidy and dynamic penalty mechanism; and the effect on the evolution of government behaviors is significantly higher than that of enterprises. The dynamic evolution of system (IV) is still a spiral curve that converges to the equilibrium point. By comparing the evolutionary paths of cleaner production in the four systems in Fig. 19, the differences in the evolutionary process under different reward and punishment mechanisms can be more clearly seen. Under the static penalty mechanism, the amplitude of the evolutionary process in the dynamic subsidy system is the largest and least stable compared to the static subsidy. In contrast, the probability of cleaner production is higher in the dynamic subsidy system than in the static one. Therefore, it is easy to conclude that the dynamic subsidy dynamic penalty mechanism is the best choice among the four mechanisms (Fig. 18).

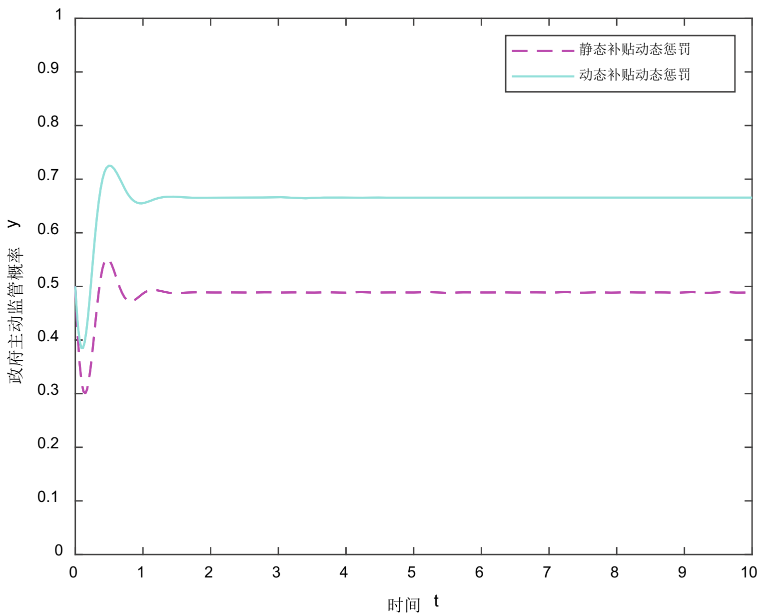


Fig. 16 Evolutionary path of proactive government regulation

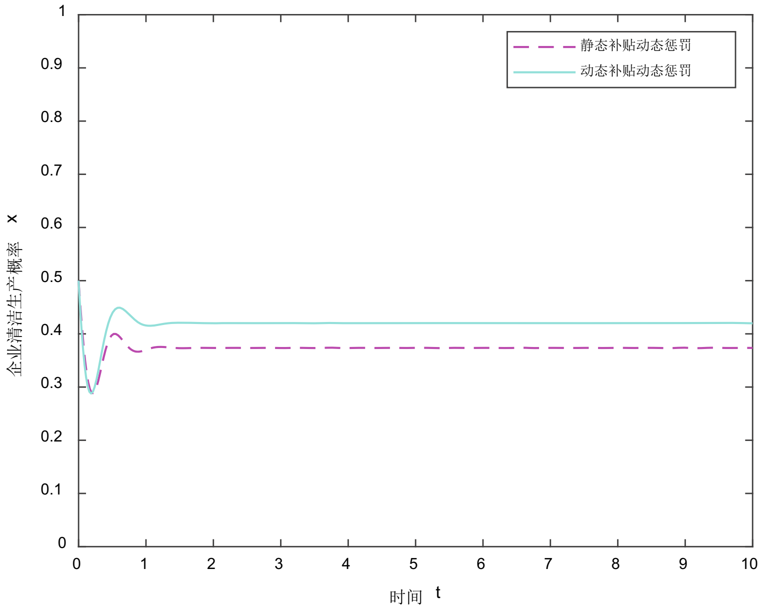


Fig. 17 Evolutionary path of cleaner production in enterprises

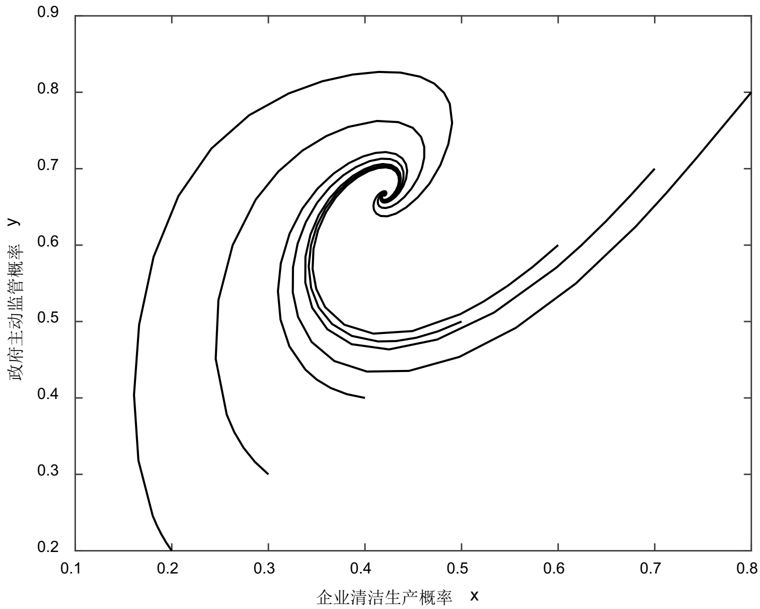


Fig. 18 Map of the dynamic evolution of system (IV)

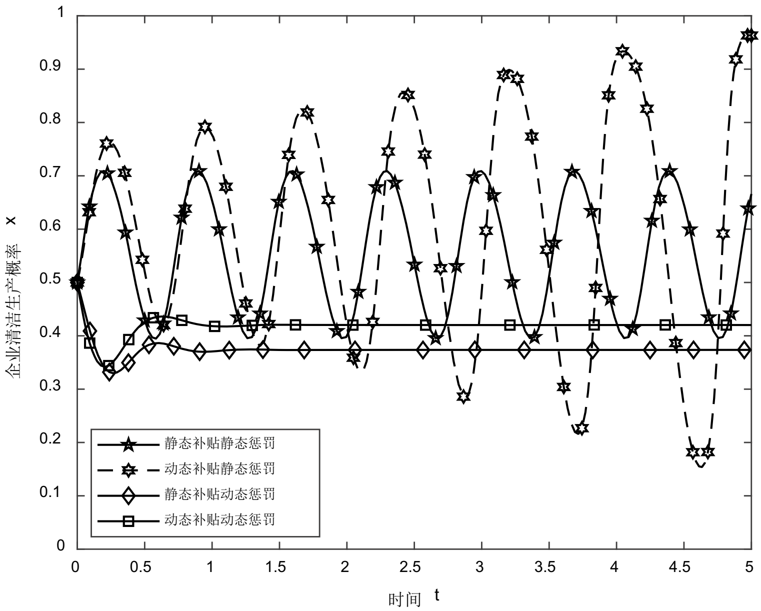


Fig. 19 Evolution of cleaner production in enterprises under the four systems

What is reflected in Figs. 20 and 21 is that the impact of the probability of reporting β on the evolution of the behaviors of local governments and industrial enterprises in system (IV) is not significantly different from that of system (III), but the probability of both government-initiated regulation and cleaner production by enterprises in system (IV) is higher overall than that of system (III), further indicating that the dynamic subsidy-dynamic penalty mechanism is superior to the static subsidy-dynamic penalty in terms of the effectiveness of the scheme.

3.4 Parametric Analysis

The main purpose here is to analyse the influence of the key parameters in system (IV), the level of rewards and penalties and the probability of reporting, on the evolutionary stabilization strategy between the government and the firm. (x_4^*, y_4^*) is taken as the evolutionary stability point of the system, and the partial derivatives of the subsidy S, the penalty P and the probability of reporting β given by the government to the enterprise for cleaner production are obtained as follows.

(1) $\frac{\partial x_4^*}{\partial S} < 0$, $\frac{\partial y_4^*}{\partial S} < 0$, x_4^* and y_4^* are decreasing functions of S. The probability of government-initiated regulation and corporate cleaner production decreases with the increase in the maximum value of subsidies and vice versa. and the magnitude of change in the former is significantly higher than that in the latter.

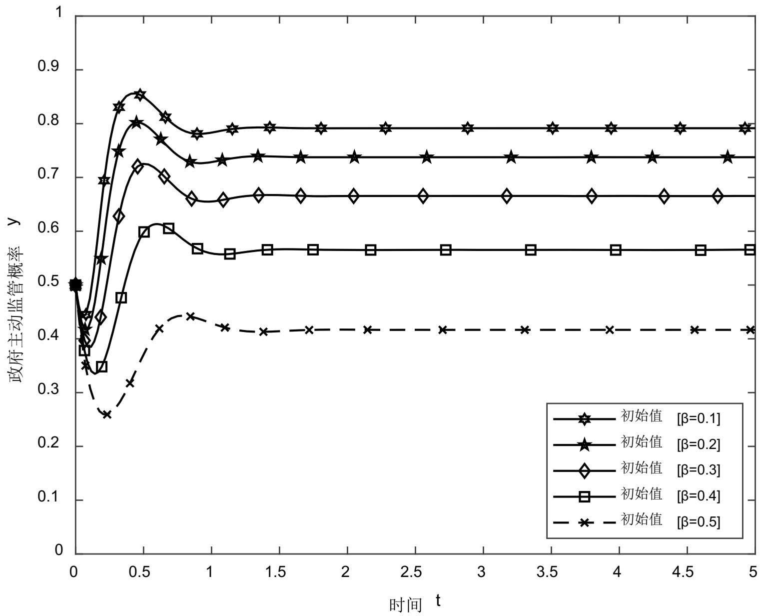


Fig. 20 Evolutionary path of government behaviors as β changes

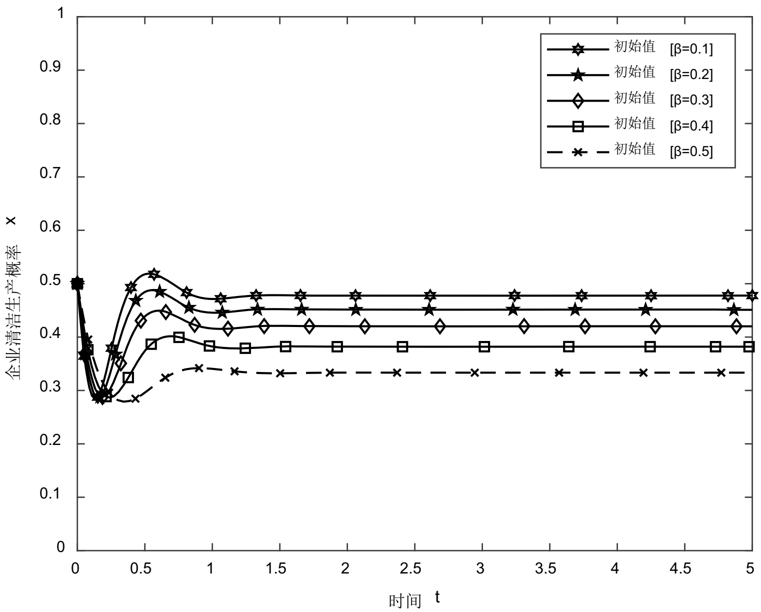
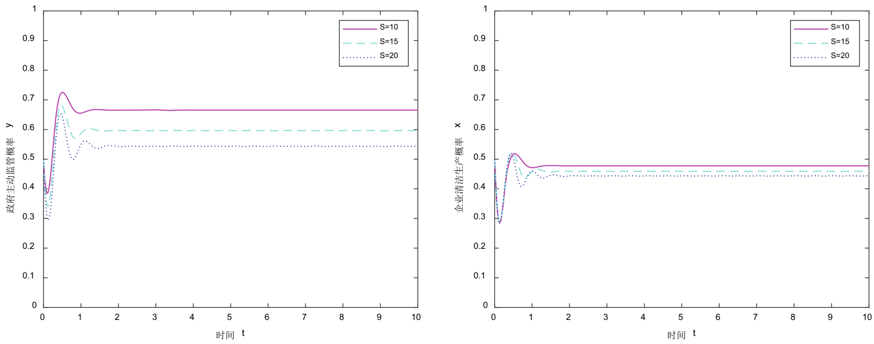


Fig. 21 Evolutionary path of enterprise behaviors as β changes

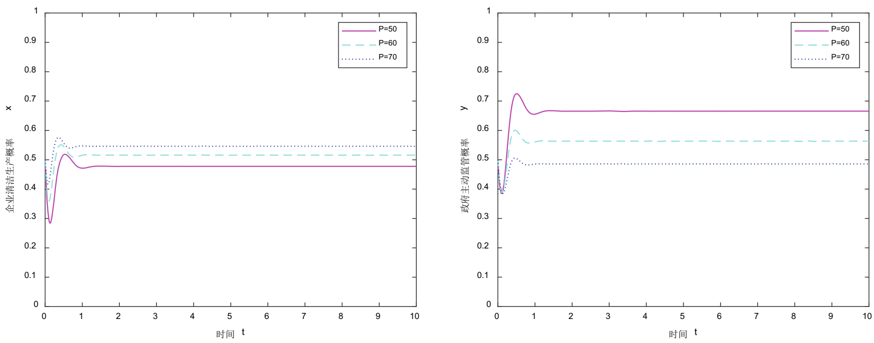
As shown in Fig. 22(a, b), the reason for this may be that as the subsidy increases, the burden of government expenditure increases, which in effect increases the cost of active regulation, while less money is actually spent on the cost of active regulation, so the probability of the government choosing an active regulation strategy decreases. In turn, after receiving high subsidies, enterprises are likely not to invest the subsidies in cleaner production due to the high cost of government monitoring the use of the funds, but to obtain higher profits through other means.

(2) $\frac{\partial x_4^*}{\partial P} > 0$, x_4^* is an increasing function of P. The probability that a firm will produce cleanly increases with the increase in the upper limit of the penalty and vice versa. From Fig. 23(a), it can be seen that after the penalties are increased, firms in turn increase the probability of choosing a cleaner production strategy due to the fear of high penalties.



(a) (b)

Fig. 22 Impact of subsidy intensity on the probability of government proactive regulation and corporate cleaner production



(a) (b)

Fig. 23 Impact of penalty intensity on the probability of government proactive regulation and enterprise cleaner production

(3) $\frac{\partial y_4^*}{\partial P} < 0$, y_4^* is a decreasing function of P. The higher the upper limit of the penalty, the lower the probability of active government regulation and vice versa. As the probability of cleaner production of enterprises increases, the environmental pressure borne by the government decreases, and therefore the probability of the government choosing an active regulatory strategy decreases in order to reduce the cost of active regulation, as shown in Fig. 23(b).
(4) $\frac{\partial x_4^*}{\partial \beta} < 0$, $\frac{\partial y_4^*}{\partial \beta} < 0$, x_4^* and y_4^* are decreasing functions of β. The probability of government proactive regulation and cleaner production decreases as the probability of reporting increases, and vice versa. The possible explanation for this is that the increase in the probability of reporting β shares more of the pressure on the government, so the government chooses to spend less on proactive regulation and more on environmental construction, so the probability of the government choosing a proactive regulation strategy decreases, and the decrease tends to increase with the increase in the probability of reporting. This phenomenon directly leads to a decrease in the probability of cleaner production by enterprises, and we can see from Figs. 20 and 21 that the sensitivity of the probability of active government regulation to changes in β is much greater than the sensitivity of the probability of cleaner production by enterprises. The benefits of a significant decrease in the probability of government regulation are higher than the risks associated with an increase in the probability of reporting, so the probability of choosing a cleaner production strategy decreases.

4 Conclusions

This paper constructs a game model of government regulation and enterprise production behaviors based on evolutionary game theory, analyses the evolutionary game and the stability of equilibrium points in the behaviors of local governments and industrial enterprises under static and three dynamic reward and punishment mechanisms, and discusses the effects of subsidy ceilings, penalty ceilings and the probability of reporting on the evolutionary outcome of the system. The following conclusions can be drawn.

(1) When the local government implements a static penalty mechanism, i.e. the intensity of government penalties is not related to the cleaning behaviors of enterprises, and the probability of third-party reporting is below 50%, it cannot play a large restraining role on industrial enterprises, and the game system between the two parties cannot automatically reach equilibrium.
(2) As the probability of third-party reporting gradually increases, the evolution of both systems will reach stability, and the government's strategy choice is more sensitive to the probability of reporting factor. Therefore, in the process of environmental construction, the government should actively adjust the reward and punishment policy for industrial enterprises to encourage them to carry out clean production, and at the same time advocate the general public to actively report non-compliant enterprises.

(3) Dynamic punishment mechanism can effectively make up for the shortcomings of the static punishment mechanism, when the government implements the two policies of static subsidy dynamic punishment and dynamic subsidy dynamic punishment for enterprises, there is an evolutionary stability strategy, at this time the game system has progressive stability, specifically as a spiral curve that constantly converges to the equilibrium point and finally converges, eventually both the local government and industrial enterprises will evolve to the equilibrium point. The dynamic subsidies and penalties are the optimal reward and punishment mechanism, and the probability of cleaner production is negatively correlated with the upper limit of subsidies and the probability of reporting, and positively correlated with the upper limit of penalties.

5 Suggestions

(1) The government should call on the public to actively monitor and report on non-compliant industrial enterprises through various social organizations and self-media platforms, so as to put into practice the concept of "green water and green mountains are golden mountains", make the public and enterprises fully aware of the need for cleaner production, and improve the efficiency of enterprises' transition to cleaner production.
(2) The government can pay close attention to the changes in the probability of third-party reporting through big data and adjust its strategy when the probability exceeds 50%, so that the government can adjust its strategy from active supervision to passive supervision, which can promote the clean production behaviors of enterprises and reduce the financial burden of government departments.
(3) The government's reward and punishment policy should be scientifically and dynamically adjusted according to the behaviors of enterprises. The decision-making behaviors of enterprises is influenced by government policies, and it is difficult for both parties to achieve stable behavioral evolution under a static punishment mechanism.
(4) Government departments should effectively reduce the costs of regulation and cleaner production by further improving the regulatory system, increasing the transparency and accuracy of information, and improving the operational capacity of regulators. At the same time, enterprises or local governments are encouraged to take the lead and work with relevant research institutions to tackle key technologies in the transformation from traditional production to cleaner production, helping enterprises to reduce the high R&D costs and speed up the promotion of cleaner production practices.

This paper only deals with the game relationship between local governments and industrial enterprises under different reward and punishment mechanisms, but does not consider the fact that in practice, enterprises' cleaner production behaviors is not only influenced by the reward and punishment mechanisms, but also by the level of local economic development, etc. Moreover, the strategies of local governments are also influenced by the responsible officials themselves and the central government, and future studies can take these factors into account for further exploration.

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Research on Financial Credit Risk Prediction Based on Supply Chain of Small and Medium-Sized Enterprises in the Steel Industry

Pei Cui and Liwei Fan

Abstract Based on the research of supply chain finance and risk management, this paper analyzes the development current and transform pressure of supply chain finance in Chinese steel industry under "carbon reduction" goals, and systematically describes the credit risk and influencing factors of three supply chain finance modes. We conducted logistic bivariate regression and constructed a risk prediction model for empirical analysis based on the data of National Equities Exchange and Quotations (NEEQ) enterprises from 2010 to 2019. The research indicates that credit risk is the main obstacle to funding mode innovation in small and medium-sized enterprises (SMEs) and there are differences between three supply chain finance modes: accounts receivable financing mode pays more attention to enterprises' profitability, while inventory pledge financing mode and prepayment financing mode have higher requirements on enterprises' quality. At present, the development of China's iron and steel industry has entered a bottleneck period, and the economic profit rate of SMEs is low. Thus, they need to select a more appropriate supply chain financing mode for supply chain financing by virtue of their own advantages and disadvantages to realize the innovation and transformation of financing mode, and at the same time decrease the loan risk for financial financing institutions and achieve benign interaction.

Keywords Supply chain finance · Steel industry · Financing models · Credit risk

1 Introduction

As a pillar industry of the national economy, the iron and steel industry has always occupied an important strategic position in the development of China's tertiary industry. Entering the stage of the fourth industrial revolution led by intelligent manufacturing in Industry 4.0, the problems of excess capacity and unreasonable

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industrial structure within the iron and steel industry are prominent, and some enterprises are facing the dual pressure of eliminating backward capacity and transforming and upgrading. Especially in recent years, with the continuous advancement of global informatization and economic globalization and the social pressure brought by "carbon neutrality" and "carbon emission reduction", the operating environment of iron and steel enterprises has undergone significant changes. Traditional iron and steel enterprises need to find their own positioning, explore the direction of reform and progress, achieve internal development goals and adapt to the external market environment in this global manufacturing revolution.

As a big manufacturing country, China must face up to the disadvantages of China's manufacturing industry when it meets the major reform of "Industry 4.0". Firstly, China's manufacturing industry is mostly concentrated in the assembly link with low value and the processing and production link of non-core components, which belongs to the middle and lower end of the industrial chain. Secondly, the development of manufacturing industry is highly dependent on material resources. In the past, too much attention was paid to production efficiency and output, and the development mode was too extensive. Finally, the technological innovation capacity is not strong, and the core technologies are limited by other countries' production energy efficiency and emission levels.

In order to solve many problems existing in the production and management center in the past and realize the transformation from a manufacturing power to a manufacturing power, China put forward the "Made in China 2025" plan during the National two Sessions in 2015 and explored the possibility of realizing the integration of informatization and industrialization in the manufacturing industry. Although China's steel industry has made very proud achievements in the past: In 2021, China's steel output ranked first in the world, 1.03 billion tons, accounting for 53% of the world's output; China exported 66.895 million tons of steel and consumed 991 million tons of steel, but it still faces many obstacles on its road to development and innovation. Especially since the 2015 countries for the economic development of the "three to go, a drop, a" task, since a large number of iron and steel enterprises are forced to face pressure production transformation, and the lack of core technology and production are heavily dependent on imported raw materials and from the side effects of the steel industry supply chain environment, the steel industry supply chain value has been verified (Fig. 1).

Steel industry is a commodity trading industry, capital intensive and large demand. The upstream and downstream of the iron and steel industry chain are mostly small and medium-sized enterprises, which lack capital and have a large demand for financing, but often fail to meet the financing review conditions of financial institutions, affecting the subsequent development of enterprises, and thus the normal and stable operation of the supply chain. Based on the difficulties and challenges, Banks and other financial institutions based on the steel industry supply chain, the supply chain on the core enterprise as a whole the credit status of enterprises in the supply chain of judgment, the important factors for the iron and steel industry provides greater access to bank financing, this is the steel industry supply chain finance theory.

Fig. 1 China's steel industry output and exports

Although theoretically supply chain finance can greatly revitalize the companies in the supply chain of the entire steel industry, there is still a large credit risk in practice, so a reasonable credit risk prediction system has become a top priority for financing banks and financing enterprises. It is customary to divide supply chain financial financing modes into three categories from the perspective of pledge: supply chain financial services based on accounts receivable mode, supply chain financial services based on inventory pledge mode and supply chain financial services based on prepayment mode. Different financing modes involve different factors in credit risk. However, in current domestic researches, there is not a relatively complete prediction system of credit risk in steel industry related to supply chain finance financing mode. Therefore this article embarks from the different steel industry supply chain finance financing pattern modeling and carried on the thorough analysis, to make up for the shortcomings of previous studies, the supply chain finance credit risk prediction provides a new train of thought, to solve the problem of small and medium-sized enterprise financing difficult problem in iron and steel industry to provide a possible solution, provides a new direction for the development of steel industry.

2 Problem Description and Research Status

Steel industry after decades of rapid development also gradually exposed the problems of its own, the first is the steel industry's own risk, at present the global economy into recession and more and more countries advocate green development, the steel industry is faced with overcapacity situation, to meet the new challenge of upgrade; Secondly, the enterprise's own management risks, including the management system is not perfect, system is not perfect; The last and most common is credit risk, also known as default risk, which refers to the risk that financial service providers fail to fulfill their obligations when they are due. Since the credit degree of financing SMEs is difficult to check and information may be asymmetric, banks and other financial institutions often have to bear greater risks. Many financial institutions in order to prevent the occurrence of credit risk is introduced into core enterprise buy-back mechanisms, but that in virtually increased the cost of financial institutions, make the financing process is more complex, and different sources of credit risk financing mode is different, so clearly recognizing various mode of credit risk sources for reduce the credit risk is the most basic step.

(1) Information asymmetry in the supply chain

Domestic supply chain finance financing pattern mainly by financial institutions in the process of financing for examination and approval of the financing enterprise audit submitted materials or by the information from other consulting firm, to evaluate the credit level of the financing enterprises, but because of financial institutions or financial institutions entrusted consulting company and financing between the existence of information asymmetry, Therefore, financial institutions cannot fully grasp the credit level and other information of financing enterprises. In order to reduce their own risks, financial institutions either choose not to lend money, or choose to pay a lot of costs to investigate the detailed information of financing enterprises, which leads to the loss of motivation for banks and other financial institutions to lend to SMEs.

In the process of the pledge collateral, due to information asymmetry, financial institutions tend to lack the value of the pledge, liquidity accurate measure level, in the case of unable to accurately measure the pledge value, if during the period of the pledged collateral value appeared larger fluctuation, it greatly reduces the financing enterprises default cost, increases the chance of corporate defaults of financing, Similarly, in order to avoid this situation, banks and other financial institutions either require financing enterprises to choose products with good liquidity, such as gold, as collateral, or spend a lot of costs to investigate the quality of collateral, such as liquidity and possible value fluctuation.

Therefore, the existence of information asymmetry in the supply chain makes the credit risk of supply chain finance more prominent.

(2) Financial institutions attach too much importance to the condition of financing enterprises

In the supply chain of financial services, Banks and other financial institutions will supply chain as a whole, relying on the core enterprise's credit level to the upstream and downstream of small and medium-sized enterprises credit and financing, but in real life, Banks and other financial institutions to the credit status of core enterprise on the supply chain as a reference, but still too much emphasis on the status of the financing enterprises, Such as transaction frequency, total transaction amount and so on, which virtually increases the difficulty of financing SME loans, but also brings huge examination costs to banks and other financial institutions.

Therefore, it is a general trend to establish a supply chain finance credit risk prediction model.

Fig. 2 Flow chart of accounts receivable pattern in iron and steel industry

In the process of obtaining supply chain financing services, SMEs in the steel industry have credit risks caused by asymmetric and opaque information, which increases the credit risks of financial institutions and leads to higher threshold for financing enterprises. Financial institutions need to pay a certain credit investigation cost to evaluate the credit status of financing enterprises before providing financial services [2].

For according to the pledge of different supply chain finance financing model, supply chain finance operation mechanism is different, different participants, so the influence factors of credit risks involved is also different, so by studying the different mechanism of supply chain finance financing mode operation to determine the mode of supply chain finance credit risk happens, the process of which determine the influencing factors, The credit risk of steel industry supply chain finance is predicted under different models.

The supply chain finance financing mode based on accounts receivable refers to a service mode in which banks and other financial institutions provide financing based on the accounts receivable enjoyed by the financing enterprises on the supply chain to the core enterprises. Therefore, receivables financing generally occurs in small and medium-sized enterprises upstream of core enterprises in the steel industry (Fig. 2).

Jiang (2014) points out that the financing risks of receivables mortgage are mainly divided into two parts, one is the enterprise credit risk, operation risk and collateral risk before the completion of loan issuance, the other is the risk of whether the capital of downstream enterprises can return after the completion of loan issuance [1]. Jiaxin (2021) points out that the receivables model can improve this problem by analyzing the financing difficulties of SMEs, and points out the risks in the receivables model from three aspects: enterprise operation risk, customer quality risk and investor fraud risk [2]. Dong (2022) points out that the accounts receivable mode can effectively reduce financing costs and relieve the pressure of small and medium-sized enterprises, and the default risk of accounts receivable financing activities will be affected by the macro environment, industry conditions and company operating conditions [3].

Supply chain finance financing mode based on inventory pledge refers to a supply chain finance service mode in which financing enterprises pledge their inventory to financial institutions to obtain financing and the core enterprises in the supply chain provide guarantee for the pledge and promise to buy back. Since there is no clear purchase and sale contract between the core enterprise and the financing enterprise, the financing enterprise can be anywhere in the supply chain (Fig. 3).

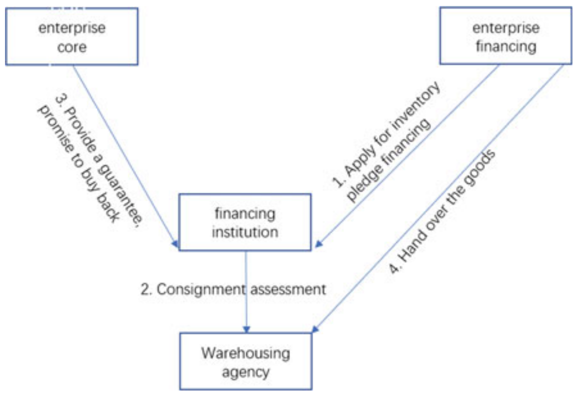


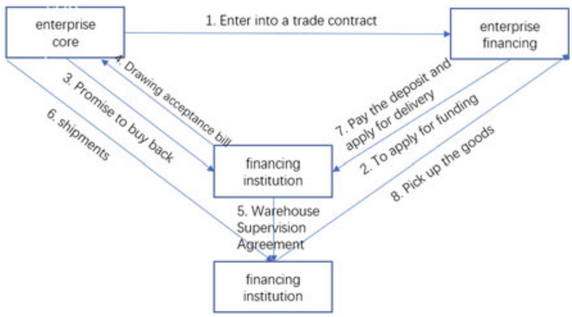
Fig. 3 Flow chart of prepayment mode in steel industry

Rong (2010) believes that the movable property pledge business can alleviate the difficulty of guarantee, but it also suffers from the risk of collateral valuation and price fluctuation, pledge management risk and pledge right risk. Accordingly, risk prevention measures are proposed [4]. Li et al. (2011) pointed out that inventory pledge financing is the core mode of supply chain finance, which can effectively alleviate the capital bottleneck in the supply chain, but the volatility of pledge price will bring risks. Therefore, the model of loan-to-value ratio of core risk control index under static pledge and dynamic pledge was analyzed and established [5]. Shao (2014) objectively analyzed the legal risks of movable property pledge, including the risk of effectiveness of pledge, the risk of realization of pledge and the risk of uncertain value of pledge, and put forward specific countermeasures for the development of supply chain finance from the legal perspective [6]. Liu et al. (2021) believe that the risk caused by information asymmetry is a key obstacle to the development of supply chain finance under the inventory pledge mode. The case study is used to analyze how the Internet of Things and blockchain affect the collateral risk, storage risk and liquidity risk of inventory pledge financing [7].

The financing mode of supply chain finance based on prepayment refers to a service mode in which banks and other financial institutions provide financing by pledging the goods sold by core enterprises to financing enterprises. Therefore, prepaid accounts financing generally occurs in the core enterprises of the steel industry in the downstream SMEs (Fig. 4).

Wang (2018) pointed out that the prepayment mode takes the sales revenue of financing enterprises as the direct repayment source, which has the advantage of increasing the bank's control over the repayment intention of financing enterprises without bringing great financial pressure to enterprises. In the prepayment mode, risks mainly come from the goods supervision party and core enterprises [8]. Ye (2019) believes that the credit risk control points of the prepaid financing mode mainly lie in the core business capability, credit level of small and medium-sized enterprises, external environment of supply chain, pledge and operational risk, etc. Based on this, a Logistic regression model is established to predict the risks [9]. Zhao (2020), through the analysis of online supply chain finance mode, thinks that

Fig. 4 Flow chart of inventory pledge financing mode in steel industry



the risks in prepaid payment mode mainly exist in imperfect laws, low maintenance of information platform, low quality of supply chain disclosure information and low supervision of logistics enterprises on pledged goods [10].

3 Prediction Model Based on Logistic

Based on the analysis of the different mode of supply chain finance operation mechanism, to determine the influence factors of credit risk, from the perspective of the influence factors, establish different mode of supply chain finance credit risk evaluation index system, using factor analysis for dimension reduction, binary regression analysis through the logistics, supply chain under the different model of financial credit risk measurement, Finally, the results are analyzed and the robustness of the model is tested.

3.1 Index Selection and Data Processing

To establish supply chain finance credit risk evaluation system under different financing modes, it is necessary to introduce different indicators to distinguish the differences between different financing modes. Therefore, by summarizing and selecting indicators in previous studies, a credit risk prediction indicator system suitable for different supply chain finance modes is re-established.

The factors that affect the financing mode of accounts receivable are mainly the ability of core enterprises, the operating ability of small and medium-sized enterprises and the quality of accounts receivable: the ability of core enterprises mainly examines the solvency of core enterprises. The solvency of an enterprise can be expressed by its liquidity ratio, quick ratio, asset-liability ratio, etc. The operating ability of small and medium-sized enterprises is mainly reflected in the enterprise quality of small and medium-sized enterprises, the operation ability of small and medium-sized enterprises and the solvency of small and medium-sized enterprises. The quality of small and medium-sized enterprises is mainly reflected by the duration of existence and registered capital of small and medium-sized enterprises. The operating capacity of SMEs is mainly reflected by year-on-year growth in operating revenue, year-on-year growth in net profit, return on net assets and return on total assets. The solvency of SMEs is mainly expressed by the asset-liability ratio, liquidity ratio, quick ratio, etc. The quality of pledge in supply chain finance financing mode based on accounts receivable mainly refers to the quality of accounts receivable, such as accounts receivable turnover.

To sum up, the final index of accounts receivable supply chain finance mode is determined as shown in the Table 1.

The main factors that affect the financing mode of inventory pledge are supply chain status and the quality of pledges of SMEs. Supply chain status mainly refers to the quality of supply chain, and the cooperation time between SMEs and core enterprises and the amount of capital between SMEs and core enterprises are taken as evaluation indicators. The qualitative analysis of the quality of pledges is mainly based on the liquidity and price stability of pledges and the vulnerability of pledges as the main indicators. Because the research object is the steel industry, the vulnerability of products in the steel industry is similar and low, so it will not be considered in the subsequent indicator judgment process.

Table 1 Supply chain finance index system under accounts receivable financing model

	First indicators	Secondary indicators
Core enterprise	Debt paying ability	Current ratio
		Quick ratio
		Asset-liability ratio
SMEs	Enterprise quality	Fixed number of years of the term
		The registered capital
	Ability to operate	Year-on-year growth in operating revenue
		Year-on-year growth in net profit
		Return on equity
		Return on total assets
		Net profit margin on sales
	Debt paying ability	Asset-liability ratio
		Current ratio
		Quick ratio
Accounts receivable	Accounts receivable quality	Accounts receivable turnover
		Accounts receivable turnover

Table 2 Supply chain finance indicators under inventory pledge financing mode

	First indicators	Secondary indicators
The core enterprise	Debt paying ability	Current ratio
		Quick ratio
		Asset-liability ratio
SMEs	Enterprise quality	Fixed number of years of the term
		The registered capital
	Ability to operate	Year-on-year growth in operating revenue
		Year-on-year growth in net profit
		Return on equity
		Return on total assets
		Net profit margin on sales
	Debt paying ability	Asset-liability ratio
		Current ratio
		Quick ratio
The pledge	Pledge mass	Price stability of pledge
		Liquidity ability of pledge
The supply chain	Supply chain quality	Fixed number of years of the deal
		Transaction amount

To sum up, the final indicators of the financial model of inventory pledge supply chain are determined as follows (Table 2).

The factors that affect the financing mode of prepaid accounts are mainly the ability of small and medium-sized enterprises, the operating ability of core enterprises and the quality of supply chain: The capacity of small and medium-sized enterprises is mainly reflected in the development potential of small and medium-sized enterprises, the profitability of small and medium-sized enterprises, the operation capacity of small and medium-sized enterprises, and the solvency of small and medium-sized enterprises, the development potential of small and medium-sized enterprises is mainly reflected by the growth rate of total assets, operating income growth rate, etc. The profitability of SMEs is mainly reflected by operating profit rate, return rate on total assets, etc. The solvency of SMEs is mainly represented by liquidity ratio, quick ratio and return on equity. Core enterprise operating capacity is mainly composed of core enterprise profitability and solvency. The profitability of core enterprises can be expressed by the main business income, return on net assets, total asset turnover and other indicators; The solvency of an enterprise can be expressed by its liquidity ratio, quick ratio, asset-liability ratio, etc. The quality of supply chain is mainly reflected in the stability of cooperation between core enterprises and SMEs, which is mainly expressed by the length of cooperation and the size of cooperation amount.

To sum up, the final index of prepayment supply chain finance mode is determined as shown in the Table 3.

Through the evaluation index system, 459 SMEs in the iron and steel industry that were listed between 2010 and 2019 were selected. However, the characteristics of the original data obtained according to the influencing factors were extremely complex and had the possibility of multicollinearity, which would seriously affect the efficiency of subsequent regression, so it was necessary to pre-process the original data. Principal component analysis is one of data preprocessing methods. Principal component analysis converts a group of possible correlation variables into a group of linear unrelated variables through orthogonal transformation, reducing the dimension of data and simplifying attributes to the greatest extent within the specified loss range.

Table 3 Indicators of supply chain finance under prepaid financing mode

	First indicators	Secondary indicators
The core enterprise	Debt paying ability	Current ratio
		Quick ratio
		Asset-liability ratio
	Enterprise quality	Fixed number of years of the term
		The registered capital
SMEs	Ability to operate	Year-on-year growth in operating revenue
		Year-on-year growth in net profit
		Return on equity
		Return on total assets
		Net profit margin on sales
	Debt paying ability	Asset-liability ratio
		Current ratio
		Quick ratio
		Liquidity ability of pledge
The supply chain	Supply chain quality	Fixed number of years of the deal
		Transaction amount

3.2 Figures and Tables

The input components of logistic regression analysis include independent variables (covariables) and dependent variables, among which the index mentioned above is taken as the independent variable. The subject of the study is the prediction of financial credit risk of steel industry supply chain under different financing modes. The dependent variable is determined as whether the risk occurs, and the method adopted is binary Logistic regression analysis. Therefore, the probability of risk occurrence is denoted as 1, otherwise, it is 0.

The enterprise credit rating publicity platform is a platform where the third-party organization conducts an all-round investigation on the enterprise through specific methods and procedures, and finally obtains the credit rating results and makes them public to the society. Enterprise credit rating evaluation is generally based on the analysis of enterprise industry, analyzing the quality of the enterprise foundation, to the enterprise management and financial analysis and so on, the specific hierarchy as AAA, AA, A, BBB, BB, B, CCC, CC, C, D, which assess for BBB grade and above for credit degree is better, for enterprises with low risks, most of the bidding and bidding of enterprises also inquire the credit rating of their partners in this way. Therefore, the data of the enterprise credit rating publicity platform are objective, fair and cover a large number of enterprises, which is more suitable for use as the dependent variable of research.

The features of the original data obtained are extremely complex and have the possibility of multicollinearity, which will seriously affect the efficiency of subsequent regression. Therefore, data preprocessing of the original data is required, among which principal component analysis is one of the data preprocessing methods. Principal component analysis converts a group of possible correlation variables into a group of linear unrelated variables through orthogonal transformation, reducing the dimension of data and simplifying attributes to the greatest extent within the specified loss range. (Notes: PEM represents the Percentage of Explained Variance).

(1) Based on accounts receivable model
(2) Based on inventory pledge model
(3) Based on prepaid payment model.

Through Tables 4, 5, and 6, it is shown that accounts receivable principal components which were extracted from the mode of the cumulative contribution rate of 84.626%, about inventory principal components which were extracted from the mode of the cumulative contribution rate reached 87.516%, principal components which were extracted from the advance payment mode of the cumulative contribution rate reached 80.561%, both can represent most of the data and information, the extent of the losses in the acceptable range, Therefore, the eigenvalue is selected as the final index to analyze the credit risk of supply chain finance, and it is named F_n (n = 1,2,3…).

Table 4 Total variance explanation of accounts receivable financing mode

Composition	Initial eigenvalues			Extract the sum of squares of loads		
	Aggregate	PEM	Accumulation (%)	Aggregate	PEM	Accumulation (%)
1	3.041	20.275	20.275	3.041	20.275	20.275
2	2.273	15.154	35.429	2.273	15.154	35.429
3	1.779	11.863	47.291	1.779	11.863	47.291
4	1.419	9.463	56.755	1.419	9.463	56.755
5	1.277	8.515	65.270	1.277	8.515	65.270
6	1.149	7.661	72.931	1.149	7.661	72.931
7	0.886	5.908	78.840	0.886	5.908	78.840
8	0.868	5.787	84.626	0.868	5.787	84.626
9	0.753	5.022	89.648			
10	0.537	3.579	93.227			
11	0.531	3.538	96.766			
12	0.290	1.931	98.697			
13	0.141	0.937	99.634			
14	0.037	0.244	99.878			
15	0.018	0.122	100.000			

Table 5 Total variance explanation of inventory pledge financing mode

Composition	Initial eigenvalues			Extract the sum of squares of loads		
	Aggregate	PEM	Accumulation (%)	Aggregate	PEM	Accumulation (%)
1	2.056	15.819	15.819	2.056	15.819	15.819
2	2.043	15.719	31.538	2.043	15.719	31.538
3	1.799	13.839	45.377	1.799	13.839	45.377
4	1.209	9.297	54.673	1.209	9.297	54.673
5	1.074	8.264	62.937	1.074	8.264	62.937
6	0.958	7.369	70.306	0.958	7.369	70.306
7	0.874	6.722	77.028	0.874	6.722	77.028
8	0.699	5.379	82.407	0.699	5.379	82.407
9	0.664	5.110	87.516	0.664	5.110	87.516
10	0.549	4.226	91.742			
11	0.439	3.378	95.120			
12	0.390	2.999	98.120			
13	0.244	1.880	100.000			

Table 6 Explanation of total variance of prepaid financing mode

Composition	Initial eigenvalues			Extract the sum of squares of loads		
	Aggregate	PEM	Accumulation (%)	Aggregate	PEM	Accumulation (%)
1	3.836	16.680	16.680	3.836	16.680	16.680
2	3.170	13.783	30.463	3.170	13.783	30.463
3	2.365	10.284	40.747	2.365	10.284	40.747
4	1.893	8.230	48.977	1.893	8.230	48.977
5	1.742	7.572	56.549	1.742	7.572	56.549
6	1.343	5.839	62.388	1.343	5.839	62.388
7	1.213	5.274	67.662	1.213	5.274	67.662
8	1.104	4.800	72.463	1.104	4.800	72.463
9	0.972	4.226	76.688	0.972	4.226	76.688
10	0.891	3.873	80.561	0.891	3.873	80.561
11	0.791	3.439	84.000			
12	0.760	3.305	87.305			
13	0.710	3.089	90.394			
14	0.625	2.718	93.112			
15	0.567	2.464	95.576			
16	0.470	2.043	97.619			
17	0.262	1.141	98.760			
18	0.112	0.487	99.247			
19	0.076	0.330	99.577			
20	0.047	0.203	99.780			
21	0.039	0.171	99.952			
22	0.011	0.048	100.000			
23	8E-11	3E-10	100.000			

3.2.1 Based on Accounts Receivable Model

Principal component scores can be expressed according to the coefficient matrix (Tables 7 and 8).

$$\begin{aligned} F1 = & -0.065x_1 - 0.095x_2 \\ & -0.027x_3 + 0.102x_4 + 0.107x_5 + 0.217x_6 + 0.158x_7 - 0.272x_8 \\ & + 0.272x_9 + 0.265x_{10} - 0.016x_{11} + 0.035x_{12} + 0.035x_{13} - 0.006x_{14} - 0.011x_{15} \end{aligned} \tag{1}$$

$$\begin{aligned} F2 = & -0.123x_1 - 0.133x_2 + 0.048x_3 + 0.009x_4 + 0.04x_5 \\ & + 0.065x_6 + 0.014x_7 + 0.012x_8 \\ & - 0.032x_9 - 0.043x_{10} - 0.001x_{11} - 0.044x_{12} - 0.243x_{13} + 0.413x_{14} + 0.405x_{15} \end{aligned} \tag{2}$$

$$F_3 = 0.156x_1 + 0.209x_2 - 0.06x_3 + 0.219x_4 + 0.303x_5$$

Table 7 Component score coefficient matrix of accounts receivable financing model

	Composition							
	1	2	3	4	5	6	7	8
Fixed number of year of the term (X1)	−0.065	−0.123	0.156	−0.197	0.178	0.473	−0.013	−0.362
Registered capital (X2)	−0.095	−0.133	0.209	−0.056	0.410	0.093	0.259	0.381
Year-on-year growth in operating revenue (X3)	−0.027	0.048	−0.060	0.605	−0.049	−0.045	−0.042	0.061
Year-on-year growth in net profit (X4)	0.102	0.009	0.219	0.114	−0.367	−0.050	0.321	0.354
Return on equity (X5)	0.107	0.040	0.303	−0.380	−0.272	−0.204	−0.039	−0.012
Rate of return on total assets (X6)	0.217	0.065	0.322	0.100	−0.122	0.058	−0.134	−0.082
Net profit margin on sales (X7)	0.158	0.014	0.200	0.277	0.090	0.482	−0.123	−0.101
Asset-liability ratio (X8)	−0.272	0.012	0.019	−0.028	−0.133	0.027	0.051	0.260
Current ratio (X9)	0.272	−0.032	−0.247	−0.081	0.146	−0.023	0.087	0.119
Quick ratio (X10)	0.265	−0.043	−0.248	−0.113	0.152	0.004	0.078	0.135
Accounts receivable turnover (X11)	−0.016	−0.001	−0.168	−0.141	−0.274	0.424	−0.582	0.542
Turnover of account receivable (X12)	0.035	−0.044	0.234	0.048	0.407	−0.284	−0.384	0.465
Asset-liability ratio (core) (X13)	0.035	−0.243	−0.022	0.027	−0.130	0.232	0.574	0.292
Current ratio (core) (X14)	−0.006	0.413	−0.001	−0.062	0.123	0.124	0.184	0.120
Quick ratio (core) (X15)	−0.011	0.405	−0.003	−0.073	0.116	0.156	0.236	0.138

Table 8 Variables in the accounts receivable financing model equation

B			Standard error	Wald	Degrees of freedom	Significant	Exp (B)
1a	REGR factor score 5	−1.114	0.246	20.602	1	0.000	0.328
	Constant	−0.568	0.160	12.657	1	0.000	0.567
2b	REGR factor score 3	−0.996	0.230	18.759	1	0.000	0.369
	REGR factor score 5	−1.726	0.338	26.120	1	0.000	0.178
	Constant	−0.748	0.183	16.642	1	0.000	0.473
3c	REGR factor score 2	0.947	0.215	19.442	1	0.000	20.578
	REGR factor score 3	−1.533	0.312	24.082	1	0.000	0.216
	REGR factor score 5	−2.614	0.483	29.321	1	0.000	0.073
	Constant	−1.016	0.219	21.491	1	0.000	0.362
4d	REGR factor score 1	1.190	0.344	11.990	1	0.001	30.288
	REGR factor score 2	1.020	0.231	19.447	1	0.000	20.774
	REGR factor score 3	−1.730	0.397	18.983	1	0.000	0.177
	REGR factor score 5	−2.768	0.532	27.034	1	0.000	0.063
	Constant	−1.199	0.251	22.884	1	0.000	0.302
5e	REGR factor score 1	1.391	0.352	15.638	1	0.000	40.018
	REGR factor score 2	1.398	0.263	28.231	1	0.000	40.047
	REGR factor score 3	−2.190	0.452	23.512	1	0.000	0.112
	REGR factor score 5	−3.416	0.593	33.145	1	0.000	0.033
	REGR factor score 7	−1.687	0.370	20.835	1	0.000	0.185
	Constant	−1.500	0.296	25.648	1	0.000	0.223

$$+ 0.322x_6 + 0.2x_7 + 0.019x_8 - 0.247x_9 - 0.248x_{10} - 0.168x_{11} + 0.234x_{12} - 0.022x_{13} - 0.001x_{14} - 0.003x_{15} \quad (3)$$

$$F_4 = - 0.197x_1 - 0.056x_2 + 0.605x_3 + 0.114x_4 - 0.38x_5 + 0.1x_6 + 0.277x_7 - 0.028x_8$$

$$-0.081x_9 - 0.113x_{10} - 0.141x_{11} + 0.048x_{12} + 0.027x_{13} - 0.062x_{14} - 0.073x_{15} \quad (4)$$

$$\begin{aligned} F_5 =& 0.178x_1 + 0.41x_2 - 0.049x_3 - 0.367x_4 - 0.272x_5 \\ & - 0.122x_6 + 0.09x_7 - 0.133x_8 \\ & + 0.146x_9 + 0.152x_{10} - 0.274x_{11} + 0.407x_{12} - 0.13x_{13} + 0.123X14 + 0.116x_{15} \end{aligned} \quad (5)$$

$$\begin{aligned} F_6 =& 0.473x_1 + 0.093x_2 - 0.045x_3 - 0.05x_4 + 0.204x_5 \\ & + 0.058x_6 + 0.482x_7 + 0.027x_8 \\ & - 0.023x_9 + 0.004x_{10} + 0.424x_{11} - 0.284x_{12} + 0.232x_{13} + 0.124x_{14} + 0.156x_{15} \end{aligned} \quad (6)$$

$$\begin{aligned} F_7 =& - 0.013x_1 + 0.259x_2 - 0.042x_3 + 0.321x_4 - 0.039x_5 \\ & - 0.134x_6 - 0.123x_7 + 0.051x_8 \\ & + 0.087x_9 + 0.078x_{10} - 0.582x_{11} - 0.384x_{12} + 0.574x_{13} + 0.184x_{14} + 0.236x_{15} \end{aligned} \quad (7)$$

$$\begin{aligned} F_8 =& - 0.362x_1 + 0.381x_2 + 0.061x_3 + 0.354x_4 \\ & - 0.012x_5 - 0.082x_6 - 0.101x_7 \\ & + 0.26x_8 + 0.119x_9 + 0.135x_{10} + 0.542x_{11} + 0.465x_{12} + 0.292x_{13} + 0.12x_{14} + 0.138x_{15} \end{aligned} \quad (8)$$

The 8 principal component variables in the supply chain financial evaluation system based on accounts receivable model were taken as independent variables, and the credit risk of the enterprise was taken as dependent variable. SPSS was used for binary logistic regression analysis, and the forward step method was used to obtain the following results.

It can be found that only F_1, F_2, F_3, F_5 and F_7 of these 8 principal components enter the equation, so the content of this table can be expressed as:

$$\mathrm{Ln}\frac{p}{1\text{-}p} = 1.391F_1 + 1.398F_2 - 2.190F_3 - 3.416F_5 - 1.687F_7 - 1.500 \quad (9)$$

Thus, it can be expressed that the credit risk of small and medium-sized enterprises in the supply chain of the iron and steel industry under the accounts receivable financing mode is:

$$P = \frac{1}{1 + e^{-1.391F_1 - 1.398F_2 + 2.190F_3 + 3.416F_5 + 1.687F_7 + 1.500}} \quad (10)$$

3.2.2 Based on Inventory Pledge Model

See Tables 9 and 10.

$$\begin{aligned} F_1 =& 0.097y_1 + 0.082y_2 + 0.243y_3 - 0.276y_4 + 0.332y_5 - 0.235y_6 + 0.095y_7 \\ & + 0.106y_8 + 0.050y_9 + 0.126y_{10} - 0.026y_{11} + 0.247y_{12} + 0.264y_{13} \end{aligned} \quad (11)$$

Table 9 Component score coefficient matrix of inventory pledge financing model

	Composition								
	1	2	3	4	5	6	7	8	9
Fixed number of year of the term (y_1)	0.097	0.158	−0.209	0.154	0.542	0.367	0.102	−0.317	−0.431
Registered capital (y_2)	0.082	0.275	−0.232	0.032	−0.090	0.312	−0.151	0.071	0.730
Year-on-year growth in operating revenue (y_3)	0.243	0.038	0.284	0.084	−0.368	−0.221	−0.054	−0.252	−0.062
Return on equity (y_4)	−0.276	−0.002	0.161	0.396	0.158	−0.003	−0.165	−0.203	0.656
Net profit margin on sales (y_5)	0.332	−0.092	−0.017	−0.318	0.042	0.137	0.261	−0.437	0.398
Asset-liability ratio (y_6)	−0.235	0.347	−0.045	−0.060	−0.207	0.024	0.054	0.179	−0.273
Quick ratio (y_7)	0.095	−0.376	−0.111	0.170	0.167	0.030	−0.152	0.464	0.090
Transaction amount (y_8)	0.106	0.053	0.161	0.405	−0.109	0.206	0.803	0.364	0.060
Fixed number of year of the deal (y_9)	0.050	0.138	−0.106	−0.035	0.428	−0.770	0.267	0.188	0.214
Asset-liability ratio (core) (y_{10})	0.126	−0.064	−0.404	0.115	−0.319	−0.033	−0.090	0.388	−0.036
Quick ratio (core) (y_{11})	−0.026	0.030	0.288	−0.467	0.239	0.289	−0.023	0.630	0.133
Product liquidity (y_{12})	0.247	0.083	0.229	0.329	0.206	0.059	−0.447	0.157	−0.203
Price rigidity (y_{13})	0.264	0.289	0.039	−0.009	−0.019	−0.140	−0.252	0.206	0.050

Table 10 Variables in the equation of inventory pledge financing model

		B	Standard error	Wald	Degrees of freedom	Significant	Exp(B)
1a	REGR factor score 2	−1.054	0.330	10.178	1	0.001	0.349
	Constant	−0.214	0.220	0.952	1	0.329	0.807
2b	REGR factor score 2	−1.286	0.392	10.744	1	0.001	0.276
	REGR factor score 6	−0.699	0.253	7.610	1	0.006	0.497
	Constant	−0.280	0.233	1.445	1	0.229	0.756
3c	REGR factor score 2	−1.876	0.524	12.824	1	0.000	0.153
	REGR factor score 6	−0.975	0.302	10.432	1	0.001	0.377
	REGR factor score 9	−0.924	0.327	8.004	1	0.005	0.397
	Constant	−0.468	0.263	3.163	1	0.075	0.627
4d	REGR factor score 2	−4.956	1.168	17.999	1	0.000	0.007
	REGR factor score 3	3.383	0.847	15.961	1	0.000	29.459
	REGR factor score 6	−2.968	0.780	14.492	1	0.000	0.051
	REGR factor score 9	−3.319	0.814	16.626	1	0.000	0.036
	Constant	−1.697	0.517	10.781	1	0.001	0.183

$$\begin{aligned} F_2 = {} & 0.158\,y_1 + 0.275\,y_2 + 0.038\,y_3 - 0.002\,y_4 - 0.092\,y_5 + 0.347\,y_6 - 0.376\,y_7 \\ & + 0.053\,y_8 + 0.138\,y_9 - 0.064\,y_{10} + 0.030\,y_{11} + 0.083\,y_{12} + 0.289\,y_{13} \end{aligned} \tag{12}$$

$$\begin{aligned} F_3 = {} & -0.209y_1 - 0.232y_2 + 0.284y_3 + 0.161y_4 - 0.017y_5 - 0.045y_6 - 0.111y_7 \\ & + 0.161y_8 - 0.106y_9 - 0.404y_{10} + 0.288y_{11} + 0.229y_{12} + 0.039y_{13} \end{aligned} \tag{13}$$

$$\begin{aligned} F_4 = {} & 0.154\,y_1 + 0.032\,y_2 + 0.084\,y_3 + 0.396\,y_4 - 0.318\,y_5 - 0.060\,y_6 + 0.170\,y_7 \\ & + 0.405\,y_8 - 0.035\,y_9 + 0.115\,y_{10} - 0.467\,y_{11} + 0.329\,y_{12} - 0.009\,y_{13} \end{aligned} \tag{14}$$

$$\begin{aligned} F_5 = {} & 0.542\,y_1 - 0.090\,y_2 - 0.368\,y_3 + 0.158\,y_4 + 0.042\,y_5 - 0.207\,y_6 + 0.167\,y_7 \\ & - 0.109\,y_8 + 0.428\,y_9 - 0.319\,y_{10} + 0.239\,y_{11} + 0.206\,y_{12} - 0.019\,y_{13} \end{aligned} \tag{15}$$

$$F_6 = 0.367\,y_1 + 0.312\,y_2 - 0.221\,y_3 - 0.003\,y_4 + 0.137\,y_5 + 0.024\,y_6 + 0.030\,y_7 + 0.206\,y_8 - 0.770\,y_9 - 0.033\,y_{10} + 0.289\,y_{11} + 0.059\,y_{12} - 0.140\,y_{13} \quad (16)$$

$$F_7 = 0.102\,y_1 - 0.151\,y_2 - 0.054\,y_3 - 0.165\,y_4 + 0.261\,y_5 + 0.054\,y_6 - 0.152\,y_7 + 0.803\,y_8 + 0.267\,y_9 - 0.090\,y_{10} - 0.023\,y_{11} - 0.447\,y_{12} - 0.252\,y_{13} \quad (17)$$

$$F_8 = -0.317y_1 + 0.071y_2 - 0.252y_3 - 0.203y_4 - 0.437y_5 + 0.179y_6 + 0.464y_7 + 0.364y_8 + 0.188y_9 + 0.388y_{10} + 0.630y_{11} + 0.157y_{12} + 0.206y_{13} \quad (18)$$

$$F_9 = -0.431y_1 + 0.730y_2 - 0.062y_3 + 0.656y_4 + 0.398y_5 - 0.273y_6 + 0.090y_7 + 0.060y_8 + 0.214y_9 - 0.036y_{10} + 0.133y_{11} - 0.203y_{12} + 0.050y_{13} \quad (19)$$

The 9 principal component variables in the supply chain financial evaluation system based on the inventory pledge model are taken as independent variables and the enterprise credit risk is taken as dependent variables. SPSS was used for binary logistic regression analysis, and the forward step method was used to obtain the following results:

It can be found that only F_2, F_3, F_6 and F_9 of these 9 principal components enter into the equation, so the content of this table can be expressed as:

$$\ln\frac{p}{1-p} = -4.956F_2 + 3.383F_3 - 2.968F_6 - 3.319F_9 - 1.697 \quad (20)$$

Thus, it can be concluded that the credit risk under the inventory pledge financing mode of SMEs in the steel industry supply chain is:

$$p = \frac{1}{1 + e^{4.956F_2 - 3.383F_3 + 2.968F_6 + 3.319F_9 + 1.697}} \quad (21)$$

3.2.3 Based on Prepaid Payment Model

See Tables 11 and 12.

$$F_1 = 0.097y_1 + 0.082y_2 + 0.243y_3 - 0.276y_4 + 0.332y_5 - 0.235y_6 + 0.095y_7 + 0.106y_8 + 0.050y_9 + 0.126y_{10} - 0.026y_{11} + 0.247y_{12} + 0.264y_{13} \quad (22)$$

Table 11 Component score matrix of prepaid financing model

	Composition									
	1	2	3	4	5	6	7	8	9	10
Fixed number of year of the term (Z1)	0.075	0.003	−0.143	−0.196	0.066	0.185	−0.094	−0.273	−0.079	0.433
Registered capital (Z2)	−0.001	−0.117	−0.171	−0.130	0.047	0.121	0.029	0.081	0.379	0.314
Year-on-year growth in operating revenue (Z3)	−0.012	0.049	0.063	−0.120	0.208	−0.223	0.409	0.107	−0.135	−0.352
Year-on-year growth in net profit (Z4)	−0.022	0.079	0.080	0.072	0.301	−0.076	−0.130	0.264	0.266	0.168
Return on equity (Z5)	−0.053	0.063	0.125	0.100	0.288	−0.082	−0.522	−0.043	0.037	0.049
Rate of return on total assets (Z6)	−0.095	0.180	0.105	0.001	0.309	0.068	−0.006	−0.049	0.046	0.121
Net profit margin on sales (Z7)	−0.043	0.135	0.015	−0.078	0.201	0.291	0.472	−0.034	0.045	0.182
Asset-liability ratio (Z8)	0.066	−0.258	0.017	0.072	0.084	−0.031	−0.015	−0.040	0.087	0.038
Quick ratio (Z9)	−0.004	0.256	−0.032	0.056	−0.248	0.126	−0.099	0.016	0.075	−0.013
Inventory turnover (Z10)	0.188	−0.001	0.059	0.025	−0.044	−0.277	0.017	0.150	0.153	0.271
Turnover of accounts payable (Z11)	0.157	−0.033	0.060	0.201	0.139	0.389	0.043	−0.070	−0.060	−0.199
Cash cycle (Z12)	0.214	0.040	0.095	0.163	−0.048	−0.033	0.038	0.080	0.060	0.076
Operating cycle (Z13)	0.208	−0.004	0.086	0.215	0.073	0.252	0.047	−0.010	−0.013	-0.101
Total asset turnover (Z14)	−0.183	−0.079	0.059	0.272	−0.060	0.062	0.070	0.069	−0.053	0.077
Inventory turnover (core)(Z15)	−0.029	0.006	0.032	0.031	0.008	−0.031	−0.028	−0.775	0.217	−0.156
Current asset turnover (Z16)	−0.203	−0.101	0.001	0.183	−0.014	0.112	0.044	0.063	−0.013	0.075
Turnover of fixed assets (Z17)	−0.098	−0.089	0.061	0.258	−0.106	0.100	0.099	0.012	−0.033	0.229
Transaction Amount (Ten thousand yuan) (Z18)	−0.036	−0.059	−0.086	−0.091	0.006	0.215	−0.115	0.183	0.575	−0.576
Transaction years (months) (Z19)	0.004	−0.049	−0.068	−0.194	0.033	0.359	−0.235	0.228	−0.367	0.022

(continued)

Table 11 (continued)

	Composition									
	1	2	3	4	5	6	7	8	9	10
Asset-liability ratio (core)(Z20)	0.011	0.041	−0.225	0.139	0.012	−0.038	0.166	0.026	0.382	0.220
Quick ratio (core) (Z21)	−0.017	−0.048	0.344	−0.177	−0.143	0.113	0.039	0.000	0.190	0.162
Current ratio (Z22)	−0.015	0.260	−0.016	0.076	−0.249	0.097	−0.068	0.075	0.077	−0.008
Current ratio (core) (Z23)	−0.019	−0.043	0.348	−0.194	−0.138	0.097	0.023	0.018	0.190	0.090

Table 12 Variables in the equation of prepaid accounts financing model

		B	Standard error	Wald	Degrees of freedom	Significant	Exp(B)
1a	REGR factor score 3	0.943	0.190	24.517	1	0.000	2.568
	Constant	−0.487	0.141	11.918	1	0.001	0.615
2b	REGR factor score 3	1.056	0.191	30.434	1	0.000	2.875
	REGR factor score 4	1.164	0.244	22.722	1	0.000	3.203
	Constant	−0.490	0.152	10.372	1	0.001	0.613
3c	REGR factor score 2	1.121	0.227	24.479	1	0.000	3.068
	REGR factor score 3	1.220	0.212	33.068	1	0.000	3.387
	REGR factor score 4	1.137	0.219	26.921	1	0.000	3.117
	Constant	−0.678	0.171	15.671	1	0.000	0.508
4d	REGR factor score 2	1.563	0.287	29.601	1	0.000	4.773
	REGR factor score 3	1.634	0.254	41.462	1	0.000	5.122
	REGR factor score 4	1.602	0.257	38.829	1	0.000	4.963
	REGR factor score 10	−1.461	0.270	29.209	1	0.000	0.232
	Constant	−0.904	0.204	19.655	1	0.000	0.405
5e	REGR factor score 2	1.461	0.288	25.691	1	0.000	4.311
	REGR factor score 3	1.647	0.260	40.095	1	0.000	5.194
	REGR factor score 4	1.478	0.265	31.025	1	0.000	4.384
	REGR factor score 6	−0.606	0.293	4.265	1	0.039	0.546
	REGR factor score 10	−1.415	0.279	25.777	1	0.000	0.243
	Constant	−0.937	0.207	20.552	1	0.000	0.392

$$F_2 = 0.158\, y_1 + 0.275\, y_2 + 0.038\, y_3 - 0.002\, y_4 - 0.092\, y_5 + 0.347\, y_6 - 0.376\, y_7 + 0.053\, y_8 + 0.138\, y_9 - 0.064\, y_{10} + 0.030\, y_{11} + 0.083\, y_{12} + 0.289\, y_{13} \tag{23}$$

$$\begin{aligned} F_3 = & -0.209\ y_1 - 0.232\ y_2 + 0.284\ y_3 + 0.161\ y_4 \\ & - 0.017\ y_5 - 0.045\ y_6 - 0.111\ y_7 \\ & + 0.161\ y_8 - 0.106\ y_9 - 0.404\ y_{10} + 0.288\ y_{11} + 0.229\ y_{12} + 0.039\ y_{13} \end{aligned} \tag{24}$$

$$\begin{aligned} F_4 = & 0.154\ y_1 + 0.032\ y_2 + 0.084\ y_3 + 0.396\ y_4 \\ & - 0.318\ y_5 - 0.060\ y_6 + 0.170\ y_7 \\ & + 0.405\ y_8 - 0.035\ y_9 + 0.115\ y_{10} - 0.467\ y_{11} + 0.329\ y_{12} - 0.009\ y_{13} \end{aligned} \tag{25}$$

$$\begin{aligned} F_5 = & 0.542\ y_1 - 0.090\ y_2 - 0.368\ y_3 + 0.158\ y_4 \\ & + 0.042\ y_5 - 0.207\ y_6 + 0.167\ y_7 \\ & - 0.109\ y_8 + 0.428\ y_9 - 0.319\ y_{10} + 0.239\ y_{11} + 0.206\ y_{12} - 0.019\ y_{13} \end{aligned} \tag{26}$$

$$\begin{aligned} F_6 = & 0.367\ y_1 + 0.312\ y_2 - 0.221\ y_3 - 0.003\ y_4 \\ & + 0.137\ y_5 + 0.024\ y_6 + 0.030\ y_7 \\ & + 0.206\ y_8 - 0.770\ y_9 - 0.033\ y_{10} + 0.289\ y_{11} + 0.059\ y_{12} - 0.140\ y_{13} \end{aligned} \tag{27}$$

$$\begin{aligned} F_7 = & 0.102\ y_1 - 0.151\ y_2 - 0.054\ y_3 - 0.165\ y_4 \\ & + 0.261\ y_5 + 0.054\ y_6 - 0.152\ y_7 \\ & + 0.803\ y_8 + 0.267\ y_9 - 0.090\ y_{10} - 0.023\ y_{11} - 0.447\ y_{12} - 0.252\ y_{13} \end{aligned} \tag{28}$$

$$\begin{aligned} F_8 = & -0.317\ y_1 + 0.071\ y_2 - 0.252\ y_3 - 0.203\ y_4 \\ & - 0.437\ y_5 + 0.179\ y_6 + 0.464\ y_7 \\ & + 0.364\ y_8 + 0.188\ y_9 + 0.388\ y_{10} + 0.630\ y_{11} + 0.157\ y_{12} + 0.206\ y_{13} \end{aligned} \tag{29}$$

$$\begin{aligned} F_9 = & -0.431y_1 + 0.730y_2 - 0.062y_3 + 0.656y_4 \\ & + 0.398y_5 - 0.273y_6 + 0.090y_7 \\ & + 0.060y_8 + 0.214y_9 - 0.036y_{10} + 0.133y_{11} - 0.203y_{12} + 0.050y_{13} \end{aligned} \tag{30}$$

The 10 principal component variables in the supply chain finance evaluation system based on the prepayment pledge model were taken as independent variables and the enterprise credit risk as dependent variables. SPSS was used for binary logistic regression analysis, and the forward step method was used to obtain the following results:

It can be found that only F_2, F_3, F_4, F_6 and F_{10} of the 10 principal components enter the equation, so the content of this table can be expressed as:

$$\ln\frac{p}{1-p}=1.461F_2+1.647F_3+1.478F_4-0.606F_6-1.415F_{10}-0.937 \quad (31)$$

Thus, it can be expressed that the credit risk of small and medium-sized enterprises in the supply chain of steel industry under the prepayment financing mode is

$$p=\frac{1}{1+e^{-1.461F_2-1.647F_3-1.478F_4+0.606F_6+1.415F_{10}+0.937}} \quad (32)$$

3.3 *Results Analysis*

3.3.1 Omnibus Tests of Model Coefficients

First, Omnibus Tests of Model Coefficients were carried out, and the regression method was to step forward. Therefore, only the last step was concerned in the global test (Tables 13, 14 and 15).

In the three models of different modes, the Omnibus test model of coefficients tested a row with $P < 0.05$, proving that at least one variable OR value included in the fitted model was statistically significant, so the model as a whole was meaningful.

Table 13 Omnibus test of model coefficients in accounts receivable financing mode

	Chi-square	Degrees of freeedom	Significant
	4.589	1	0.032
Block	144.069	5	0.000
Model	144.069	5	0.000

Table 14 Omnibus test of model coefficients under inventory pledge financing mode

	Chi-square	Degrees of freedom	Significant
	34.673	1	0.000
Block	68.663	4	0.000
Model	68.663	4	0.000

Table 15 Omnibus test of model coefficients in prepaid accounts financing mode

	Chi-square	Degrees of freedom	Significant
	4.589	1	0.032
Block	144.069	5	0.000
Model	144.069	5	0.000

3.3.2 Results Analysis

The results of credit risk prediction model of supply chain finance in iron and steel industry under accounts receivable model

$$p = \frac{1}{1 + e^{1.391F_1+1.398F_2-2.190F_3-3.416F_5-1.687F_7-1.500}} \quad (33)$$

Can see F_1, F_2 value is higher, the lower the risk probability, F_5 took the largest weight, which accounted for the largest index in the F_5 is accounts receivable turnover, registered capital, so the higher the registered capital, the higher the account receivable turn over, based on the model of supply chain finance accounts receivable financing credit risk is lower, F_3 findings and the weights of the F_3 mainly represents the return on net assets and return on total assets of the financing enterprise. The higher the return on net assets and return on total assets, the stronger the profitability of the enterprise. Therefore, it is concluded that the higher the profitability of the financing enterprise, the lower the supply chain financial credit risk of the financing enterprise.

Results of supply chain financial credit risk prediction model in steel industry under inventory pledge model

$$p = \frac{1}{1 + e^{-4.956F_2+3.383F_3-2.968F_6-3.319F_9-1.697}} \quad (34)$$

F_2 has the largest weight, and the indexes that have the largest proportion in F_2 are the asset-liability ratio and quick ratio of financing enterprises. Therefore, the stronger the debt paying ability of financing enterprises is, the lower the credit risk of supply chain finance based on inventory pledge financing mode. The second is F_3 and F_9. In F_3, the largest proportion is the asset-liability ratio and quick ratio of core enterprises, etc. F_3 indicates that the stronger the solvency of core enterprises, the lower the credit risk. In F_9, the indicators with the largest proportion are the duration of the financing enterprise, the registered capital and the rate of return on net assets, etc. F_9 component indicates that the higher the quality of the financing enterprise, the lower the credit risk, the more stable the supply chain, the lower the credit risk, the higher the product liquidity ability, the lower the credit risk.

The results of credit risk prediction model of supply chain finance in iron and steel industry under prepayment model

$$p = \frac{1}{1 + e^{1.461F_2+1.647F_3+1.478F_4-0.606F_6-1.415F_{10}-0.937}} \quad (35)$$

F_3 has the largest weight, and the largest proportion of indicators in F_3 is the asset-liability ratio, liquidity ratio and quick ratio of core enterprises. Therefore, the stronger the solvency of core enterprises, the lower the credit risk of supply chain finance based on the prepayment model. The second is F_2, F_4 and F_{10}. In

F_2, the indexes with the largest proportion are asset-liability ratio, liquidity ratio and quick ratio of financing enterprises. Therefore, The F_2 component indicates that the higher the debt paying ability of financing enterprises, the lower the credit risk. The F_4 component indicates that the higher the asset turnover rate of the financing enterprise, the lower the credit risk. In F_{10}, the indexes that account for the largest proportion, such as transaction amount, duration of existence and registered capital, etc. Therefore, F_{10} indicates that the more stable the supply chain, the better the quality of the financing enterprise, the lower the credit risk.

3.4 Robustness Test

The data used in the establishment of the model above are all SMEs listed in the steel industry before 2020. In order to verify the robustness of the model, the data of SMEs listed in the steel industry after 2020 are added on the basis of the original data to verify the accuracy of the model. On the other hand, the data after 2020 are introduced to observe whether the influencing factors of credit risk of supply chain finance will change under various modes under the global disaster of COVID-19.

Robustness analysis can be divided into three types. One is to change the value based on data, such as value at different times or test value in different industries. One is to start from independent variables and change some independent variable data, such as the turnover of current assets is replaced by the turnover of cash flow; One is to change the value of the dependent variable starting from the dependent variable, which generally occurs when the dependent variable of the test data is obtained in different ways. The last way is to start from the method and change the method adopted, which is often to verify the robustness of the conclusion through comparison of methods.

In this paper, the financial credit risk of supply chain in the iron and steel industry is studied. Most of the data selected in the early stage are SMEs listed in the iron and steel industry from 2010 to 2020. When verifying the robustness of the model, enterprises listed before 2010 and enterprises listed after 2020 are included. It can also verify whether the model is robust under the epidemic force majeure.

The new data are used to predict the supply chain finance credit risk prediction model, and goodness of fit test is carried out to test the robustness of the model. The goodness of the so-called fit test is to judge whether the predicted value of the model is consistent with the observed value. If the results are relatively consistent, the model is considered to have good fitting degree. Otherwise, the model will be rejected, proving that the model is not robust enough.

(1) Quantitative evaluation of goodness of fit effect.

Established y is the data to be fitted, y means $\overline{y}$, The fitted data is $\hat{y}$, so

Table 16 Summary of the model under accounts receivable financing mode

	Minus 2 logarithmic likelihoods	Cox-snell R squared	Nagelkerke R squared
1	238.783a	0.144	0.196
2	215.173b	0.238	0.324
3	190.833b	0.324	0.441
4	168.859c	0.394	0.535
5	142.536c	0.467	0.635

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} = 1 - \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}_i\right)^2} \tag{36}$$

where SST is the sum of total squares, SSR is the sum of regression squares, SSE is the sum of residual squares, and R^2 is the determinable coefficient of goodness of fit, also known as the determination coefficient. The maximum value of R^2 is 1, and the larger R^2 is, the better the goodness of fit of the model is (Tables 16, 17 and 18).

Quantitative evaluation of these supply chain finance credit risk prediction models shows that the models have good fitting degree.

(2) Qualitative evaluation of goodness of fit effect.

Hosmer–Lemeshow goodness of fit test (H–L test) can be used to evaluate whether the test method of the model is optimized by fully using the input information. The

Table 17 Abstract of the model under inventory pledge financing mode

	Minus 2 logarithmic likelihoods	Cox-snell R squared	Nagelkerke R squared
1	119.167a	0.148	0.198
2	110.551a	0.219	0.294
3	100.845b	0.293	0.392
4	66.172c	0.504	0.674

Table 18 Abstract of the model under prepaid accounts financing mode

	Minus 2 logarithmic likelihoods	Cox-Snell R squared	Nagelkerke R squared
1	292.428a	0.132	0.179
2	258.642b	0.244	0.331
3	226.699b	0.336	0.457
4	187.709c	0.434	0.589
5	183.121c	0.445	0.603

Table 19 Hosmer–Lemeshow test in accounts receivable financing model

	Chi-square	Degrees of freedom	Significant
1	12.720	8	0.122

Table 20 Hosmer–Lemeshow test under inventory pledge financing model

	Chi-square	Degrees of freedom	Significant
1	6.164	8	0.629

Table 21 Hosmer–Lemeshow test in the prepayment financing model

	Chi-square	Degrees of freedom	Significant
1	10.168	8	0.253

higher the significance is, the better the model fit is. Generally, $P > 0.05$ is used as the basis for accepting the model (Tables 19, 20 and 21).

P values of the three models are all greater than 0.05, indicating that the fitting degree of the three models is good from the qualitative evaluation (Tables 22, 23 and 24).

Table 22 Model classification table under accounts receivable financing mode

Classification table				
Actual measurement		Forecast		
		Is there a risk		Correct percentage
		0	1	
Is there a risk	0	110	15	88.0
	0	18	60	76.9
Overall percentage				83.7
The boundary value is 0.500				

Table 23 Model classification table under inventory pledge financing mode

Classification table				
Actual measurement		Forecast		
		Is there a risk		Correct percentage
		0	1	
Is there a risk	0	50	4	92.6
	1	4	40	90.9
Overall percentage				91.8
The boundary value is 0.500				

Table 24 Model classification table of prepaid accounts financing mode

Classification table				
Actual measurement		Forecast		
		Is there a risk		Correct percentage
		0	1	
Is there a risk	0	133	17	88.7
	1	19	76	80.0
Overall percentage				85.3
The boundary value is 0.500				

In conclusion, financial supply chain based on the pattern of the accounts receivable credit risk model prediction accuracy is 83.7%, based on the inventory model of supply chain finance credit risk model prediction accuracy of 91.8%, based on the pattern of advance payment of supply chain finance credit risk model prediction accuracy is 85.3%, higher prediction precision, better model feasibility. The robustness of the models is good.

4 The Empirical Analysis

Liaoning xin zhong technology co., LTD. (hereinafter referred to as L) was established in 2010, is A research and development manufacture of mining equipment, machine manufacturing industry, from the upstream steel group procurement of steel, A enterprise is important supplier of L company, A company for L company provide raw materials such as steel, L will raw materials through manufacturing Cheng-GangTie development, Downstream customers are sellers of steel equipment. For several years, the existence of ENTERPRISE A in the supply chain has guaranteed the development of enterprise L and the smooth financing of enterprise L. For the banks that provide financing, what is the credit risk status of Company L and what mode should Company L obtain supply chain financial services to obtain financing more easily.

Firstly, supply chain financial services are provided through the accounts receivable model. Information is collected according to the model and summarized as follows: L Company was established in 2011 with registered capital of 102,485,500 yuan. In 2022, compared with last year, its operating revenue increased by 241.27%, its net profit increased by 70.38%, and its return on equity was 2.11%. Total asset return rate is 1.13%, net sales interest rate is 1.69%, asset-liability ratio is 45.98%, liquidity ratio is 1.59, quick ratio is 0.24, receivables turnover is 56.44, receivables turnover is 6.38, and the asset-liability ratio of core enterprise A in the supply chain of COMPANY L is 51.03%. The current ratio and quick ratio of enterprise A are 0.78 and 0.46 respectively.

According to the calculation, the credit risk of L company in the supply chain financial service of accounts receivable mode is

$$P = \frac{1}{1 + e^{-26820.34729}} \tag{37}$$

Therefore, the risk of L company providing supply chain financial services through accounts receivable mode is 1.

Secondly through the inventory model of supply chain finance services, according to the model to collect information, in addition to the above-mentioned information include L company product price stability, according to the qualitative rating of 4 Product liquidity (market demand) qualitative rating of 5, A enterprise with L company trading limit for 8.2478 million yuan.

According to calculation, the credit risk of L company in supply chain financial service with inventory pledge mode is

$$P = \frac{1}{1 + e^{56905.56}} \tag{38}$$

Therefore, the risk of SUPPLY chain financial services provided by L company through inventory pledge mode is 0.

Finally, supply chain financial services are carried out through the prepaid accounts model. Information is collected according to the model. In addition to the information mentioned above, inventory turnover is 239.39, accounts payable turnover is 100.35, cash cycle is 195.48, business cycle is 295.83 days, total asset turnover is 0.67, inventory turnover is 1.5. The turnover rate of receivables is 6.38, the turnover rate of accounts payable is 3.59, the turnover rate of current assets is 0.91, and the turnover rate of fixed assets is 3.61. The transaction amount with core enterprise A is 8.2478 million yuan, and the transaction life with core enterprise A is 22 months. The asset-liability ratio of core enterprise A is 51.03%. The liquidity ratio of core company A was 78 percent, and the quick ratio of core company A was 46 percent.

According to the calculation, the credit risk of L company is

$$P = \frac{1}{1 + e^{-11602.17602}} \tag{39}$$

Therefore, the risk of L company providing supply chain financial services through prepayment mode is 1.

Through the comparison of the three models, it can be found that for the same enterprise, different supply chain finance financing modes have different results. For the example of COMPANY L, it is easier to choose the inventory pledge mode for loan service than loans based on other pledges.

According to the information provided by the model, it can be found that SMEs in the iron and steel industry need to pay attention to different information of enterprises when they adopt different supply chain financing modes. If they adopt accounts receivable mode for supply chain financing, they should pay more attention to enterprise quality and accounts receivable turnover. If inventory pledge mode is adopted for supply chain financing, more attention should be paid to the enterprise operation ability and product liquidity ability of financing enterprises, while if prepayment mode is adopted for supply chain financing, more attention should be paid to supply chain quality and profitability of financing enterprises.

For iron and steel industry of small and medium-sized enterprises, located in the upstream of the core enterprise in the supply chain of small and medium-sized enterprises, because the downstream is a large enterprise capital abundant, so through the mode of accounts receivable financing is more likely, for supply chain with core enterprise have cooperation for a long time for the small and medium-sized enterprises, supply chain quality is better, so more likely to get financing by advance payment mode, The inventory pledge model may be more suitable for those enterprises with high product recognition and strong liquidity.

5 Conclusion and Prospect

In this paper, under the background of supply chain finance financing model, in-depth analysis of the current situation of the iron and steel industry supply chain finance financing, combined with the present situation of the iron and steel industry and supply chain finance development give the feasibility of the financial development of steel industry supply chain, based on the steel industry listed small and medium-sized enterprises as well as the corresponding supply chain core enterprise on the panel data, Collinearity problem using principal component analysis (PCA) to alleviate the original data, the method of using binary logistic regression analysis of different financing model of iron and steel industry of small and medium-sized enterprises credit risk analysis is made on the corresponding risk prediction model, and the model are omnibus, hosmer and Lemeshow Test, by expanding the robustness test sample size, Finally, the following conclusions are drawn:

Accounts receivable financing mode, the influencing factors of supply chain finance credit risk is more of the accounts receivable turnover, the registered capital, the second also includes financing companies return on net assets, return on total assets and so on, so for accounts receivable financing mode of financing the higher corporate profitability, lower financing enterprise supply chain finance credit risk.

Inventory impawn financing mode, the influencing factors of supply chain finance credit risk is more financing enterprises of asset-liability ratio, quick ratio, the second is the marketability of products, the financing enterprise's registered capital and so on, so for inventory impawn financing financing mode of enterprise quality is higher, the higher the debt paying ability, enterprise supply chain financing financial credit risk is lower.

Prepaid account receivable financing mode, the factors influencing the supply of financial credit risk is more of a core enterprise of the asset-liability ratio, current ratio and quick ratio, the second is the fixed number of year of the deal, size, etc., so for prepaid account receivable financing mode, the greater the stability of the supply chain, finance companies of enterprise quality, the better, the lower the credit risk.

Based on the above conclusions, the research significance is as follows: when banks and other financial institutions provide supply chain financial services, they can predict the credit risk of financing enterprises to reduce their own risks; Small and medium-sized enterprises choose a more suitable supply chain financing mode to obtain financing by virtue of their own advantages and disadvantages and prove it through empirical analysis.

Block chain in essence is a Shared database technology, main show is decentralized distributed bills, each block between share trading information, make the information of the chain block traceability, more ensures the symmetry and transparency of information, thus theoretically block chain technology can reduce the risk of financial services provider in the supply chain financial service [46]. State Grid established the blockchain supply chain financial cloud platform for the first time to enable upstream suppliers of the supply chain to handle receivables factoring through the platform. The connection between the platform and the supply chain system not only improves the efficiency of transactions, but also directly obtains transaction details, making supply chain financial services more efficient and secure. The iron and steel industry involves a large number of enterprises and the transaction relationship is complicated, which makes the traditional supply chain financial services face serious information asymmetry. When the number of enterprises on the block chain is large, the block chain supply chain financial platform can better serve the financial service providers. As a commodity trading industry, the iron and steel industry has a huge industrial system, which is suitable for the establishment of blockchain supply chain financial services. Treasure, for the first time in 2019 launched block chain supply chain financial platform - TongBao platform, different from 3.0 stage supply chain financial trading platform, TongBao platform financing through debt obligations transfers from the core enterprise, in document flow process, trading information is recorded on the whole and the interaction between the various nodes, greatly alleviate the information asymmetry, The biggest possible to eliminate corporate fraud, to ensure the authenticity and transparency of the transaction.

Blockchain supply chain financial service platform provides a relatively successful solution to the financing dilemma of SMEs in the steel industry, which is the general trend of the development of supply chain finance in the steel industry.

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Construction of Oil and Gas Pipeline Project Cost Node Management Mode

Ruihua Sun and Xuanzhuo Liu

Abstract As the main way of oil and gas transportation, the pipeline project is related to the energy lifeline of the whole country. Under the background of "one national network", the current pipeline project competition is fierce, and the cost control requirements are higher. How to reduce cost and increase efficiency has become the first consideration of all enterprises, and the implementation of fine cost management has become a consensus. Based on the above background, based on the oil and gas projects cost management as the research object, analyzes the problems existing in the current pipeline project cost management, illustrates the characteristics of the node cost management mode and construction method, and then based on the operation cost method to build the cost of the node management framework, and explains the key link and the construction of management system, It is concluded that the construction of cost node management mode can reduce cost and increase efficiency for oil and gas pipeline projects. In order to provide a new idea for pipeline project cost node management.

Keywords Pipeline project · Cost management · Activity-based costing · The cost of the node

1 Introduction

In order to promote the interconnection of pipeline networks, better allocate oil and gas resources nationwide, improve the allocation efficiency of oil and gas resources, and ensure the safe and stable supply of oil and gas energy, the national pipeline network group has set the goal of "one network nationwide" by merging inter-provincial and intra-provincial pipeline networks and implementing a uniform tariff

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rate. However, since the transmission volume of inter-provincial and intra-provincial pipelines is not of the same order of magnitude, the implementation of a uniform price at the same level of yield will result in different degrees of losses for pipelines with smaller intra-provincial transmission volumes [1]. Coupled with the current increasingly fierce competition in the pipeline industry, how to reduce costs and increase efficiency has become a key concern for oil and gas companies in order to increase their survival space.

2 Current Problems of Cost Management in Oil and Gas Pipeline Projects

1. Cost management methods are lagging. Due to the long-term Chinese oil and gas enterprises, especially the state-owned large oil and gas enterprises are subject to the traditional planned economy concept, the management concept is relatively backward, and the application of new cost management concepts and methods is still insufficient [2]. According to a survey by Xing Guixian et al., 51.4% of construction enterprises have adopted the target cost method, 38.9% have adopted the planned cost method, 18.1% have adopted the standard cost method, and the more advanced operation cost method has hardly been adopted [3]. These traditional methods cannot accurately provide the composition of construction costs of different projects, especially after the adoption of new personnel allocation or technology, they cannot accurately reflect the cost changes, which makes managers unable to obtain real and effective information in time for accurate personnel and material allocation or optimization.
2. Extensive management. In most oil and gas pipeline projects, the common problems are the lack of competition caused by high engineering costs and the shortage of funds caused by lagging project settlements. This is a comprehensive reflection of deep problems such as extensive management model and weak execution [4], and lack of innovative ideas, lack of perfect processes and methods, and untimely information delivery are all manifestations of extensive management. Since one of the characteristics of oil and gas pipeline projects, especially long-distance pipeline projects, is that they span a wide range of areas, and the environmental conditions and even customs involved may vary greatly, these problems can lead to poor overall project quality, shifting responsibilities among project parties, and other situations, just pipeline projects produce problems such as schedule delays, resulting in increased costs.
3. Insufficient awareness of cost control. The completion of an oil and gas pipeline project involves many aspects, most people do not have the awareness of cost control. And the oil and gas pipeline project traverses a wide area, there will be local projects employing local workers, which makes the cost control awareness weak. The project management pays too much attention to construction progress

and quality, and some project departments seem to have set up complete responsibilities and division of labor mechanisms, but in fact, they are virtual; many constructions personnel are trying to complete more tasks in a short time, ignoring the consumption of machinery costs, resulting in the increase of project costs. In fact, these are because the quantitative salary of the management staff and construction personnel according to the completion of the volume of work or work hours to get wages, the cost of the whole project is not linked to their own interests, and naturally will not be seriously controlled.

There is no accurate and complete reflection of the input and output situation and there is a disconnect between the situation on the project and the management, at the same time there is a lack of a sound system, the lack of refinement, standardization, and scientific management, etc., are the problems that exist in the process of cost management, should take these problems as a breakthrough, and strive to explore a scientific, systematic and refined cost node management model applicable to the practice of oil and gas pipeline projects, and can be promoted in the enterprise.

3 Theoretical Basis for Constructing a Cost Node Management Model for Oil and Gas Pipeline Construction Projects

The field of cost management has undergone a revolution in the last few decades. The first was the emergence of activity-based costing in the 1980s, which is slowly replacing the traditional standard cost system. The second was the combination of operations-based management and other cost management techniques has provided new ways to reduce costs in both the horizontal and vertical aspects of the value chain and product life cycle.

Activity-based costing (ABC) is a costing and management method that measures the cost of jobs and cost objects and evaluates job performance and resource efficiency by dynamically tracking and reflecting all job activities involved in cost objects. The ABC product strategy was introduced to the management of the company, which became the beginning of the application of job costing and provided useful information for decision making. In the 1880s, the ABC product strategy was introduced to the management of enterprises, which became the beginning of the application of activity-based costing and provided useful information for decision making. In the 1940s, Eric Kohler, an American accountant, gave a professional description of job costing and job accounting in his “Dictionary for Accountants”, which formally introduced the idea of activity-based costing into business management accounting. George J Staubus, on the other hand, published “Activity Costing and Input–output Accounting” in the 1970s based on Kohler’s research. In the book, he assembled activity cost management into a cost management system for the first time, comprehensively introduced jobs, job consumption, inputs and outputs, and summarized the relevant calculation methods. Based on George J Staubus’s research, Robin

Cooper and Robert S Kapland put forward the epoch-making assertion that "Products consume work and work consumes resources" [5], and on this basis, they proposed the Cost driver theory. Since then, the job costing method has been developed in various industries. Robin Cooper and Robert S. Kaplan created a system for obtaining more accurate product costs. The most significant difference between the job costing method and other systems is the allocation of indirect costs. In this system, cost allocation is based on the activities required to obtain the product. ABC helps managers to know exactly where to take action to drive profits [6]. Horngren et al. (2000) argue that the ABC is most useful in industries and companies with multiple products, especially in highly competitive industries. The job costing process allocates costs to products based on the resources used in the product, identifying all activities performed to produce the product and all resources consumed by these activities [7].

At first, the job costing method was implemented only in manufacturing companies. It was not until Carola Raab and Kathleen B Nelson (2010) applied the job costing method to a bakery in a casino in Las Vegas and extended the application to the restaurant industry, which was the first time that job costing was applied in the service industry in addition to the manufacturing industry and got good results [8].

In "Nodal Method Project Management and BIM Application", Cai Jiaming mentioned that modern engineering project management is a large system with strong correlation among systems, a large amount of data calculation, processing of various complex relationships, the need to use and store a large amount of information, and the need for professional organizations to implement specialized management. Domestic engineering project management is more on the owner's own management, to set up a command or similar institutions to implement the project; The electronic product code (EPC) mode of advantage has not been more people understand, only in individual projects to be applied project management contract (PMC) mode for most of the domestic The project management contract (PMC) model is still a new concept to most people in China, and is only applied in recent years in large domestic joint venture projects, with a large gap between the advanced management technology of foreign engineering companies. In addition, the quality of project management personnel is generally low, and they have not mastered the advanced management techniques. Engineering project management technology is relatively backward. Wang Xuehong (2015) shows that the traditional standard cost method has hindered the development of enterprises. She proposed an innovative cost development concept, indicating that the new concept can improve the market competitiveness of enterprises and promote the development of enterprises [9]. Liu, Yong and Li, Hui (2015) proposed that enterprises with a complete cost management system can further improve the internal management of enterprises. They decomposed the project from four aspects: structure, construction, resources, and cost, and carried out a detailed elaboration of the specific ways and processes to build a cost management system [10]. In recent years, there are experts and scholars from different industries who have done a lot of study and research in this area, hoping that this cost management model will be promoted in the actual production and operation of enterprises in general and oilfield enterprises in particular [11].

Through the compilation and reading of the literature, it can be found that all scholars agree that the current standard cost method has reached a bottleneck and cannot better manage the project in a more scientific and effective way. Innovation is imperative. The job costing method can be combined with system theory, value chain and other theoretical systems, which can be more flexible to cope with the diverse project characteristics nowadays and can be more effectively applied and promoted in the competitive environment.

Foreign countries, especially developed countries, have earlier research on cost accounting and control management. They have accumulated relatively rich theoretical research. The problem that needs to be solved in foreign countries is to develop the operation cost method into a mature method that can be applied to various fields and can be implemented smoothly by companies according to local conditions. The foreign literature has been able to apply not only in the manufacturing and construction industries but also in the service industry. Through the analysis and application of the activity costing method in different types of companies, the company has a new management idea of cost management, and at the same time, the company is prompted to better combine the application of the activity costing method with the function embedding and data connection between the existing information management system, so as to provide a reliable information basis for the application of job costing method.

In China, although all industries have been developing rapidly from theory to technology in recent years, there are still obvious shortcomings. One of them is that the operating cost method is mostly applied in enterprises, while less applied in projects. And most domestic enterprises tend to give priority to standard cost management for cost accounting and control, the actual use of the application of the job costing method combined with the application of research is not much. There is not enough cost information accuracy to provide support for cost control; the second is that there are more obstacles in the specific application of job costing: the basic level of information technology ability, the comprehensive management level of the company, the comprehensive quality of the staff and the ability to accept new things, etc.

4 The Connotation and Characteristics of the Cost Node Management Model of Oil and Gas Pipeline Projects

The oil and gas pipeline project cost node management mode is to take the oil and gas pipeline project as the object, based on the in-depth analysis of project characteristics, status quo and potential and on the premise of continuous optimization of the cost management system, through the analysis of project process, cost motivation, etc., comprehensive budget theory, operation cost management theory, key point control theory and cost motivation theory, with budget management as the center, and Through the analysis of project process and cost motivation, we integrate comprehensive budget theory, operation cost management theory, key point control theory and cost motivation theory, centering on budget management and integrating budget preparation, process control, cost accounting, cost motivation analysis and assessment and evaluation, we form a set of scientific cost management specification to realize the refinement, scientific and standardization of cost management. By grasping the key nodes of cost management and implementing effective management to continuously optimize the enterprise operation process, we can effectively control investment, increase project benefits, streamline the operation process and achieve the ultimate goal of cost reduction and efficiency.

Oil and gas pipeline project cost node management in turn mainly includes the following features.

1. Oil and gas pipeline project cost node management takes nodes as the object [12]. A pipeline project is composed of many sub-component works. Similar sub-component works can be simplified into important nodes and cost control and management can be carried out around them. A series of processes such as continuous refinement, reform, and assessment are used to reach a rationalized decomposition and control of the process flow.
2. Oil and gas pipeline project cost node management has operational variability. An oil and gas pipeline project often includes many links, including earthwork, pipe section installation, pipeline penetration crossing, cathodic protection, hydraulic protection, etc. The richness of the operation also leads to the variability of the operation.
3. Oil and gas pipeline project cost node management has spatial and temporal variability: the pipeline project is different from other projects, it wears across a wide range, the geographic situation is complex, the climate environment changes greatly, coupled with the project duration is long, the difference in time and space will lead to the existence of spatial and temporal variability of oil and gas pipeline projects.
4. The management inputs to the cost nodes of oil and gas pipeline projects are looked at as a whole. Controlling costs is not simply about controlling resource inputs; sometimes additional inputs may be required to achieve overall project cost reductions and efficiencies. For example, if the introduction of a large piece of equipment costs a fortune, but it can significantly speed up the project schedule, and the reduced labor costs and duration more than compensate for its expense, then the piece of equipment is still worth introducing.

5 Construction of Cost Node Management Model for Oil and Gas Pipeline Projects

5.1 *Basic Framework of Cost Node Management Model for Oil and Gas Pipeline Projects*

In general, the nodal cost management of oil and gas pipeline projects is to find the cost nodes by various methods such as fishbone diagram analysis, barrel theory analysis, and build a unit cost database by combining with the fixed hair, then prepare the budget plan and control plan for each project according to the database, and carry out process monitoring by combining with the plan. Finally, the project results are evaluated and summarized, and rewards and punishments are given to the responsible personnel to motivate them to form positive feedback, and the process is recycled again in the next project for continuous optimization.

The basic framework of specific cost node management is shown in Fig. 1.

5.2 *Key Aspects of Application Cost Node Management for Oil and Gas Pipeline Projects*

1. Select cost nodes. Cost nodes are divided into dominant cost nodes and limiting cost nodes. One is the main factor that causes the cost to occur and the other is the main reason that restricts the cost reduction. To find the dominant cost node a fishbone diagram analysis is generally used (as shown in Fig. 2). In the process of accomplishing the goal, the whole project will be designed with many management activities and construction processes, corresponding to the respective personnel, items, etc. After decomposition at various levels, a fishbone-shaped structure diagram can be formed, according to the structure diagram the key factors necessary to complete the project can be analyzed, and the key factors found that affect the cost of key operations are the cost nodes. And to find the limiting cost node will generally use the method of analyzing the short board operations. Focused analysis of the weakest link in cost control can improve the upper limit of cost control and expand the space for cost reduction.
2. Construct the cost node database. Based on the cost driver analysis, the standard cost driver rate of cost nodes can be calculated. Then, based on the consultation with relevant professionals, financial personnel and management as well as the consumption quota of oil construction and installation projects and the estimated budget index of oil construction and installation projects, the cost node database of pipeline projects can be constructed. In the cost item subdivision, cost item standards are set by combining the management requirements of different dimensions such as operation, process, responsibility unit and budget. Standard cost base data, which are entered on-site by cost-related staff, are checked from time

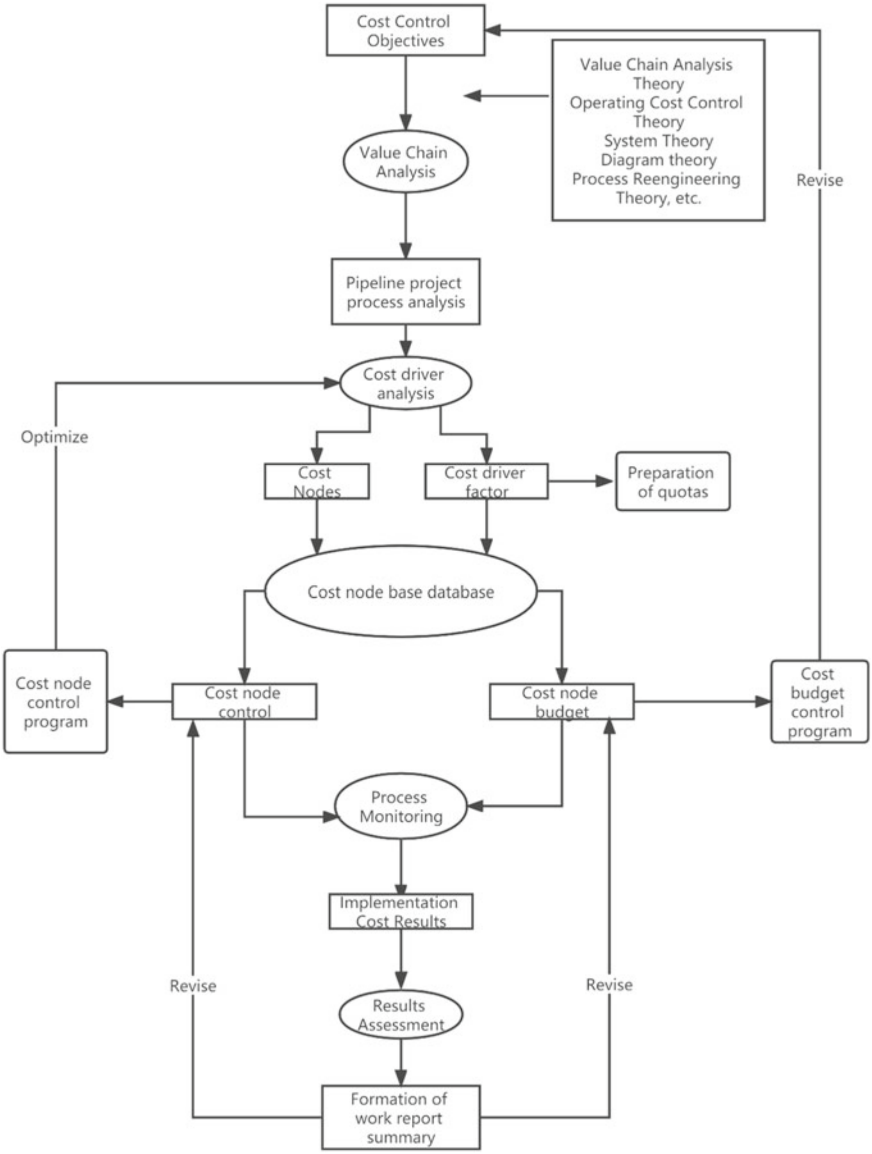

Fig. 1 Basic framework of cost node management

to time according to the base data provided by the technical department to ensure the accuracy of the data [13]. The cost drivers of the basic operation centers of the oil and gas pipeline project are shown in Table 1.

3. preparation of cost node budgets. Budgeting can be divided into two parts: basic analysis and specific analysis, where the basic analysis is divided into two parts:

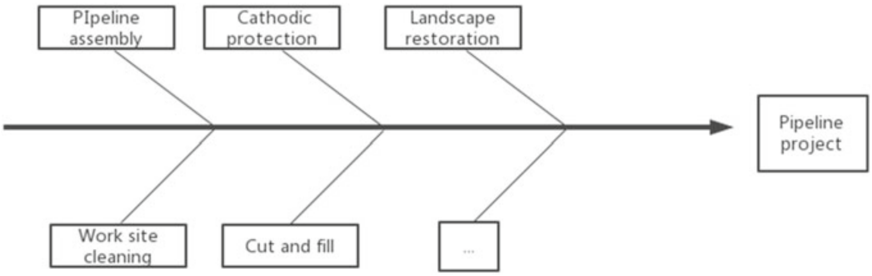

Fig. 2 Schematic diagram of fishbone analysis for pipeline projects

status quo analysis and forecast analysis [14]. The analysis of the current situation of the pipeline project is mainly divided into two parts: the basic situation and the technical route, see Fig. 3.

The pipeline project forecast is based on the analysis of the current situation, taking into account local energy demand trends and development plans, local policies, etc. to forecast the project potential. Based on the basic project specifications and physical workload, the project cost budget can be prepared, which can be divided into three major parts: labor cost budget, project engineering cost, and other cost budgets. The preparation of the cost node budget program is a crucial part of the cost node management model.

4. Prepare the cost node control program. Using cost database and budgeted workload to prepare cost node budget program, then compare and analyze the real consumed resources and budgeted consumed resources through comparative analysis method, and control cost nodes effectively and timely through early warning control, process control and feedback control, etc., while preparing cost node control program.
5. Application of appraisal management system. The completion of responsibility costs and the implementation of cost budgets are used to analyze the reasons for not meeting the targets, and to amend and adjust the budget program and control program. Gradually establish a performance appraisal model that combines performance with planning goal achievement, value creation, business growth, and innovation input [15].

6 Components of Cost Node Management System for Oil and Gas Pipeline Projects

The management model usually reflects the management concept and ideas of the organization, and its specific operation requires the support of multiple management systems. For the organization and implementation of the cost node management mode of oil and gas pipeline projects, a collaborative, high-quality and efficient cost node management system for oil and gas pipeline projects should be created. Using the

Table 1 Operating cost drivers of oil and gas pipeline projects

Project name	Activity centers	Cost consumption	Cost drivers
Line	Earthwork construction	Labor Costs, Machinery Costs etc.	The volume of earth-rock work
	Pipeline installation	Labor Costs, Pipe Materials Costs, Transport Charge, Anti-corrosion Coatings etc.	Pipe length
	Pipeline crossing projects	Labor Costs, Machinery Costs, Auxiliary materials etc.	Crossing length
	Cathodic protection	Labor Costs, Materials Costs, Testing Fee etc.	Pipe length
	Ecotype hydraulic protection	Labor Costs, Materials Costs etc.	Pipe length
Valve chest	Civil works	Labor Costs, Materials Costs, Machinery Costs etc.	Floor space
	Electrical engineering	Labor Costs, Materials Costs etc.	Laid length
	Communication engineering	Labor Costs, Materials Costs, Installation Costs etc.	System number
	Automatic-control engineering	Labor Costs, Materials Costs, Installation Costs etc.	System number
	Craft	Labor Costs, Materials Costs etc.	System number
	Fire fight engineering	Labor Costs, Materials Costs etc.	System number
	Heating engineering	Labor Costs, Materials Costs etc.	System number
	Cathodic protection	Labor Costs, Materials Costs etc.	Number of design
Station	Civil works	Labor Costs, Materials Costs, Machinery Costs etc.	Floor space
	Electrical engineering	Labor Costs, Materials Costs etc.	Laid length
	Communication engineering	Labor Costs, Materials Costs, Installation Costs etc.	System number

(continued)

Table 1 (continued)

Project name	Activity centers	Cost consumption	Cost drivers
	Automatic-control engineering	Labor Costs, Materials Costs, Installation Costs etc.	System number
	Craft	Labor Costs, Materials Costs etc.	System number
	Fire fight engineering	Labor Costs, Materials Costs etc.	System number
	Heating engineering	Labor Costs, Materials Costs etc.	System number
	Cathodic protection	Labor Costs, Materials Costs etc.	Number of design

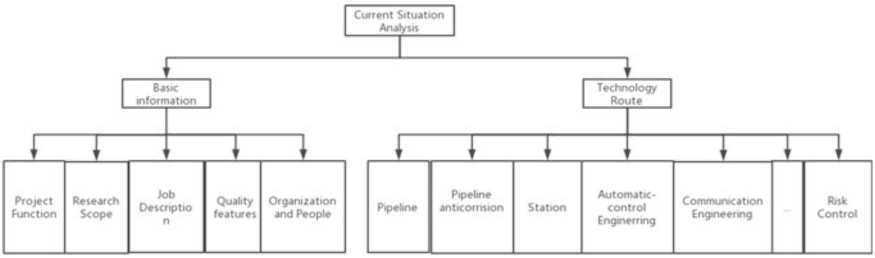

Fig. 3 Analysis model of the current situation of budgeting

relevant methodological concepts of system engineering, a cost node management objective system suitable for oil and gas pipeline projects should be established in terms of objectives, responsibilities, operation, and assessment [16].

1. Oil and gas pipeline projects cost node management target system. At the early stage of the project, according to the progress and quality requirements of the construction side of the project and the specific parameters and difficulties of the project, combined with the data of similar pipeline projects in the past, the overall target, medium-term target, short-term target, and other progress targets and project-specific targets such as duration target, quality target, information target, and HSSE target are set for the whole project. The target cost is decomposed and implemented to project departments and grassroots management groups at all levels, and then each department at lower levels will make daily detailed target plans to ensure the achievement of the overall project target according to the specific requirements from higher levels and the actual implementation stage of the project, such as weather, temperature, geographical conditions, and departmental inspections. Through the feasibility and controllability of the target, the purpose of cost control is achieved.

2. Oil and gas pipeline project cost node management responsibility system. On the basis of the target cost determination, the cost is decomposed into specific cost nodes through the division of operation centers. The target cost of the whole project is the responsibility of the project manager, and each cost node is assigned to the person in charge of the department in charge of that operation center after it is formulated, and the specific construction process is focused on by each team. It should be ensured that each worker understands his own responsibility and has the awareness of cost control when carrying out the work, so as to ensure that the cost node management can be effectively promoted and implemented at the grassroots level and will not be reduced to an empty shelf.
3. Oil and gas pipeline project cost node management operation system. The operating system is the core to ensure the realization of target costs. First of all, the basic analysis can be carried out for the basic situation of the project, mainly the scope of the study (including time scope, market scope, work scope, etc.), work content, environmental analysis of the project route area (including national policy, market environment, etc.), future change forecast, etc., and on top of this basic analysis, the specific analysis of the cost budget and the preparation of a reasonable budget. Based on the decomposition of cost nodes and budgeting, we improve the process, optimize the procedures, and supervise the whole project process in terms of materials, equipment, machinery, schedule, personnel, safety, etc. We establish a comprehensive, systematic, and efficient operation system covering all projects, which can make the whole management system more scientific, standardized, and refined.
4. Oil and gas pipeline projects cost node management assessment system. Without a proper appraisal mechanism and positive feedback and stimulation, employees will lack the motivation to implement it, and eventually, the reform will only be in superficial form, which will not only fail to achieve the purpose of cost-saving but also add unnecessary processes. The construction progress, quality, cost control, and various financial indicators of the project will be analyzed, and a special team will conduct an assessment of the completion of each node leader's goals and compare them according to the scores. At the same time, this report will be submitted to the relevant departments and linked to the rewards and punishments for the year. Only by setting appropriate budgets and indicators, improving them gradually, and giving actual rewards to the employees who reach the targets or even exceed them, can we motivate every employee to actively control costs, so that the positive cycle of management mode can be opened and the purpose of long-term effective cost control can be achieved.

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Supporting Ability of Science and Technology Research on the Influence of Industrial Structure Optimization Effect

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Abstract Scientific and technological support capacity refers to the ability of knowledge, technology, talents, information and other elements to support the development of science and technology. Improving the support capacity of science and technology can effectively promote scientific and technological innovation and broaden the development mode of various industries, which is the main reason for promoting the optimization of industrial structure. One of the driving forces. Based on the panel data of 30 provinces (municipalities and autonomous regions) in China from 2009 to 2019, this paper will for the first time introduce the scientific and technological environment Support capacity is incorporated into the evaluation index system of scientific and technological support capacity, through improved knowledge production functions, selection of suitable panel modules, Empirically explores the impact of scientific and technological support capabilities on industrial structure optimization. The results show that: (1) China's provincial science and technology branches. The support capacity shows the characteristics of "polarization, strong in the east and weak in the west", which corresponds to the state of high east and low west at the current stage of the national economy. (2) The ability of scientific and technological support has obviously promoted the improvement of The optimization level of China's industrial structure, and has promoted the process of promoting the central and western regions. Degrees higher than in the eastern region. (3) Subdivide the scientific and technological support capacity into scientific research fund support capabilities, technical level support capabilities, and science and technology. After five dimensions of talent support ability, science and technology policy support ability and scientific and technological environment support ability, It is found that

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the support capacity of the scientific and technological environment has the greatest effect on the optimization level of the industrial structure, the support capacity of the technical level has the smallest effect on the optimization level of the industrial structure, and the support capacity of the scientific and technological policy has not effectively promoted the optimization level of the industrial structure.

Keywords Scientific and technological support capacity · Industrial structure optimization · Regional heterogeneity

1 Introduction

In the Fourth Plenary Session of the Nineteenth Central Committee of the Communist Party of China, it was clearly put forward that improving the "scientific and technological support" system plays an important supporting role in social development, improving the "scientific and technological support" system can directly and effectively promote scientific and technological innovation, and scientific and technological innovation, as the key driving force for industrial structure optimization, plays an important role in changing the industrial proportion, promoting the rational allocation of factors, broadening the industrial development model, improving industrial production efficiency, and upgrading the industrial demand structure. Referring to the relevant literature, the ability of science and technology support refers to the ability to support the development of science and technology by elements such as knowledge, technology, talents, and information [1–3]. In the case of China's demographic dividend gradually losing and economic growth slowing down, it is an urgent goal for China to directly promote scientific and technological innovation by improving the "scientific and technological support" system and creating an intensive and efficient industrial model to provide sustained impetus for economic development.

The research of domestic and foreign scholars in the support capacity of science and technology is mainly reflected in the construction of index systems and measurement methods. Based on the three dimensions of science and technology input, science and technology organization and science and technology products, the scientific and technological support capacity of various provinces in China was evaluated for the first time by using the entropy right law and divided into grade levels [4]. Through the hierarchical analysis method, a comprehensive evaluation system of scientific and technological support capabilities was constructed from four levels: the level of scientific and technological investment, the ability to transform scientific and technological achievements, the ability to promote scientific and technological promotion and service, and the ability of science and technology to promote industrial development, and the results showed that the scientific and technological support capacity failed to give full play to the role of promoting economic development [5]. On the basis of existing research, the index level is further expanded, and a more comprehensive regional scientific and technological support capacity index system is established through this analysis method and hierarchical analysis method, and the study shows that the imbalance in the development of scientific and technological support capacity in industrial development in various regions is caused by the difference in economic and social conditions and scientific research investment capacity between regions [6].

As the foundation of scientific and technological innovation capabilities, scholars at home and abroad have made rich research on the impact of scientific and technological innovation on industrial structure optimization. Some studies have empirically analyzed the positive promotion of industrial structure optimization at different scales, different spatial scientific and technological innovations and technological progress [7, 8]. Some scholars have also used the DEA method to find that the overall level of optimization of China's scientific and technological innovation−driven industrial structure is not high, and the development between regions is unbalanced. With the help of the two−stage system GMM model, the interactive development mechanism relationship between scientific and technological innovation and industrial structure optimization is explored [9]. Through the construction of LSTAR model, the relationship between scientific and technological innovation and industrial structure optimization is "inverted U−shaped" [10].

It can be seen that scholars' research on scientific and technological support capacity has achieved rich results, but there are still the following deficiencies: (1) The evaluation indicators of existing scientific and technological support capabilities are mainly based on hard support capabilities, such as technical level, R&D investment level, etc., and less take into account soft support capabilities, such as the economic and social basic conditions that support industrial development, as well as the environmental conditions for scientific and technological innovation and the construction of scientific and technological innovation culture. (2) The research on scientific and technological support capacity mainly focuses on the measurement and evaluation of the level of scientific and technological support capacity, and there is less literature focusing on the impact of scientific and technological support capacity on industrial structure optimization. In order to make up for the above deficiencies, this paper expands from the following aspects: (1) On the basis of the four dimensions of scientific research funds, scientific and technological talents, technical level, and scientific and technological policy, the introduction of scientific and technological environment dimensions to build an indicator system to measure the level of scientific and technological support capabilities, further improve the measurement system of scientific and technological support capabilities, and analyze the development status of China's scientific and technological support capabilities. (2) Construct a measurement model of the impact of scientific and technological support capacity on industrial structure optimization, and explore the impact effect of scientific and technological support capacity on industrial structure optimization. (3) From the three levels of national, regional and scientific and technological support capacity subdivision dimensions, the heterogeneity analysis of the impact effect of different characteristics of scientific and technological support capacity on industrial structure optimization is carried out, and targeted suggestions are provided for further promoting industrial structure optimization in order to achieve scientific and technological support capabilities.

2 Theoretical Basis

Scientific and technological support capacity is the basis of scientific and technological innovation ability, scientific and technological support capacity is mainly through directly affecting the ability of scientific and technological innovation and then promote the optimization of industrial structure, enhance the ability of scientific and technological innovation can improve the technical level of various industries, broaden the development mode of various industries, is one of the main driving forces to promote the optimization of industrial structure. This is consistent with the conclusion that scientific and technological innovation is a dynamic process from the generation of ideas to the adjustment of resource allocation, and then to the development, transformation and application of technology, which will eventually promote the improvement of the level of industrial structure optimization [11]. With reference to relevant research, this paper divides the scientific and technological support capacity into five aspects: the support capacity of scientific and technological talents, the support capacity of scientific and technological funds, the support capacity of technical level, the support capacity of scientific and technological policy and the support capacity of scientific and technological environment.

2.1 The Impact of the Support Capacity of Scientific and Technological Talents on the Optimization of Industrial Structure

Studies have shown that the dynamic process of redistribution of production factors such as human capital and material resources is the essence of industrial structure optimization and upgrading, and in this process, the stock and structure of human capital have an important role in promoting the optimization and upgrading of industrial structure [12]. In the process of continuous development and evolution of the industry, appropriately increase the number of R&D personnel in universities, scientific research institutions and enterprises, and then increase the proportion of R&D personnel and employed personnel, so as to achieve the effect of expanding the scope of technology application, increasing the frequency of use and promoting technological progress, thereby accelerating the speed of industrial development, promoting the process of industrial structure upgrading, and completing industrial structure optimization [13]. At the same time, the increase in R&D personnel will promote the improvement of human capital level, and human capital investment is the basis for rationalizing the industrial structure, so the increase in R&D personnel will also achieve industrial structure optimization by promoting the rationalization of industrial structure [14].

2.2 The Impact of Sientific and Technological Capital Support Capacity on Industrial Structure Optimization

Rationally strengthening R&D funding has played a significant role in promoting the upgrading of industrial structure and rationalizing industrial structure. The increase in R&D funding will accelerate the rate of technological progress, and technological progress will continue to update and improve the management mode, technology transformation and application process, rationally adjust the inherent technical relationship between industries, promote the rational allocation of production factors, and realize the rational development of the industry. According to Wang Xinhong's research, the technological progress brought about by R&D funding will also lead to the overall upgrading of high-tech industries and promote the development of the industry to a higher level [15]. Therefore, R&D funding is to indirectly promote the optimization of industrial structure by directly influencing technological progress [16].

2.3 The Impact of Technical Level Support Capacity on Industrial Structure Optimization

According to relevant research, technological progress mainly promotes the optimization of industrial structure through two ways. First, the industrial structure will be advanced through technological progress and innovation that will give birth to high−tech industries and increase the proportion of service industries [17]. Second, technological progress can improve the technical level of production equipment in various industries, thereby promoting the improvement of labor productivity, promoting the flow of production factors from low−productivity sectors to high−productivity sectors, achieving a more rational allocation of factors and increasing output, and gradually solving the uncoordinated and unbalanced phenomenon between supply and demand, so as to realize the rationalization of industrial structure.

2.4 The Impact of Science and Technology Policy Support Capacity on Industrial Structure Optimization

Science and technology policy is one of the important ways for the state to promote scientific and technological activities and stimulate scientific and technological innovation. Science and technology policies can determine the ability of high−tech industries to allocate scientific and technological resources by influencing their ability to allocate scientific and technological resources [18]. Improving the ability to allocate scientific and technological resources can promote a more rational allocation of production factors and realize the rationalization of industrial structure. Improving the ability of scientific and technological innovation can bring about technological progress, improve the technical level of the industry, increase the proportion of high−tech industries, and realize the heightening of the industrial structure.

2.5 The Impact of Scientific and Technological Environmental Support Capacity on Industrial Structure Optimization

The information and communication environment, the financial service environment, and the infrastructure environment will all indirectly have an impact on the ability of science and technology to support the optimization of industrial structure [19]. Through the Schumpeter endogenous growth model, numerical simulation is carried out to investigate: financial development is to reduce the financing cost of technological innovation, thereby improving the rate of technological progress and achieving industrial structure optimization and upgrading; The superior infrastructure environment and developed communication environment will achieve technological progress and improve departmental production efficiency by promoting technology diffusion, increasing net capital inflows, and promoting the flow of labor resources, and thus promoting the optimization of industrial structure.

3 Research Design

3.1 Sources of Data

This paper uses panel data from various provinces, municipalities and autonomous regions in China to empirically analyze the impact of scientific and technological support capabilities on the optimization level of industrial structure. Due to the difference in social system and statistical caliber, the research sample of this paper does not cover the Hong Kong Special Administrative Region, the Macao Special Administrative Region and the Taiwan Region, and in view of the incomplete statistical data of the Tibet Autonomous Region, the research sample is temporarily excluded, so the return sample of this paper includes panel data from 30 provinces, municipalities and autonomous regions Chinese mainland 2009−2019. The data studied in this paper are from: China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Financial Statistics Yearbook, China High−tech Industry Statistical Yearbook, Wonder Database, the website of the People's Government of the People's Republic of China and the website of the provincial people's government.

3.2 Research Methods and Variable Measurements

3.2.1 Improved Entropy Method

Entropy value method evaluation model is to introduce entropy value in the evaluation model to calculate the weight of the indicator, the entropy value and the amount of information are inversely proportional, and the uncertainty is proportional, the dispersion of an indicator is small, the degree of information difference is small, the amount of information contained is small, the uncertainty is large, and the entropy value obtained in the end is very large. A large entropy value indicates that the indicator has a large impact on decision−making, and the weight given is large. In this paper, the entropy value method will be used to calculate the weights of each dimension of the scientific and technological support capacity of Heilongjiang Province, and the evaluation results will be obtained through the final synthesis. The specific calculation formula of the entropy value method is as follows:

(1) Data standardization

Positive indicator:

$$y_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \tag{2.1}$$

Inverse indicator:

$$y_{ij} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})} \tag{2.2}$$

Here, the original value of the jth indicator in the i region in a given year is represented, representing the standardized data.

Since there is a 0 indicator in the data, the standardized data needs to be panned as follows:

$$z_{ij} = y_{ij} + 0.0001 \tag{2.3}$$

(2) Calculate the proportion of indicators

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \tag{2.4}$$

(3) Calculate information entropy

$$e_j = -\frac{1}{lnm}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}) \tag{2.5}$$

where m represents the number of regions.

(4) Determine the weights

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{n}\left(1 - e_j\right)} \tag{2.6}$$

(5) Calculate the score

$$F_i = \sum_{j=1}^{n}\left(w_j * z_{ij}\right) \tag{2.7}$$

3.2.2 Variable Definition and Measurement

(1) Explanatory variables: Industrial Structure Optimization Level (YH)

Industrial structure optimization refers to the process of coordinated development of various industries, continuous improvement of the overall level of industrial development and economic benefits, and continuously meet the rationalization and upgrading of social growth needs. Therefore, the industrial structure optimization level (YH) in this paper is measured by the industrial structure rationalization level (TL) and the industrial structure heightization level (TS) by the improved entropy method weighted comprehensive measure. The rationalization of industrial structure refers to the resource allocation efficiency of each industry and the quality of aggregation between industries, which is a reflection of the degree of effective utilization of resources and the degree of coordination between industries. The heightening of industrial structure refers to the transition and transformation of the focus of industrial development from low-level to high-level, and is the process of establishing and realizing a high-efficiency industrial structure. With reference to relevant studies, the rationalization level of industrial structure and the level of heightening of industrial structure are measured respectively [20, 21]. And the formulas are as follows:

$$TL = \sum_{i=1}^{n}\left(\frac{Yi}{Y}\right)\ln\left(\frac{Yi}{Li}\cdot\frac{Y}{L}\right) \tag{2.8}$$

$$TS = \sum_{i=1}^{n} y_i \cdot i \tag{2.9}$$

TL is the Thiel index, the reverse index, representing the rationalization of the industrial structure, TS is a positive indicator, representing the heightening of the industrial structure, Y represents the output value, L represents the number of employment, i represents the industry, n represents the number of industrial sectors, and yi represents the proportion of the output value of the primary industry in the total output value. The smaller the TL value, the more reasonable the industrial structure; The larger the TS value, the higher the industrial structure.

(2) Explanatory variables: scientific and technological support capacity (TECH)

Most of the existing research measures the level of scientific and technological support capacity in terms of hard support capabilities such as talent level, innovation level, and scientific and technological development level at the provincial level. This paper takes into account the hard support ability and soft support capacity of scientific and technological support capacity, and provides a strong scientific and technological support capacity for the healthy and scientific development of regional industries under the new normal. Therefore, this paper integrates the soft support capability of scientific and technological environment support capacity into the evaluation of scientific and technological support capability, and comprehensively measures the development level of scientific and technological support capacity from five levels: capital, talent, technology, policy and environment, and the evaluation system is shown in Table 1.

(3) Control variables

Based on the relevant research results of the existing literature, four major control variables affecting the industrial structure are selected [22, 23]. (1) Economic development level (Eco). Economic development is an important driving force for industrial structure optimization, and this paper uses regional GDP to measure, unit ten thousand yuan. (2) Foreign Investment (FDI). Foreign direct investment can bring new technology and management experience, which is conducive to improving the level of industrial development, but if foreign investors tend to invest in the secondary industry, it may aggravate the imbalance in the industrial structure. (3) Financial development level (Fdi): the stable and healthy development of finance can provide strong support for market players in financing and risk avoidance, and is an important supporting force to promote the optimization of industrial structure. (4) Labor level (Cz). Labor level is an important factor affecting the optimization of industrial structure, this paper is expressed in terms of the number of urban units at the end of the period, the unit is 10,000 people.

3.3 Model Settings

Based on the deformation of the knowledge production function, according to the influencing factors selected above [24], can be constructed as follows: (4.1) panel regression model:

$$YH_{it} = ktTECH_{it}{}^{\alpha 1} Eco_{it}{}^{\alpha 2} Fdi_{it}{}^{\alpha 32} Fin_{it}{}^{\alpha 4} Cz_{it}{}^{\alpha 5} \varepsilon_{it}{}^{\mu} \tag{2.10}$$

In the formula, YH and TECH represent the optimization level of industrial structure and the ability of scientific and technological support respectively, and the calculation formula is the same as above; Eco represents the level of economic development, measured by regional GDP; FDI stands for the level of openness to the outside

Table 1 Evaluation system of scientific and technological support capacity

Level 1 indicators	Level 2 indicators	Level 3 indicators
Scientific and technological support capabilities	Supporting capacity of scientific and technological talents	Enterprise R&D personnel are full-time equivalent
		Full-time equivalent of R&D staff at universities
		R&D personnel in scientific research institutions are full-time equivalent
		Ratio of R&D personnel to employed persons
	Scientific research funding support capacity	Corporate R&D expenditure
		Government R&D expenditures
		R&D funding expenditures for universities and research institutions
		Total R&D of the region as a share of the region's GDP
	Technical level support capabilities	The number of effective invention patents of the enterprise
		The number of invention patents effectively in universities
		The number of invention patents effectively used by scientific research institutions
		Number of high-tech enterprises
	Support capacity for science and technology policies	National science and technology related policies
		Provincial science and technology related policies
	Supporting capacity of the scientific and technological environment	The total value of the stock market
		Electricity consumption
		Road mileage
		Per capita postal and telecommunications business volume

world, measured by the amount of foreign direct investment; Fin represents the level of financial development and is measured by the loan balance of financial institutions at the end of the year; Cz stands for labor force level and is measured by the number of people at the end of the employment period in urban units. In order to minimize dimensional differences and heteroscedasticity between factors, all factors need to be logarithmic, and the positivistic model after processing is as shown in formula (4.2).

$$lnYH_{it} = \alpha_0 + \alpha_1 lnTECH_{it} + \alpha_2 lnEco_{it} + \alpha_3 lnFdi_{it} + \alpha_4 lnFin_{it} + \alpha_5 lnCz_{it} + \varepsilon_{it} \quad (2.11)$$

4 Empirical Analysis

4.1 Measurement of the Level of Scientific and Technological Support Capabilities

This paper uses the improved entropy value method to evaluate the support capacity of provincial science and technology, and the specific measurement results are shown in Table 2, due to limited space, only the measurement results of odd−numbered years are displayed. The entropy value method is also used to evaluate the support capacity of provincial scientific and technological talents, the support capacity of provincial scientific research funds, the support capacity of provincial technical level, the support capacity of provincial science and technology policies and the support capacity of provincial scientific and technological environment, and the specific measurement results and rankings are shown in Table 3.

Beijing's scientific and technological support capacity ranks first and is far ahead of the second, and its talent, capital, policy and scientific and technological environment support capacity scores are ranked first, indicating that Beijing's economic prosperity, the scale of scientific research institutions and universities, the development of educational environment, good policy system, high level of communication facilities, and the superior scientific and technological public services supported by the prosperous economy and political center provide superior conditions for the good operation of Beijing's science and technology support system (Xu Duoduo and Zhou Xiaoting, 2016). Excluding Beijing, a political center and an economic center, a municipality with very special conditions, the analysis of the measurement results of other provinces can be seen that the scientific and technological support capabilities of various provinces in China show the characteristics of "polarization, strong east and weak west", which corresponds to the state of "high in the east and low in the west" at the current stage of the country's economy: Most of the high−tech industries and leading enterprises are gathered in the eastern and coastal areas, because the geographical position is suitable for the rapid development of various industries, forming a strong aggregation effect and a large scale advantage, so its talent, capital, technology, policy and environmental development level is high, and most of the eastern and coastal areas have a higher level of scientific and technological support capacity development; The level of scientific and technological development in the central and western regions is not as good as that in the eastern region, mainly because

Table 2 Evaluation results of scientific and technological support capacity

Province	2009	2011	2013	2015	2017	2019	Mean	Ranking
Beijing	0.730	0.752	0.773	0.761	0.697	0.612	0.701	1
Guangdong	0.416	0.421	0.409	0.449	0.534	0.654	0.496	2
Jiangsu	0.376	0.400	0.386	0.405	0.477	0.427	0.445	3
Shanghai	0.288	0.342	0.460	0.489	0.410	0.341	0.364	4
ZheJiang	0.227	0.301	0.245	0.280	0.312	0.308	0.289	5
Shandong	0.214	0.234	0.225	0.240	0.270	0.217	0.246	6
Shaanxi	0.192	0.155	0.131	0.152	0.181	0.232	0.180	7
Sichuan	0.129	0.159	0.136	0.155	0.215	0.277	0.176	8
Hubei	0.156	0.177	0.128	0.137	0.173	0.243	0.172	9
Liaoning	0.155	0.170	0.132	0.131	0.145	0.189	0.163	10
Tianjin	0.131	0.160	0.126	0.144	0.138	0.108	0.159	11
Anhui	0.078	0.109	0.107	0.129	0.178	0.233	0.138	12
Hunan	0.129	0.103	0.112	0.117	0.131	0.211	0.131	13
Henan	0.116	0.134	0.105	0.120	0.127	0.128	0.126	14
Hebei	0.097	0.114	0.078	0.085	0.113	0.177	0.121	15
Fujian	0.083	0.118	0.110	0.113	0.131	0.126	0.121	16
Chongqing	0.055	0.061	0.059	0.069	0.093	0.108	0.084	17
Jilin	0.139	0.090	0.062	0.067	0.084	0.057	0.083	18
Heilongjiang	0.082	0.109	0.070	0.072	0.077	0.052	0.080	19
Inner Mongolia	0.045	0.071	0.048	0.047	0.053	0.054	0.077	20
Jiangxi	0.063	0.067	0.043	0.050	0.064	0.164	0.073	21
Shanxi	0.084	0.086	0.057	0.047	0.052	0.051	0.066	22
Yunnan	0.045	0.046	0.039	0.048	0.061	0.148	0.061	23
Xinjiang	0.050	0.041	0.043	0.045	0.043	0.122	0.056	24
Guangxi	0.037	0.048	0.060	0.061	0.048	0.047	0.053	25
Gansu	0.037	0.042	0.037	0.036	0.039	0.039	0.044	26
Guizhou	0.027	0.028	0.027	0.035	0.051	0.057	0.039	27
Ningxia	0.015	0.017	0.025	0.027	0.039	0.033	0.027	28
Qinghai	0.030	0.030	0.019	0.015	0.020	0.020	0.023	29
Hainan	0.010	0.014	0.013	0.015	0.018	0.015	0.016	30
Mean	0.141	0.153	0.142	0.151	0.166	0.182	0.160	–

it is difficult to meet the needs of the development of scientific and technological support capabilities, and most of the financial institutions, high—tech industries, and leading enterprises do not develop in the central and western regions. In addition, due to the "siphon effect" leading to a large number of scientific and technological resources in the central and western regions, such as scientific research and technical talents and research and development funds, scientific research personnel are

Table 3 Talent, capital, technology, policy, scientific and technological environment support ability score and ranking

Talent support		Financial support		Technical support		Policy support		Environmental support	
Beijing	0.736	Beijing	0.682	Guangdong	0.635	Beijing	0.850	Beijing	0.773
Jiangsu	0.541	Guangdong	0.624	Beijing	0.532	Shanghai	0.353	Guangdong	0.610
Guangdong	0.503	Jiangsu	0.621	Jiangsu	0.523	Shaanxi	0.207	Shanghai	0.408
Shanghai	0.399	Shandong	0.485	ZheJiang	0.290	Jiangsu	0.199	ZheJiang	0.404
ZheJiang	0.377	Shanghai	0.421	Shanghai	0.277	Liaoning	0.168	Jiangsu	0.372
Shandong	0.302	ZheJiang	0.358	Shandong	0.211	Guangdong	0.167	Shandong	0.287
Tianjin	0.244	Tianjin	0.239	Hubei	0.147	Hubei	0.166	Sichuan	0.211
Sichuan	0.214	Sichuan	0.232	Liaoning	0.144	Anhui	0.159	Fujian	0.211
Shaanxi	0.207	Shaanxi	0.229	Sichuan	0.142	Tianjin	0.146	Henan	0.194
Hubei	0.198	Hubei	0.221	Shaanxi	0.133	Hebei	0.146	Hebei	0.181
Liaoning	0.183	Liaoning	0.204	Anhui	0.113	Sichuan	0.134	Inner Mongolia	0.178
Henan	0.160	Anhui	0.177	Hunan	0.109	Hunan	0.113	Hubei	0.170
Fujian	0.155	Henan	0.164	Tianjin	0.097	Xinjiang	0.103	Liaoning	0.154
Anhui	0.153	Hunan	0.163	Henan	0.095	Inner Mongolia	0.103	Xinjiang	0.152
Hunan	0.151	Fujian	0.156	Fujian	0.083	Jiangxi	0.093	Yunnan	0.151
Heilongjiang	0.125	Hebei	0.135	Heilongjiang	0.069	ZheJiang	0.089	Hunan	0.147
Hebei	0.124	Chongqing	0.108	Jilin	0.069	Jilin	0.081	Shaanxi	0.146
Jilin	0.122	Heilongjiang	0.093	Chongqing	0.062	Henan	0.066	Anhui	0.137
Chongqing	0.108	Jiangxi	0.080	Hebei	0.059	Chongqing	0.065	Shanxi	0.133
Shanxi	0.085	Jilin	0.075	Jiangxi	0.049	Yunnan	0.058	Guizhou	0.128
Jiangxi	0.072	Shanxi	0.070	Shanxi	0.037	Fujian	0.055	Chongqing	0.112

(continued)

Table 3 (continued)

Talent support		Financial support		Technical support		Policy support		Environmental support	
Beijing	0.736	Beijing	0.682	Guangdong	0.635	Beijing	0.850	Beijing	0.773
Guangxi	0.069	Inner Mongolia	0.051	Guangxi	0.035	Guangxi	0.048	Tianjin	0.111
Yunnan	0.056	Gansu	0.050	Yunnan	0.033	Heilongjiang	0.044	Heilongjiang	0.097
Inner Mongolia	0.055	Guangxi	0.047	Gansu	0.026	Gansu	0.039	Jiangxi	0.093
Gansu	0.048	Yunnan	0.041	Guizhou	0.020	Shanxi	0.037	Gansu	0.088
Guizhou	0.033	Guizhou	0.026	Xinjiang	0.011	Ningxia	0.029	Guangxi	0.085
Xinjiang	0.030	Ningxia	0.023	Inner Mongolia	0.011	Shandong	0.029	Qinghai	0.084
Ningxia	0.027	Xinjiang	0.016	Hainan	0.006	Qinghai	0.027	Jilin	0.082
Qinghai	0.010	Qinghai	0.010	Qinghai	0.003	Guizhou	0.020	Ningxia	0.079
Hainan	0.009	Hainan	0.002	Ningxia	0.001	Hainan	0.006	Hainan	0.068

Table 4 Descriptive statistics of the main variables

Variable	Obs	Mean	Std.Dev	Min	Max
YH	330	0.321	0.210	0.053	1.000
TECH	330	0.160	0.161	0.010	0.773
Eco	330	2.184e + 04	1.874e + 04	939	1.080e + 05
Fdi	330	1.557e + 07	2.579e + 07	2.349e + 05	1.953e + 08
Fin	330	6.881e + 04	6.310e + 04	3.199e + 03	3.853e + 05
Cz	330	543	377	51	2065

the core of scientific and technological innovation activities, and the indirect loss of technology caused by the direct loss of talents and funds makes it difficult for the central and western regions to meet the needs of favorable scientific and technological development for a long time, so the external environment for the construction of scientific and technological support capacity development in the central and western regions is too different from that in the eastern region.

4.2 Descriptive Statistics

Descriptive statistics are given on the main variables in this article (see Table 4). The results show that the minimum value of scientific and technological support capacity is 0.010, the maximum value is 0.773, the mean value is 0.160, and the standard deviation is 0.161, indicating that the development level of Scientific and Technological Support Capacity in China shows the characteristics of polarization, and the degree of development of scientific and technological support capacity in various regions shows great differences; in the statistics of the optimal development level of industrial structure, the average value is 0.321, the maximum value reaches 1, and the minimum value is 0.053, and the large numerical gap shows that the level of optimization and development of China's interregional industrial structure is unbalanced. From the perspective of control variables, there are also certain gaps between different regions in terms of economic development level, foreign direct investment, financial services development level and labor level.

4.3 The impact of Scientific and Technological Support Capacity on Industrial Structure Optimization

According to the above model, this paper uses stata software to ensure the rigor of the model by adding control variables and whether the time effect is fixed, and Table 5 reports the linear estimation results of the influence of scientific and technological support capacity on industrial structure optimization. Among them, model (1) is the regression result without adding control variables, model (2) is the reference regression estimation result of controlling time effects and regional effects, model (3) is the fixed effect estimation result of controlling time effects and regional effects, and model (4) is the estimation result of regional effects of uncontrolled time effects.

It can be seen from Table 5 that regardless of whether the control variable is added or not, the scientific and technological support capacity has a significant role in promoting the optimization of the industrial structure. In the benchmark regression, the coefficient of influence of scientific and technological support capacity on industrial structure optimization was 0.283, and it was significantly below the 1% level, that is, the level of scientific and technological support capacity increased by 1%, and the degree of industrial structure optimization increased by 0.283, indicating that the development level of scientific and technological support capacity and the optimization and upgrading of industrial structure were positively correlated. From the regression results of the control variables: the level of economic development is increased by one unit, and the level of industrial structure optimization is reduced by 0.991 units, indicating that the industrial structure has not achieved structural optimization with the improvement of the regional economic development level, and the possible explanation is that technological progress and the improvement of human capital level are the main factors for the optimization of the industrial structure, and economic growth is not directly related to it; The level of FDI is raised by one unit, The improvement of the level of industrial structure optimization by 0.331 units shows that the improvement of the level of foreign direct investment is conducive

Table 5 The effect of scientific and technological support capacity on industrial structure optimization

Varible	lnYh			
	(1)	(2)	(3)	(4)
lnTech	0.221[c] (4.40)	0.283[c] (5.69)	0.138[b] (2.24)	0.143[b] (2.2337)
lnEco		−0.991[c] (−8.54)	−0.774[c] (−3.04)	−0.458[a] (−1.9110)
lnFdi		0.331[c] (8.95)	−0.207[c] (−3.12)	−0.022 (−0.3104)
lnFin		0.402[c] (4.14)	−0.221 (−1.10)	0.471[c] (2.6159)
lnCz		0.236[b] (2.31)	0.231 (1.26)	−0.467[c] (−2.7137)
Constant term		−2.074[c] (−3.41)	10.068[c] (4.39)	1.503[a] (1.7889)
Time effect	Yes	Yes	Yes	No
R^2	0.607	0.607	0.178	0.068

Note T statistical values in parentheses [a, b, c] indicate that they are significant at the 10%, 5% and 1% levels, respectively to the optimization of the industrial structure, so it can further absorb the leading practical experience of foreign countries and give play to the advantages of being a latecomer to promote the technological progress of the industry, so as to provide good conditions for the realization of industrial structure optimization; the level of financial service environment is increased by one unit, and the level of industrial structure optimization is increased by 0.402 units, indicating that a good financial service environment is beneficial to many aspects of industrial structure optimization; the labor level is increased by one unit, and the level of industrial structure optimization is increased by 0.236 units The possible explanation is that the improvement of the labor force level promotes the improvement of the technical level, which in turn promotes the optimization of the industrial structure.

4.4 The Impact of the Subdivision Dimension of Scientific and Technological Support Capacity on the Optimization of Industrial Structure

The scientific and technological support capacity is divided into five dimensions: talent, capital, technology, policy and environment for regression analysis, and the specific results are shown in Table 6.

The four dimensions of scientific and technological talent support ability, scientific research fund support ability, technical level support ability and scientific and technological environment support ability have passed the significance level test of 1% on the optimization of industrial structure, and the direction of action is positive. However, Table 6 shows that there are significant differences in the effects of each dimension. The impact of scientific and technological environmental support capacity on industrial structure optimization is the greatest, which may be the result of the country's vigorous advocacy and support for the development of the basic environment in recent years; The second is the ability of scientific and technological talents to support and scientific research funds, the technical level support capacity has a relatively small impact on the optimization of industrial structure, may be due to the lack of scientific and technological innovation, low efficiency of technological transformation and other reasons, the coefficients are 0.3112, 0.2184, 0.1899, 0.1179; the ability to support science and technology policies has no significant impact on the optimization of industrial structure, the reason for this phenomenon may be that the policy formulation is biased, the pertinence is not strong, and the effect period is long. It shows that the promotion effect of scientific and technological support capacity on industrial structure optimization is achieved through the support capacity of scientific and technological environment, the support ability of scientific and technological talents, the support capacity of scientific research funds and the support capacity of technical level, and the support capacity of science and technology policies has not effectively promoted the optimization of industrial structure.

Table 6 The impact of the subdivision dimension of scientific and technological support capacity on the optimization of industrial structure

Metric logarithm	lnYh				
lnrc	0.2184[c] (5.1879)				
lnzj		0.1899[c] (6.0848)			
lnjs			0.1179[c] (2.7441)		
lnzc				−0.0019 (−0.2622)	
lnhj					0.3112[c] (4.7715)
lneco	−0.9709[c] (−8.1255)	−1.0288[c] (−9.0939)	−1.0288[c] (−7.9268)	−1.1975[c] (−10.3344)	−1.0330[c] (−8.8234)
lnfdi	0.3408[c] (9.2003)	0.3581[c] (10.0376)	0.3399[c] (8.2587)	0.3905[c] (10.4870)	0.3744[c] (10.3556)
lnfin	0.4579[c] (4.7912)	0.4585[c] (4.9091)	0.5376[c] (5.5642)	0.5899[c] (6.0722)	0.3546[c] (3.3837)
Lncz	0.1552 (1.3801)	0.1875[a] (1.8022)	0.2046 (1.4793)	0.4758[c] (4.8656)	0.3671[c] (3.7758)
Constant term	−2.6970[c] (−4.9002)	−2.6573[c] (−5.3465)	−3.4295[c] (−5.0337)	−5.1371[c] (−15.1209)	−2.7014[c] (−4.6186)
R^2	0.6016	0.6127	0.5783	0.5686	0.597

Note T statistical values in parentheses [a, b, c] indicate that they are significant at the 10%, 5% and 1% levels, respectively.

Regarding the control variables, according to the results of Table 6, in the regression analysis of the optimization of the industrial structure by subdividing the scientific and technological support capacity into five dimensions, the regression coefficient of the economic development level is significantly below the 1% level, indicating that the industrial structure has not been optimized with the improvement of the regional economic development level, and the possible explanation is that the society attaches insufficient importance to the high−quality economic development. In addition, the regression coefficient of the development level of FDI and financial services is significant below the 1% level, reflecting that promoting FDI and improving the development level of financial services can significantly promote the optimization of industrial structure, while showing that there is still room for development to bring benefits brought by improving the level of foreign trade, and it should further expand trade in the international community, promote the division of labor and investment between countries, introduce high−quality factor resources and learn from development experience, and continue to promote industrial structure optimization [24].

4.5 Regional Heterogeneity Tests

Due to the certain differences in the level of scientific and technological development, economic development, geographical environment and political factors in various regions of China, and the organizational forms and business models of the main industries in different regions, the samples selected in this paper are classified according to the eastern region, the central region and the western region, and the heterogeneity of the region is further analyzed, and the analysis results are shown in Table 7. The results show that whether it is the eastern, central or western regions, the scientific and technological support capacity has a significant role in promoting the optimization of industrial structure. The largest promotion effect is in the western region, followed by the central region, and the smallest is in the eastern region.

For the effect of scientific and technological support capacity in the eastern region on the optimization of the industrial structure is less than that in the central and western regions, the possible reasons analyzed in this paper are: First, the eastern region is the most economically developed region in China, compared with the central and western regions, the eastern region has a modern industrial operation mechanism with higher maturity and faster response, the aggregation effect and scale advantage are obvious, and the scientific and technological support capacity has reached a certain level. Therefore, the spillover dividend of scientific and technological support capacity for the optimization of industrial structure in the eastern region may have been released long ago, and the marginal contribution may be weakened. In contrast, the power of scientific and technological support capacity to optimize the industrial structure in the central and western regions is relatively strong. Second, in the new round of the strategy for the large−scale development of the western region, the Chinese government has provided a large amount of policy and financial support to

Table 7 Heterogeneity test results

lnYh			
Metric logarithm	Eastern	Central	Westward
lntech	0.1792[b] (2.4988)	0.1890[a] (1.8444)	0.2161[b] (2.2388)
lneco	−0.9249[c] (−3.5507)	−2.5050[c] (−5.0896)	−2.1450[c] (−4.9966)
lnfdi	−0.0228 (−0.3817)	0.2099 (1.5170)	0.0331 (0.3636)
lnfin	0.8794[c] (4.1192)	1.8143[c] (5.3561)	1.8133[c] (5.9160)
lncz	−0.1761 (−1.4925)	−0.1352 (−0.4399)	−0.3216 (−1.1034)
_cons	0.3621 (0.5207)	1.6423 (0.9271)	1.9302 (1.2494)
R^2	0.2378	0.4600	0.4446

Note: T statistical values in parentheses [a, b, c] indicate that they are significant at the 10%, 5% and 1% levels, respectively

the western region, and has made a clear layout and promoted the construction from the aspects of enhancing the ability of innovative development, forming a modern industrial system, optimizing the structure of energy supply and demand, promoting the integration of urban and rural development, and strengthening infrastructure planning and construction, so that the level of scientific and technological support capacity has been continuously improved, the optimal allocation efficiency of resources is relatively high, and the promotion effect of industrial structure optimization is closer to the pareto optimal state. Third, in the process of innovation cooperation, knowledge sharing and information exchange in the three major regions, the central and western regions can learn from the advanced R&D and management experience of the eastern region, and can also introduce high—level knowledge and high technology and excellent human resources from the eastern region. The factor dividends that the eastern region can obtain from the central and western regions are relatively small, resulting in the more significant effect of scientific and technological support capacity on the optimization of the industrial structure in the central and western regions (Li Haichao and Xiao Yao, 2021). Fourth, the central region is manifested as lagging behind the eastern and western regions in terms of talent, capital, technology, policies and the environment, mainly because the resource aggregation and liquidity in the central region are not as good as in the eastern region, and the government policy support is not as strong as that in the western region, and because of the geographical proximity to the eastern coastal area, some funds and talents flow to the coastal areas, so the effect of scientific and technological support capacity on the optimization of the industrial structure in the central region is between the eastern and western regions.

4.6 Robustness Test

The methods of robustness testing mainly include: changing the measurement method of explanatory variables and explanatory variables, changing the model, changing the sample size, and reducing the selection error of the sample. In this paper, the robustness test of the model is performed by changing the measurement of the core explanatory variables, changing the sample size, and changing the model structure, and the specific test results are shown in Table 8.

The second column is to change the measurement of the core explanatory variables: linear weighting method to re−measure the technical support capability and substitute it into a fixed−effects model for regression. The fourth column is to change the measurement method of sample size: due to the special national conditions of Our country, the municipality has incomparable policy advantages of other cities, so the existence of the municipality is equivalent to the existence of extreme values, and the regression after excluding the extreme values of the municipalities is helpful to verify the robustness of the regression. In the regression results of changing the measurement of core explanatory variables and changing the sample size, the effect of scientific and technological support capacity on industrial structure optimization is positive, that is, the direction of the estimation coefficient of the core explanatory variable is consistent with the basic regression. The measurement method of changing the model: the ability of scientific and technological support will promote the optimization of industrial structure, and the optimization of industrial structure will also enhance the ability of scientific and technological support, that is, there are endogenous problems caused by independent variables and dependent variables being causal and causal. Therefore, drawing on the practice of some scholars, the

Table 8 Robustness test results

Metric logarithm	Substitution variable regression	Teo SLS	Small sample size
lnTech	0.376^{b} (2.40)	0.241^{c} (3.620)	0.115^{a} (1.876)
lnEco	-8.08×10^{-7} (−0.51)	-1.021^{c} (−9.710)	−0.0796 (−0.267)
lnFdi	$-7.70\times10^{-10\ a}$ (−1.70)	0.358^{c} (9.330)	−0.083 (−0.839)
lnFin	$9.50\times10^{-7\ b}$ (2.12)	0.421^{c} (3.930)	0.363 (1.250)
lnCz	$1.10\times10^{-4\ c}$ (2.62)	0.262^{b} (2.300)	−0.177 (−1.131)
Constant term	$0.269^{\ c}$ (8.22)	-2.671^{c} (−3.280)	-1.137^{a} (−1.720)
R^2	0.689	0.610	0.396

Note T statistical values in parentheses $^{a,\ b,\ c}$ indicate that they are significant at the 10%, 5% and 1% levels, respectively first−order lag value of the core explanatory variable is used as a tool variable for 2SLS estimation [25]. The results of 2SLS regression are basically consistent with those of OLS model and fixed effect model, and the estimated coefficients of the technical support capacity of core explanatory variables are significantly positive. At the same time, it is found that the estimation coefficient after considering the endogenous problem is greater than the estimated coefficient of the basic regression, indicating that the role of scientific and technological support capacity in promoting industrial structure optimization will be underestimated without considering endogenousness. The direction of the estimated coefficients of the core explanatory variables of the robustness test is consistent with the fundamental regression, indicating that the empirical results are more reliable.

5 Research Conclusions and Policy Recommendations

5.1 Conclusions of the Study

This paper selects the panel data of 30 provinces, municipalities directly under the Central Government and autonomous regions (except Tibet) from 2009 to 2019, comprehensively measures the level of industrial structure optimization based on the five dimensions of talent, capital, technology, policy and environment, constructs the level of industrial structure optimization from the two dimensions of industrial structure heightization and industrial structure rationalization, and empirically studies the impact of scientific and technological support capabilities on industrial structure optimization in sub−regions and sub−dimensions. The main conclusions are as follows:(1) The scientific and technological support capacity of various provinces in China shows the characteristics of "polarization, strong in the east and weak in the west", and the level of scientific and technological support capacity in Beijing and most of the developed areas in the east is higher than that in the central and western regions. (2) From a national perspective, the ability of scientific and technological support has a significant positive impact on the optimization level of industrial structure. (3) From a regional point of view, the impact of scientific and technological support capacity on the optimization level of industrial structure is significantly positive in the eastern, central and western regions. The ability to support science and technology has the greatest effect on the optimization of the industrial structure in the western region, followed by the central region, and the ability to support science and technology has the smallest effect on the optimization of the industrial structure in the eastern region. (4) From the perspective of the subdivision of scientific and technological support capacity, there are heterogeneity characteristics that the scientific and technological environment support capacity has the greatest positive promotion effect on the optimization level of industrial structure, the technical level support capacity has the smallest positive promotion effect on the optimization level of industrial structure optimization, and the scientific and technological environment support capacity has not effectively promoted the optimization level of industrial structure.

5.2 Policy Recommendations

Based on the findings of the study, the following policy recommendations were drawn:

First, give full play to the leading role of technological progress in optimizing the industrial structure. Aiming at the problem that the technical level support ability has little effect on promoting the optimization of industrial structure. Independent innovation should be strengthened to improve the efficiency of technology transformation and utilization, for example, increase the intensity of examination and approval of technology patents, eliminate the occurrence of "false" patents, and appropriately reduce the passing time of technology patent examinations; Incentives such as additional invention awards and honorary titles for technology patents that have a greater substantial impact on social progress; Implement active policies, actively develop foreign trade, introduce, imitate and learn advanced technologies, give full play to the technological diffusion effect of leading industries, introduce technologies through foreign trade, and give play to the dual role of foreign trade and technological progress in optimizing the industrial structure.

Second, strengthen regional exchanges, cooperation and innovation. When formulating policies, local governments should not consider the economic development of their regions in isolation, but also need to pay attention to the development policies of the surrounding areas, break down market barriers for local protection, and eliminate institutional and institutional obstacles to the flow of factors and knowledge spillover between regions. For example, appropriate evacuation of some of the mature high–tech industries in the east to neighboring areas; The central and western regions take the initiative to build a learning and exchange platform to promote data and information sharing and professional exchanges between regions; The central and western provinces regularly send study groups to the developed provinces in the east to learn development experience, technical products and service knowledge, while the eastern developed provinces also regularly send teams to the central and western regions to guide and supervise the development of the industry. In short, integrate regional resource advantages, strengthen exchanges and cooperation between various regions, spread and transfer some industrial resources of scientific and technological achievements from developed areas to backward areas, narrow the gap between the eastern, central and western regions, and promote the optimization of the overall industrial structure.

Third, give full play to the leading role of the government and ensure the effective implementation of policies. The government should understand the actual situation of each industry through field research, and make reasonable planning and guidance for the development of science and technology with the help of various tools and means such as administration, law, and economy; Policy support to enhance the targeted purpose, specific instructions are clear and clear, the implementation of innovative funding targets in place, the establishment of policy supervision groups to inspect the implementation effects of local policies from time to time, and find problems to be "fast and accurate" to deal with. The government should further increase support for scientific and technological innovation, strengthen the supervision and support of newly entered science and technology enterprises, and effectively promote the implementation of innovation−driven development strategies, but also avoid the "short−sightedness" of scientific and technological innovation support, especially the need to maintain sufficient "patience", prevent risks such as violations, and give continuous policy and financial support to scientific research and some long−term and high−risk technology development activities, effectively improve regional scientific and technological support capabilities, promote the development of scientific and technological industries, and optimize the industrial structure.

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Is Technology−Linked Return an Effective Factor for A−Share Stock Selection?

Niu Dayong and Liu Pan

Abstract Research objectives: the impact of technology-linked return on stock returns in China's A-share market and heterogeneity analysis. Methods: This paper selects Shanghai and Shenzhen A-share listed companies from 2010 to 2021 as samples, and uses Fama-Macbeth two-step model and GMM model for empirical analysis. The results show that: in monthly data, when there is a high technology-linked return between enterprises, the rate of return of focus companies will be affected by its high technology-linked return; further research finds that when the technology links is studied through industry division, it is found that the technology links between enterprises in industries such as medicine and manufacturing is more obvious. When the regional indicators are added, it is found that the technology-linked return in the central region is more obvious. Next, in order to better verify the effectiveness of the stock selection strategy based on this factor, this paper constructs an investment portfolio for data retest, and draws the conclusion that after adding this factor, excess returns can be obtained. After adding industry and regional factors, the returns of stocks are further improved. Innovation: Heterogeneity analysis of technology-linked return confirms that industry and regional factors can improve the effectiveness of technology-linked return in China's stock market. Research value: It enriches and expands the related research results and related applications of technology-linked return in China.

Keywords Technology−linked return · Industry factors · Regional factors

1 Introduction

Affected by the new coronal epidemic and the intensified competition among countries, technological innovation has increasingly become a key factor for enterprises to cultivate core competitiveness. In recent years, China's support for enterprise science and technology innovation continues to increase, especially the establishment of

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science and technology innovation board, represents the country's high support for science and technology innovation at the strategic level. Enterprises are the vanguard of technological innovation, and technological innovation is the source of competitiveness of enterprises. Although technological innovation is essential for enterprises, isolated technological innovation will have certain risks, and there is often a certain degree of cooperation and spillover between enterprises, which makes similar patent layout between enterprises, resulting in technological connections.

In today's society, the relationship and cooperation between enterprises has not only stayed in the same industry and upstream and downstream, cross-industry cooperation exists widely. For example, Internet companies provide cloud computing services for home appliance manufacturing enterprises. Although these enterprises do not seem relevant, they are concerned about the same technical field. Under the influence of R & D or knowledge spillover, they have technology links with each other, which makes them also have certain connections in the stock market returns. Although this kind of connection is not very obvious, and they are not shown in the public disclosure of information, but in the industry and product level seemingly unrelated enterprises will have a high degree of connection in the patent, and ultimately will be reflected in the stock price changes, resulting in 'technology momentum', affecting the stock price changes of high−tech related enterprises. This kind of stock price fluctuation caused by technology association is called technology−linked return. As a new perspective to study the stock price changes between enterprises, technology−linked return is of great research value.

In fact, technology-linked return have been verified in foreign stock markets, but there are few studies on China's stock market, and there is still a lack of research on how to use this indicator to further improve portfolio returns. With China's increasing emphasis on technological innovation and intellectual property protection, it is necessary to conduct in-depth research on technology correlation, a new perspective to examine the relationship between technological innovation and enterprises, combined with China's market reality.

Based on previous studies, this paper uses the sample data of A-share listed companies in China from 2010 to 2021 to study the impact of technology-linked return factor on monthly stock returns, and further studies the heterogeneity of technology-linked return factor through industry and region, which provides new ideas for relevant quantitative financial research.

2 Literature Review and Theoretical Analysis

There are many academic studies on the concept of technological association, and China's relevant studies have confirmed the effectiveness of technological association. At the same time, it is believed that the focus company will have a certain relationship with other enterprises with technological association in R & D. As a composite indicator of technology-linked return, although foreign scholars have verified that focus companies will be affected by other companies with technology linkages in stock prices, there is little research in China. The technology−linked return aims to interpret the volatility of the company's stock price through the new perspective of patent layout between enterprises. The proposed index expands the number of quantitative factors, and its unique perspective fits the background of China's key development of science and technology leading enterprises, so the effectiveness of the factor in the Chinese market is worth verifying.

The construction of technology-linked return was first proposed by Jaffe (1986). Jaffe believes that an enterprise will not conduct technology research in isolation. Due to the reasons of risk and technology bottleneck, enterprises will have links in the related fields of technology overlap, and produce technology spillover through cooperation, investment and trading (Lee, 2019). Technology spillover is an important manifestation of technology links. The successful construction of technology-linked return has attracted more foreign scholars to conduct in-depth research. With the deepening of research, foreign scholars have found that companies with technology linkages may not be in an industry or need not provide similar products (Bloom, 2013). Furthermore, we construct the technology-linked return factor Charles (2019) by combining the technical correlation and stock returns, and find that the factor will bring excess returns in stock selection, which is called 'technical momentum'. The technology−linked return factor is the core of this study. Duan Binglei (2022) through the study of China's stock market technology links factor, the factor can predict the target company in the next 1−3 weeks of stock returns and future fundamentals changes, and the momentum of technology links in state-owned enterprises and innovation policy after the promulgation of more prominent.

In the stock market, the response of the company's stock price to information is not necessarily timely. Leading and lagging are widespread, which makes it feasible for us to predict the stock price through various factors. From the perspective of investors' limited attention, investors are unable to obtain full information in time and make effective identification of it (Peng and Xiong, 2006), resulting in a certain predictability of future stock prices (Hou, 2007), hong et al., 2007; Menzly and Ozbas, 2010). Different from investors' attention, there are related studies that the leading and lagging relationship of stock price is related to the transmission of market information. For example, there are more and more relevant research reports in the capital market, but the tracking targets of analysts are often limited (Hirshleifer and Teoh, 2003). Tracking hot events and hot enterprises leads to differences in the density of research reports. The more the number of research, the more fully the enterprise's information will be reflected, and the greater the impact on the stock price (Chan and Hameed, 2006). The difference in the number of research will make the information transmitted from high research enterprises to low research enterprises, resulting in a leading and lagging relationship (Feng Xunan and Xu Zongyu 2014). In addition, some scholars believe that the proportion of fund holdings (Pan Ningning, Zhu Hongquan, 2015) and shareholder ties (Dong Dayong, 2013) will also affect the leading lag relationship. From the perspective of capital markets, studies have focused on the impact of firm size, suggesting that the stock price of large firms is faster for smaller firms (Kanas, 2004); in terms of trading volume, studies have found that high-volume stocks usually react faster to market information than low-volume stocks (Ma Chaoqun and Zhang Hao, 2005). It should be pointed out that the technology-linked return factor studies the past earnings of technical peers to predict the future earnings of focus companies. Therefore, this paper selects the technology-linked return factor of the previous month to predict the current rate of return to illustrate the effectiveness of this factor.

When the factor of return on technology linkage was proposed, Charles et al. (2019) believed that it crossed the limitation of the industry. Even if enterprises in different industries produce different products, their stock prices will be affected by "technology momentum" as long as they have technology linkage. Although technology-linked return exclude the impact of the industry, it is undeniable that the industry is an important factor affecting stock prices. Existing studies have analyzed and studied the technological innovation and diffusion of pharmaceutical (Wang Shasha, 2021), high-end equipment manufacturing (Chen Yue, 2017) and electronic information industry (Su Xiaohua, 2015) from the perspective of technology association, and concluded that technology association plays an important role in these industries. Therefore, in many industries in the capital market, it is of great significance to study whether there are industries with high visibility in the return on technology linkages and whether enterprises in these industries can bring higher excess returns.

From a regional perspective, regional factors have different impacts on enterprise innovation. Specifically, because of the direct driving effect of technological innovation, innovation will show the strongest in the east, followed by the middle and the weakest in the west (Wenli, 2022). Combined with the eight comprehensive economic zones in China, the innovation ability and growth rate of the eastern region are the highest (Minghai et al., 2018). The influencing factors are also diverse, such as areas with more foreign investment will have strong innovation ability (Guifang and Sichen, 2021), and areas with better intellectual property protection will have a positive impact on enterprise innovation. Although there are few studies on the regional differences of technology−linked return, from the existing research results of technology-related and technological innovation, regional factors have an impact that cannot be ignored. More innovative enterprises are often more likely to produce technology spillover, and then produce momentum effect on stock prices. Therefore, this paper will also consider the impact of different regions on corporate technology−linked return.

To sum up, compared with foreign research results, there are few targeted studies on technology−linked return in China, and most of the existing studies focus on the validity of the factor, and there are few studies on heterogeneity. This paper will further enrich the relevant achievements in this field and expand the application space of technology−linked return by analyzing the heterogeneity of technology−linked return.

3 Research Design

This paper selects all A−share listed companies from 2010−2021 as the analysis samples, and selects the following samples according to needs: (1) excluding listed companies in the financial industry; (2) Excluding ST and * ST listed companies; (3) Excluding missing financial data samples. The patent data and financial data of this paper are derived from CNRDS and Wande database.

Based on the research results of Charles (2019), this paper uses monthly technology−linked return data as the research cycle. The aggregate data on end−of−year patents are often used in building technology linkages and technology−linked return (Khimich and Bekkerman, 2017), Charles et al., 2019), but the early patent information in China is imperfect. If the full patent data are used, it will inevitably affect the results. In addition, considering the existence of China's enterprises to adjust business scope, static patent data is difficult to reflect the future direction of enterprise development. And the stock market price often can more fully reflect the past information, the past patent information is difficult to explain the future stock returns. Finally, considering the data acquisition factors, it is difficult to define when the stock patent expires. In summary, this paper takes the incremental patent data newly acquired each year as the construction basis of key variables.

In terms of the classification of industries, this paper adopts the Shenwan industry classification. Considering the small number of enterprises in some industries and the correlation between industries, this paper carries out an appropriate amount of consolidation, such as the consolidation of agriculture, fishery, animal husbandry and forestry into an agriculture, forestry, animal husbandry and fishery, and the consolidation of real estate development and real estate operation into real estate industry. In terms of geographical classification, for the north−south classification, referring to Xu (2020), the Qinling−Huaihe River in geography is used as the classification below, while for the east−west classification, the relevant government reports are used for classification.

3.1 Research Model Setting

In this paper, Fama−Macbeth cross−sectional regression method is used to study the explanatory power of technology−linked return on future stock returns. Its biggest advantage is to exclude the influence of residual correlation on standard error. The residual rate of return of stock has a high correlation on cross−section. Therefore, this correction is essential for accurate calculation of standard error, so it is widely used in the risk factor test of various asset pricing models.

In order to test the explanatory power of technology related income to future stock returns, this paper establishes the following basic Fama−Macbeth regression model:

$$RET_{i,t+1} = \alpha_0 + \alpha_1 TECHRET_{i,t} + \alpha_2 Controls$$

$$+\sum Company+\sum Month+\varepsilon_{i,t} \quad (1)$$

In the formula, $RET_{i,t+1}$ is the t + 1 monthly yield of company i, $TECHRET_{i,t}$ is the t monthly technology−linked return of company i, Controls is the control variable, Company and Year are the company and monthly virtual variables respectively.

Next, the following Fama−Macbeth regression model is constructed by adding the interaction term MOD according to the needs of regional research:

$$RET_{i,t+1}=\beta_0+\beta_1 TECHRET_{i,t}+\delta_1 MOD*TECHRET_{i,t}+\delta_2 MOD$$
$$+\beta_2 Controls+\sum Company+\sum Month+\varepsilon_{i,t} \quad (2)$$

3.2 Data Sources

Because patent data is needed to measure technology relevance in this paper, the coverage of sample size and the integrity of patent data should be taken into account in the process of sample selection. Taken together, this paper selects all A−share listed companies from 2010−2021 as the research object. The data in this article is sourced from the Chinese Research Data Services Platform. Among them, the financial indicators come from the annual report data from 2010 to 2021, and the stock return data is selected from January 2011 to October 2021. The stocks of financial stocks and ST stocks are deleted, and other financial indicators are required to be non−empty. In addition, this paper requires the company to have at least one new patent when screening the sample company. This paper selects patent data for listed companies each year authorized patents, data are from CNRDS database.

3.3 Indicator Description

(1) Construction of technical linkage indicators

In order to construct the technical association index, this paper refers to the method of Charles et al. (2019), uses CNRDS database to obtain the annual invention patent licensing data of all enterprises listed in A−shares from 2010 to 2021, and uses Python programming to obtain the international patent secondary classification number of each patent. For each enterprise, the proportion of the number of patents under the same classification number in the total number of patents obtained in the year is calculated, and the patent layout vector $Ti = (S_1, S_2,..., S_\mu,..., S_{131})$ of each enterprise is constructed. Furthermore, through the following formula, the correlation coefficient of patent layout vector between two enterprises is calculated.

$$\boldsymbol{TECH}_{i,j} = \frac{(T_i T_j^{'})}{(T_i T_i^{'})^{1/2} (T_j T_j^{'})^{1/2}} \tag{3}$$

The value of $TECH_{ij}$ index is between 0 and 1. The more similar the patent layout of the two companies, the higher the value of $TECH_{ij}$, and vice versa. $TECH_{ij}$ is equal to $TECH_{ji}$. In addition, drawing on Lee et al. (2019)s practice, this paper randomly defines one of the companies as the focus company, which is called technology peers.

(2) Construction of Technology Related Income Factor

On the basis of technology linkages, foreign scholars have further found that stock prices reflect technology linkages among firms (Khimich and Bekkerman, 2017), and that the changes in stock prices of firms with technology linkages are predictable. Charles et al. (2019) built a 'technology−related income factor' on the basis of technology linkages and found that significant excess returns could be obtained by using this factor for stock selection, which they called 'technology momentum'. This paper uses the method of Charles et al. (2019) to construct the index of technology related income of listed companies. The specific calculation method is:

$$TECHRET_{it} = \sum\nolimits_{j \neq i} \left(\frac{TECH_{ij} \bullet RET_{jk}}{\sum\nolimits_{j \neq i} TECH_{ij}} \right) \tag{4}$$

Among them, $TECHRET_{it}$ denotes the technology−linked return corresponding to the focus company i at t time point, $TECH_{ij}$ is the technical correlation index above, RET_{jk} denotes the stock price return of j company with technical correlation with i company in the past k months. In the following study, k = 1 is taken as the benchmark. The meaning of the formula is that the technology related rate of return of focus company i is a weighted average of the technology−linked return of all technical peers except itself.

(3) Control variable setting

Refer to relevant research results. In this paper, the control variables are set as follows: stock market value SIZE, book market value ratio BM (book market value ratio = shareholders' equity/company market value), profitability GP (total profitability = (operating income−operating cost)/total assets at the beginning of the period), R & D expenditure ratio RD (R & D expenditure ratio: R & D expenditure/shareholders'equity), REV (short−term return reversal variable, defined as the stock return of the sample company in t−1 month) and MOM (medium−term price momentum variable, defined as the cumulative stock return of the sample company between t−12 months and t−2 months). In terms of financial indicators, the SIZE index selects the total market value of listed companies at the end of June each year and takes logarithm. BM, GP and RD indicators are taken from the annual report data of listed companies at the end of the previous year, and these indicators are matched with the return rate from June to the end of May of the next year.

Table 1 Definition and description of each variable

Type	Variable	Variable definition
Core explanatory variables	TECHRET	Returns of technology−linked
Explained variable	RET	Monthly return of company stock price
Control variable	SIZE	Total market value of the company
	BM	Book−market ratio
	GP	Total profitability
	RD	R & D expenditure ratio
	REV	Short−term income reversal variable
	MOM	Medium−term income reversal variable
Moderator variable	NB	North−South classification variables
	DZX	East−West classification variables

In the construction of the north−south zero−one variable, the northern enterprise value is 0, and the southern enterprise value is 1. Accordingly, considering the small number of listed companies in the central and western regions, this paper will merge the listed companies in the central and western regions, and the value of the central and western regions is 0, and the eastern region is 1. Two zero−one variables are further multiplied by the technology−linked return to construct the corresponding multiplier (Table 1).

4 Empirical Analysis

4.1 Descriptive Statistics

The descriptive statistics of the variables in this study are shown in Table 2 below. The median and average values of the explained variable and the explained variable are close, indicating that there is no left and right deviation and no standardized data processing. In addition, the mean value of TECHRET and the absolute value of each quantile are smaller than RET, because TECHRET is a weighted average of RETs of all companies except for itself weighted by technical relevance, so TECHRET is smaller than RET. The values of variable RET and variable REV are consistent, mainly because both are returns and have many common values. The median of MOM is negative but the average is positive, indicating that most of the recent medium−term returns of sample firms are down, which is related to the sample selection period.

Table 2 Descriptive statistics

Variable	Observed value	Mean	Sd	Min	P25	P50	P75	Max	VIF
RET	190,114	0.01	0.14	−0.29	−0.07	0.00	0.07	0.45	–
TECHRET	190,114	0.01	0.08	−0.17	−0.03	0.01	0.05	0.24	1.02
REV	190,114	0.01	0.14	−0.30	−0.07	0.00	0.07	0.45	1.01
MOM	190,114	0.11	0.55	−0.58	−0.23	−0.02	0.28	2.11	1.00
RD	190,114	0.05	0.12	0.00	0.02	0.04	0.06	0.24	1.02
BM	190,114	0.40	0.28	0.06	0.21	0.34	0.52	1.39	1.05
GP	190,114	0.06	0.10	−0.20	0.02	0.05	0.10	0.33	1.11
SIZE	190,114	15.74	0.98	14.03	15.05	15.61	16.29	18.67	1.06

Finally, the variance expansion factor on the right side of the table is far less than 10, indicating that there is no collinearity between explanatory variables.

4.2 Empirical Results

Table 3 shows the regression results of technology−linked return on the next period of return. This paper adds industry dummy variables to the regression after the basic regression to illustrate that industry factors will not affect the visibility of technology−linked return. Tables 1 and 2 show the regression based on Fama two−step model. (1) Without control variables, the technology−linked return is significantly indigenous to the return on the next period at 1%, and the sign of the technology−linked return is positive, indicating that in the monthly cycle, the technology−linked return has a positive impact on the return on the next period. (2) It shows the regression results after adding control variables. The results show that the explanatory variables are still in the 5% suite, and the symbol is also positive, indicating that there is a predictable correlation in the return rate of the company that is technically related. (3) and (4) in the table show the regression results after adding the virtual variables of the industry, in which (3) the regression does not contain control variables, and (4) the regression adds control variables. It is shown in the table that the explanatory variables are significantly indigenous under the condition of 1%, which indicates that after adding the industrial control variables, the technology−linked return still has a significantly positive impact on the return of enterprises in the next period.

Table 3 Technology−related return rate and future return rate

	(1)	(2)	(3)	(4)
	RET	RET	RET	RET
TECHRET	0.0890[c]	0.0743[b]	0.0867[c]	0.0698[c]
	(2.6406)	(2.4404)	(3.0841)	(2.6421)
REV		−0.0252[c]		−0.0251[c]
		(−2.8346)		(−2.8638)
MOM		0.0017		0.0015
		(0.3955)		(0.3461)
RD		0.0431[c]		0.0446[c]
		(3.5303)		(4.2862)
BM		0.0072		0.0068
		(1.6094)		(1.5552)
GP		0.0168[a]		0.0162[a]
		(1.8653)		(1.8015)
SIZE		−0.0041[a]		−0.0040[a]
		(−1.7493)		(−1.7135)
_cons	0.0069	0.0640	0.0085	0.0646
	(0.9413)	(1.5674)	(1.2523)	(1.6403)
N	190167	190167	190114	190114
Industry virtual variables	No	No	No	No

t statistics in parentheses
[a]$p < 0.1$, [b]$p < 0.05$, [c]$p < 0.01$

4.3 The Empirical Results After Adding Industry Factors

On the basis of the above, consider which industries have strong technology momentum effect in each industry. In this section, this paper continues to use the Fama two−step method for regression. Table 4 below shows the industry−by−industry regression results after referring to the Shenwan industry classification. Some industries have not been shown. The main reason is that the data amount is small or there is a data fault, so stata software cannot carry out regression. From the effective regression can be seen, metal smelting, pharmaceutical biology, machinery and equipment and computer technology related to these four industries in the statistical significance of the yield is remarkable.

Table 4 Industry regression results

Industry	Agriculture	Chemistry	Metal	Vehicle	Food & Beverage	Textile & Costume	Light industry
	RET	RET	RET	RET	RET	RET	RET
TECHRET	0.0406	0.0394	0.1186*	0.0328	−0.2062	0.0892	0.0672
T Ratio	(−0.2575)	(−0.7766)	(−1.6611)	(−0.2221)	(−1.5422)	(−1.0446)	(−0.5217)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3309	22937	8172	7497	4188	4239	3820
Industry	Medicine	Public utilities	Traffic	Real estate	Trade retail	Social service	Synthesis
	RET	RET	RET	RET	RET	RET	RET
TECHRET	0.2076**	−0.1264	0.2486	0.4562	−0.548	−0.0162	−2.0251
T Ratio	(−2.4231)	(−0.8559)	(−0.2122)	(−0.3897)	(−1.1631)	(−0.0570)	(−1.5412)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	15766	2137	1514	1015	2731	2979	901
Industry	Architectural ornament	Electrical equipment	Mechanical equipment	Computer	Communication industry	Coal	petroleum industry
	RET	RET	RET	RET	RET	RET	RET
TECHRET	0.0509	0.0622	0.0880*	0.1147**	−0.8907	−0.3160**	0.0919
T Ratio	(−0.3449)	(−0.8021)	(−1.8296)	(−1.9848)	(−0.7942)	(−2.0167)	(−0.6497)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	5440	16241	37201	36349	1229	1535	1694
Industry	environmental protection						
	RET						

(continued)

Table 4 (continued)

Industry	Agriculture	Chemistry	Metal	Vehicle	Food & Beverage	Textile & Costume	Light industry
TECHRET	−0.1132						
T Ratio	(−0.5637)						
Control variable	Yes						
N	2010						

4.4 The Empirical Results of Adding Regional Factors

In the following, regional factors are further added to study the technology−linked return, and Table 5 shows the regression results. (1) It shows the regression results after adding the north and south factors. It can be seen that the intersection and multiplication of the technology−linked return and the north and south regional indicators are not statistically significant. It can be found that the distribution of enterprises in the north and south has little effect on the technology−linked return. (2) It shows the regression results after adding the factors of eastern, central and western regions. The results show that the interaction term of the composite of the technology−linked return and the regional indicators of eastern, central and western regions is obvious under the condition of 5%, but the symbol before the coefficient is negative, indicating that the technology−linked return of enterprises operating in the central and western regions of China is high. Because this paper takes the merger of the central and western enterprises as a group, so in order to explore the specific region of the enterprise technology−linked return is more obvious, this paper further to the middle, east and west group regression.

The results of the classification regression are shown in Table 6 below. From the perspective of explicitness, only the regression results of explanatory variables in the central and eastern regions are significantly positive, and the regression results of explanatory variables in the western region are not significantly indigenous. From the regression results of the central and eastern regions, the return on enterprise technology linkages in the central region is more significant than that in the eastern region, and the explanatory variable coefficient in the central region is larger than that in the eastern region. In terms of control variables, except for the MOM mid−term reversal variable, other variables in the eastern region are significantly indigenous, while the control variables in the central region are less significantly indigenous. As a result, this paper believes that the eastern region has the largest number of enterprises, more influencing factors, and more positive R & D, resulting in lower response of stock returns to technological R & D than that of the central region. In recent years, the central region has developed rapidly, the growth of enterprises is good, and the technology spillover in the eastern region is more obvious, so the technology related yield is more obvious.

5 Retest Results Based on Technology−Linked Return

On the basis of measurement verification, in order to further illustrate the effectiveness of the factor of technology−linked return after adding industry and regional factors, this paper compares the market return of China's stock by constructing investment portfolio, and intuitively reflects the excess return caused by industry and regional factors.

Table 5 Regression results of regional heterogeneity

	(1)	(2)
TECHRET	RET	RET
	0.0694**	0.1119***
NB	(2.0208)	(2.7738)
	−0.0009	
TECHRET*NB	(−0.4482)	
	0.0082	
DX	(0.3335)	0.0011
TECHRET*DZX		(0.3634)
		−0.0500**
REV	−0.0251***	(−2.0119)
		−0.0252***
MOM	(−2.8220)	(−2.8277)
	0.0018	0.0017
RD	(0.4024)	(0.3908)
	0.0427***	0.0420***
BM	(3.4954)	(3.5673)
	0.0073*	0.0070
GP	(1.6579)	(1.5703)
	0.0161*	0.0157*
SIZE	(1.8342)	(1.7990)
	−0.0040*	−0.0041*
_cons	(−1.7215)	(−1.7436)
	0.0631	0.0639
N	(1.5797)	(1.5960)
	190114	190114

t statistics in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

On the market rate of return, this paper combines previous papers and securities research papers, using the Shanghai and Shenzhen 300 index. In order to facilitate the image display, this paper constructs an index to reflect the return on investment portfolio of the rate of return on technology—linked return. At the same time, the CSI 300 index point in June 2011 is used as the initial point of the investment portfolio, which can more intuitively show the excess return between the two.

In terms of the number of constituent stocks in the construction of the portfolio, considering that the different number of constituent stocks will affect the yield calculation, as well as the rapid rise and reversal fall caused by the stock price momentum effect, this paper refers to the construction method of the previous portfolio (Duan

Table 6 Regression results of central, eastern and western regions

	East	Mid	West
TECHRET	RET	RET	RET
	0.0584*	0.1129**	0.0895
REV	(1.8991)	(2.6028)	(1.4402)
	−0.0236**	−0.0288***	−0.0265**
MOM	(−2.4968)	(−2.6963)	(−2.6141)
	0.0018	0.0007	0.0033
RD	(0.4003)	(0.1397)	(0.6687)
	0.0506***	0.0371**	−0.0164
BM	(3.8830)	(2.5943)	(−0.8423)
	0.0095**	0.0017	0.0005
GP	(2.0235)	(0.3077)	(0.0857)
	0.0159**	0.0117	0.0226*
SIZE	(2.0142)	(0.7180)	(1.6602)
	−0.0045*	−0.0033	−0.0029
_cons	(−1.9592)	(−1.3483)	(−1.1360)
	0.0700*	0.0534	0.0493
N	(1.7292)	(1.2955)	(1.0812)
	138413	30308	21393

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Binglei, 2022) and repeated tests, and decides to choose 50 enterprises in the head to construct the portfolio.

In the construction of investment portfolios with the whole market stocks as samples, this paper sorts them from high to low based on the monthly technology−linked return. The top 50 are selected to form investment portfolios, which are bought on the last trading day of t−1 and sold on the last trading day of t. The portfolio holding period is based on one month and adjusted at the end of each month. In order to avoid a stock weight is too large impact on the portfolio, the portfolio design requires each stock to buy equal weight allocation, the end of the month also to ensure equal weight adjustment. Considering that the portfolio is constructed in the form of index, transaction costs such as transaction fees and transfer fees are ignored in the retest. The return of each period of the portfolio is shown in the figure below, and the measurement indexes of the investment effect of all portfolios are shown in Table 7.

Figure 1 below shows the retest results of the investment portfolio (hereinafter referred to as the full sample portfolio) with the whole market stock as the sample. The yellow line reflects the retest results of stock selection under the condition of technology−linked return, and the blue line reflects the trend of Shanghai and Shenzhen 300 market return. It is very intuitive to show that stock selection based

Table 7 Investment effect comparison of portfolio

Investment effect measure index	CSI 300 (%)	Total sample combination (%)	Industry portfolio (%)	Eastern region combination (%)	Central region combination (%)	Western region combination (%)
Total revenue of strategy	59.86	329.92	507.12	354.18	348.32	237.54
Strategic annualized returns	4.8	15.7	19.76	16.34	16.19	12.94
Maximum retracement	−40.56	−44.70	−39.157	−44.45	−38.27	−55.04

on technology−linked return can bring very high excess returns. Although the gap between the two is not large in the first few years, with the passage of time, since March 2013, the two have begun to great differentiation, and the portfolio showed a large increase beyond the market. Even during the two rebounds following the 2015 stock crash, the portfolio showed strong resilience, approaching its 2015 high twice. In terms of annualized return, the full−sample portfolio is 15.7%, and the Shanghai and Shenzhen 300 are 4.8%. It can be seen that the technology−linked return factor significantly increases the return on investment. In terms of total return, the full−sample portfolio also significantly outperformes the market portfolio. But in the withdrawal, the combination is larger, indicating that the combination has greater volatility.

Next, this paper verifies the retest results after joining the industry. As shown in Fig. 2, we take the full sample portfolio in the above figure as a comparison to show

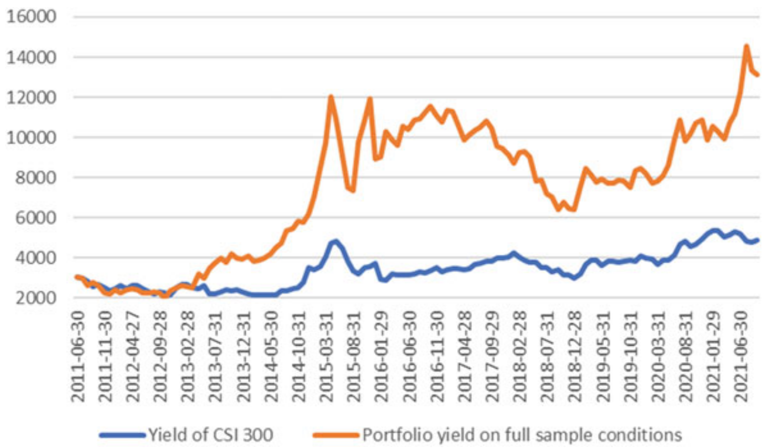

Fig. 1 Full sample portfolio return results

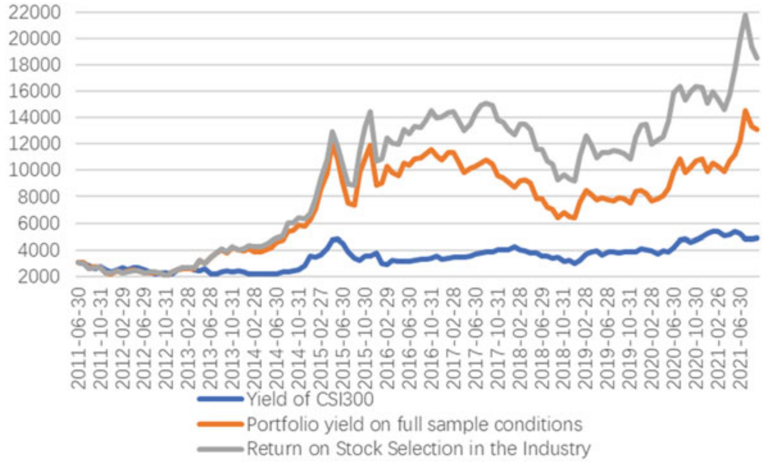

Fig. 2 Retest results after considering industry

whether joining the industry factor will bring higher returns. Portfolio construction is the same as above, but this article selects only four industries that show significant results in the subsector regression above. As shown in the following figure, the gray line represents the return on investment portfolios in the industrial context, with an annual return of 19.76%, which is much higher than the annual return on investment portfolios in the full sample of 15.7%. After the market plunges, the investment portfolios of the industrial samples show stronger resilience. It can also be seen from the maximum withdrawal in the table that the industrial investment portfolio is the smallest, or even smaller than Shanghai and Shenzhen 300. From the total yield point of view, the total return of 10 years is as high as 5 times, and the full sample portfolio is 3.29 times, indicating that industry factors have better effect on the factor.

Further, based on the full sample, this paper conducts retests by dividing enterprises in the eastern, central and western regions. Similarly, this part introduces the portfolio of Shanghai and Shenzhen 300 and the full sample as the control group, and further compares the excess return rate under the influence of regional factors. The gray, yellow and light blue lines in the figure represent the return on investment portfolio of enterprises located in the eastern, central and western regions, respectively. Through comparison, it can be found that in most of the time, the return on investment portfolio in the central and western regions is lower than that in the full sample portfolio. But compared with the western region, which is far below the full sample portfolio, the yield in the central region has increased significantly in recent years. From the total income in the table, the eastern and central regions have surpassed the yield of the full sample portfolio at the same time, but the total income gap between the eastern and central regions is only 5.86%. This comparison can be found that enterprises in the central region have gained more and more 'technology momentum' effects. However, compared with the investment portfolio of the industry, regional factors have little effect on the improvement of investment income (Fig. 3).

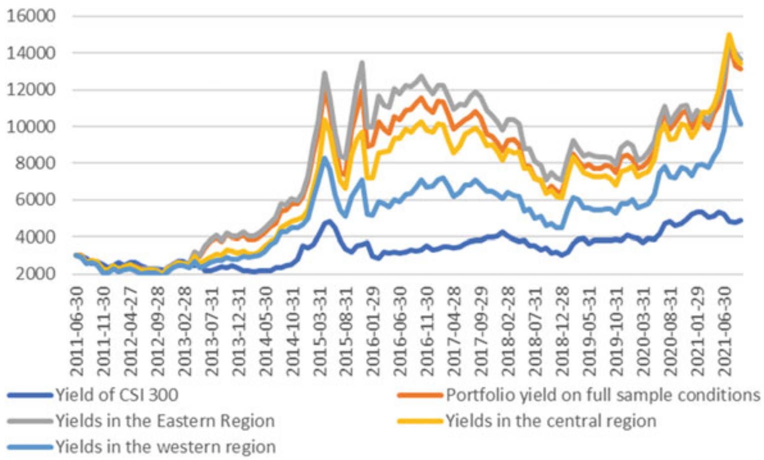

Fig. 3 Retest results considering region

In addition to the above test, this paper also tries to buy the top 50 and sell the last 50 strategies according to the level of technology−linked return, and through the construction of grey correlation degree to give different weights to the variable multi−factor stock selection strategy. But according to the results, the yield is not as good as the above results, this article no longer shows here.

6 Robustness Test

In order to verify the robustness of the results, this paper replaces the measurement model to re−test the results. Considering that the GMM model can exclude the influence of the correlation of residuals on the cross−section on the standard error, we select the GMM model and reconstruct the regression by combining the explanatory variables, explained variables and control variables above. The results are shown in Table 8. It can be seen from the results that the technology−linked return is still significant, indicating that the conclusion of this paper is robust.

7 Conclusion

As a newly proposed quantitative factor, the technology−linked return has been rarely studied in China. It is worth further studying how this new quantitative factor can be better used in quantitative finance. This paper takes the monthly data of A−share listed companies from 2010 to 2021 as samples. Through empirical research, it is found that the index of technology−linked return is effective in China's

Table 8 Robustness test

	(1)	(2)
L.RET	RET	RET
	−0.0123***	−0.0832***
TECHRETT	(−2.73)	(−30.6268)
	0.1132***	0.1215***
REV	(11.87)	(25.2184)
		−0.1064***
MOM		(−49.3143)
		−0.0285***
RD		(−31.2747)
		0.0210**
BM		(2.0009)
		−0.0038
GP		(−0.9279)
		−0.0783***
SIZE		(−5.5986)
		−0.0411***
_cons	0.0118***	(−29.5766)
		0.6683***
N	(22.20)	(29.3146)
		185338

t statistics in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

capital market. Because of the similarity of patent layout, the fluctuation of stock price of enterprises with high technology linkage will produce "technology momentum" to the focus companies, and affect the stock price of the focus companies. Further, after adding industry factors, it is found that there are some industries whose technology−linked return is significantly affected. At the same time, through the construction of portfolio, it is found that the portfolio return under the influence of industry factors is the highest. After adding regional factors, listed companies in the central region have a more significant impact on the technology−linked return. After constructing investment portfolios, it is found that the overall return of enterprises in the central region is lower than that of enterprises in the eastern region, but the income gap between the two is narrowing in recent years. In general, the regional difference rate of return has a smaller increase than the full sample portfolio rate of return.

The main enlightenment of this paper is the following three points: First, the technology−linked return is effective in China's capital market, which can provide a new stock selection idea for institutional investors such as funds. Second, for industries that are sensitive to the technology−linked return, focusing on the enterprises can obtain the rate of return far beyond the average market return. While paying attention to the factor of the technology−linked return, it is also necessary to pay attention to the industry. Third, in recent years, the 'technology momentum' of enterprises in the central region is more and more strong, for investors can increase the attention of enterprises in the corresponding region.

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Research on the Impact of the "Circle Layer" Structure of the Beijing–Tianjin–Hebei Urban Agglomeration on Energy Ecological Efficiency Under the Dual Carbon Goal

Si Wang and Xinshu Xu

Abstract Promoting the strategy of carbon peaking and carbon neutrality is a broad and profound economic and social systemic change, in which the low-carbon energy transition will be the key to realizing the "dual carbon" goal. This paper uses the panel data of 13 cities in the Beijing–Tianjin–Hebei urban agglomeration in China from 2010 to 2020, combined with the urban gravity model to calculate the degree of "circle" structure of the urban agglomeration, and uses the undesired SBM model to calculate the energy ecological efficiency. The threshold effect of the "circle layer" structure of the Beijing–Tianjin–Hebei urban agglomeration on energy ecological efficiency. The results show that the impact of the "circle layer" structure of the Beijing–Tianjin–Hebei urban agglomeration on the energy ecological efficiency is "inverted U-shaped". However, with the saturation of agglomeration, the constraining effect of the crowding effect will appear, which will reduce the energy ecological efficiency. Therefore, it should be necessary to optimize the spatial structure of urban agglomerations, coordinate the development plans and strategies of urban agglomerations of different development scales, improve technological innovation capabilities to improve energy ecological efficiency, and promote the realization of the dual-carbon goal.

Keywords Dual carbon goals · Beijing–Tianjin–Hebei · Urban agglomeration · Circle structure · Energy eco-efficiency

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1 Introduction

In September 2020, General Secretary Xi Jinping announced at the 75th United Nations General Assembly that "China will increase its nationally determined contribution, adopt more powerful policies and measures, and strive to achieve a peak in carbon dioxide emissions before 2030, and strive to achieve this before 2060. carbon neutral". The Second Biennial Update Report on Climate Change of the People's Republic of China shows that in the composition of my country's carbon emissions, emissions related to energy activities account for 77.7% of the total. As the core area of national strategic development, the Beijing–Tianjin–Hebei urban agglomeration has caused various environmental quality problems in the process of rapid urbanization, which have seriously affected the sustainable development of the urban agglomeration. The economic development model has caused many air pollution problems and has become the most polluted urban agglomeration in China [1]. It is not only necessary to optimize the spatial structure and management pattern of the urban agglomeration, enhance the comprehensive carrying capacity of the city, and promote the economic development of the urban agglomeration. Resource constraints make the resource environment match the stage of economic development. This paper attempts to interpret the mechanism and degree of influence of economic agglomeration and crowding effects on reducing energy intensity by capturing the changing characteristics of energy eco−efficiency in the Beijing–Tianjin–Hebei urban agglomeration from the perspective of the "circle-layer" structure, so as to explore the joint effects of space and market forces. Feasible options for improving energy eco-efficiency provide a theoretical foundation for subsequent research on energy conservation and emission reduction.

2 Literature Review

2.1 Research on the "Circle Layer" Structure of Urban Agglomerations

In the context of economic globalization and informatization, urban agglomerations have become an important development model for regional cultivation of core growth poles and the main body of world economic activities by virtue of their unique development advantages. When the agglomeration develops to a certain extent in the central city, there will be a trend of outward expansion due to the saturation of the agglomeration degree. With the continuous formation of secondary economic development belts, this circular movement enhances the influence of the central city and covers the entire When the region reaches a steady state, a "circle layer" structure within the urban agglomeration is formed. Tong HL and Shi PJ (2020) used factor analysis to evaluate the urban comprehensive quality of each city in Lanxi urban agglomeration, used GIS spatial analysis to obtain temporal distance, and used gravity model and social network analysis method to analyze the structure of the spatial network It is found that the scale effect of Lanxi urban agglomeration is gradually emerging, and it is gradually forming an urban agglomeration with Lanzhou and Xining as the core and Lanxi high−speed rail as the axis, which is very attractive and spreads to surrounding cities [2]. Wang Ming [3] took the urban agglomeration around Changsha-Zhuzhou-Xiangtan City as the research object, and used the gravity model to quantitatively analyze the evolution of the interaction relationship within the urban agglomeration from 2007 to 2016. Through the cross-domain adjustment of the industrial structure, and the implementation of a performance appraisal mechanism that combines incentives and constraints to solve the problem of circle differentiation [3].

2.2 Research on the Energy Eco−Efficiency of the Beijing–Tianjin–Hebei Urban Agglomeration

The energy problem is the focus and hotspot of the current academic research, and the energy and all kinds of problems related to it have been paid much attention by scholars at home and abroad. With the development of the global economy, resource issues, environmental issues, and ecological issues have become increasingly prominent. The ecological and environmental issues brought about by them cannot be ignored, and the issue of energy eco-efficiency has attracted much attention. Wang Shaohua [4] constructed a regional energy efficiency evaluation index system including 3 criteria of economy, energy and environment and 12 specific indicators, and comprehensively used the entropy method and the coupling coordination degree model for analysis, and proved that the Beijing−Tianjin−Hebei region from 2001 to 2012 energy efficiency has been significantly improved [4]. Deng Tian [5] used the single factor energy efficiency measurement method and the entropy method to measure the energy efficiency of the secondary industry and conduct a comprehensive evaluation of environmental pollution, and used the FGLS model to empirically analyze the existence of a "U" shape between the energy efficiency of the secondary industry and environmental pollution. Relationships and Inverted "N" Relationships [5].

2.3 Research on the Impact of Urban Agglomeration "Circle Layer" Structure on Energy Eco−Efficiency

At present, the research on the impact of the "circle layer" structure of urban agglomeration on energy eco−efficiency mainly focuses on the impact of economic agglomeration on energy efficiency in the region. Wu Xiaobo et al. believed that when agglomeration develops to a certain extent in a central city, there will be a trend of outward expansion due to the saturation of the agglomeration degree. With the continuous formation of secondary economic development belts, this circular movement enhances the influence of central cities., and cover the entire area to reach a steady state, forming a "circle layer" structure within the urban agglomeration [6]. On the other hand, with the continuous expansion of the economic scale of urban agglomerations, the excessive concentration of factor density can easily lead to a decline in productivity, resulting in redundant construction, industrial structure convergence and excess production capacity. This crowding effect makes it difficult to avoid excessive energy consumption. Shi Bo and Shen Kunrong [7] found that energy efficiency and urbanization level show a U−shaped change, and the urbanization rate reaching the threshold of 55.46% will create conditions for industrial agglomeration of industrial enterprises, and then can improve energy utilization through economies of scale efficiency [7]. Li Zhi [8] used the variable intercept model to analyze the degree of influence and mechanism of energy intensity reduction by the "circle layer" structure of urban agglomerations. Swarm overcrowding can lead to increased energy intensity [8].

To sum up, this paper intends to expand the existing research in the following aspects: First, unlike the existing research on regional energy eco−efficiency, this paper aims at carbon neutrality and carbon peaking, taking into account the effect of carbon dioxide. Emission and absorption, take the green coverage area of the built−up area as one of the expected outputs, and take the "three wastes" as one of the undesired outputs, accurately measure the energy ecological efficiency of the Beijing−Tianjin−Hebei urban agglomeration, and help the region achieve carbon neutrality through green innovation. The second is to use the Hansen panel threshold model to link the "circle" structure of urban agglomerations with energy eco−efficiency, and to study the threshold effect of the "circle" structure of urban agglomerations on energy eco−efficiency and other influencing factors on energy Driven by eco−efficiency.

3 "Circle Layer" Structure and Development Status of Energy Eco−efficiency in Beijing−Tianjin−Hebei Urban Agglomeration

3.1 Development Status of the "Circle Layer" Structure of the Beijing−Tianjin−Hebei Urban Agglomeration

The general economic structure of urban agglomerations can be divided into two levels. One is the scale density of central cities that characterize regional agglomeration. Central cities play a vital role in radiation and diffusion in the formation of urban agglomerations. Only when a central city reaches a considerable size or density, its urban functions can meet the needs of providing regional services, and the wide area "delimited" by the urban agglomeration will strive to establish close connections and cooperation with the central city. The second is the overall scale density of the circle. The increase in the overall size and density of the urban agglomeration will help to promote the division of labor and the horizontal connection and cooperation between regions within the region. A high−efficiency urban agglomeration not only has a developed central city as the central core, but must also have a relatively high level of efficiency. The periphery of high−scale and dense urban agglomerations serves as the support for regional integrated development. Only by promoting and complementing each other can the two promote the overall high−efficiency development of the urban agglomeration economy. The density pattern of the internal elements of the urban agglomeration reflects the strength of the spatial agglomeration effect of the urban agglomeration and the intensity of its radiation to the outside world. The spatial connection between the important node cities, including the central city, has become the key to measuring the spatial connection status and benefits within the urban agglomeration. Drawing on the researches of Zhong Yexi and Wen Yuzhao, the gravity model is used to calculate the degree of economic closeness between the central city and the cities in the circle. The calculation formula is as follows:

$$g = \frac{Y_i Y_j}{D^2{}_{ij}} \tag{1}$$

Among them, Y_i represents the GDP of the hinterland city i and the central city j in the urban agglomeration, $Y_i Y_j$ represents the product of the GDP of the two cities, and D represents the actual traffic distance between the hinterland city i and the central city j. In order to describe the relative degree of transformation of the economic connection between the central city and the hinterland city, firstly calculate the external radiation intensity of the central city and the economic connection strengths g_{city} and g_{region} between the central city and the hinterland city respectively, The economic connection strength ratio G_{RC} of the difference between the size and density of the city and the hinterland city, namely

$$G_{RC} = \frac{g_{region}}{g_{city}} \tag{2}$$

Among them, $g_{region} = Y_i Y_j / D^2{}_{ij}$, $g_{city} = Y^2{}_j / r^2{}_j$, where G_{RC} represents the hinterland city i and The ratio of the gravitational intensity between the central cities j to the gravitational intensity of the central city itself, where the radius of the central city $r^2{}_j = A_j / \pi$, A = the administrative division area of the central city.

G_{RC} reflects the scale density of the central city and the conversion difference between the scale and density of the central city and the hinterland city. The larger the value is, the greater the degree of economic connection between the central city and the hinterland city is than the central city’s own external radiation intensity, and the smaller the value is This shows that the central city’s external radiation intensity is higher (Fig. 1).

It can be seen from Fig. 1 that Tianjin and Langfang have larger “circle layer” structure values, indicating that they are more closely related to Beijing’s economy

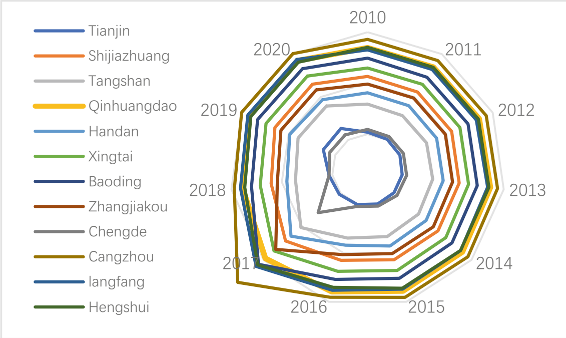

Fig. 1 "Circle layer" structure of the Beijing–Tianjin–Hebei urban agglomeration

than other cities, while other cities are more strongly affected by Beijing's radiation intensity. According to the calculation results, the Beijing–Tianjin–Hebei urban agglomeration can be divided into three circles. The first circle is mainly composed of Beijing, Tianjin and Langfang, which is the circle with the strongest economic strength in the Beijing–Tianjin–Hebei. For example, Beijing's economic aggregate has been relatively stable and has developed rapidly. The second circle is mainly composed of four cities, namely Tangshan, Baoding, Cangzhou and Shijiazhuang, with strong comprehensive strength. The third circle is composed of Zhangjiakou, Chengde, Hengshui, Qinhuangdao, Handan, Xingtai, etc., which are far away from Beijing, so they form a group of their own.

3.2 *Development Status of Energy Eco–Efficiency in the Beijing–Tianjin–Hebei Urban Agglomeration*

Data Envelope Analysis (DEA) is a method to measure the relative efficiency of decision–making units based on multiple inputs and multiple outputs. Previous studies usually use the traditional CCR, BBC and other models in the DEA method. Such models mostly measure the efficiency of decision–making units from a radial and perspective, and do not consider the slack of input variables and the problem of undesired output, resulting in results that deviate from reality. The SBM model considering undesired output proposed by Tonn can take the slack variable into account in the objective function, which breaks through the obstacles caused by undesired output and traditional radial and angular DEA models, and provides a more accurate measure of efficiency. The model is:

$$p = \frac{1-\left(\frac{1}{m}\right)\sum_{i=1}^{m}\left(\frac{s_i^-}{x_{i0}}\right)}{1+\frac{1}{(s_1+s_2)}\left[\sum_{r=1}^{s_1}\left(\frac{s_r^g}{y_{r0}^g}\right)+\sum_{r=1}^{s_2}\left(\frac{s_r^b}{z_{r0}^b}\right)\right]} \tag{3}$$

$$\text{s.t.}\begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda - s^g \\ z_0^b = Z^b\lambda + s^b \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases} \tag{4}$$

Among them, p represents the efficiency value of the decision−making unit, and the value is between 0 and 1; m, s_1, s_2 represent the number of inputs, expected outputs and undesired outputs, respectively; s represents the slack of input and output; λ is the weight vector. The objective function p is strictly monotonically decreasing with respect to s^-, s^g and s^b and s^b; when p = 1, the efficiency of the decision−making unit is optimal, and the effective frontier is reached; if p < 1, the efficiency of the decision−making unit is missing and needs to be adjusted by adjusting Input−output volume is improved.

Combined with the input and output data of the 13 cities in the Beijing−Tianjin−Hebei from 2010 to 2020, the energy ecological efficiency was calculated using MATLAB software. Among them, the input indicators are selected from the three dimensions of labor force, capital and energy. The labor force selects the ratio of the number of urban employment in each city in the previous year to the number of urban employment in this year. The capital selects the actual fixed asset investment calculated with 2008 as the base period, and the energy Select the total energy consumption of each city. Output indicators are divided into expected output and undesired output due to resource consumption and industrial pollution. The expected output selects the regional GDP (current year price) variable to reflect the economic growth brought about by energy consumption, and selects the “green coverage of built−up areas”. Area” to measure the ecological benefits of each region, and undesired outputs include industrial sulfur dioxide emissions, industrial wastewater emissions, and industrial dust emissions. The selection of specific indicators is shown in Table 1.

The calculation results are shown in Table 2. The average energy ecological efficiency of Beijing reaches 0.666, and Qinhuangdao ranks second with an efficiency value of 0.663. The efficiency values of other cities are significantly lower than that of Beijing. From the perspective of specific cities, Tangshan and Tianjin ranked third and fourth respectively, while Baoding had the lowest efficiency value. Looking at the overall change trend of energy eco−efficiency of each city in the Beijing−Tianjin−Hebei urban agglomeration, it was relatively stable from 2010 to 2016, and in 2017, most cities showed a downward trend, and from 2018 to 2020, the energy eco−efficiency showed a fluctuating upward trend.

Table 1 Energy eco−efficiency evaluation index system

Indicator	Variable	Variable description
Input indicator	Energy input	Regional energy consumption/10,000 tons of standard coal
	Capital investment	Fixed asset investment/100 million yuan
	Labor input	Urban employment/10,000 people
Expected output indicator	Economic growth	Regional GDP/100 million yuan
	Ecological benefits	Green coverage area of built−up area/ha
Unexpected output indicator	Environmental pollution	Discharge of industrial wastewater/10,000 tons
		Industrial sulfur dioxide emissions/ton
		Industrial smoke and dust emissions/ton

4 Study Design

4.1 Data Sources

The research sample of this paper selects the panel data of 13 prefecture−level cities in the Beijing−Tianjin−Hebei urban agglomeration from 2010 to 2020. The data comes from the "China Statistical Yearbook", "China Urban Statistical Yearbook", "China Energy Statistical Yearbook" and provincial and municipal statistical yearbooks. Considering the difference in the development level of transportation infrastructure in different urban agglomerations, this paper selects the inter−city highway traffic distance for investigation. The actual highway distance data source is the Atlas of China's Highway Operation Mileage. A few missing data were supplemented by smooth interpolation.

4.2 Variable Selection

(1) Explained variables. Energy Ecological Efficiency (EE) is a comprehensive index that takes into account regional energy consumption and ecological benefits. The core idea is to create as much social value as possible with less energy consumption and environmental impact. The relevant indicators have been calculated above using the SBM−DEA model that includes undesired outputs.
(2) Core explanatory variables. The "circle structure" of urban agglomeration is to use the urban gravity model to calculate the ratio of the gravitational strength

Table 2 Energy ecological efficiency of 13 cities in Beijing−Tianjin−Hebei

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	AGV
Beijing	0.532	0.549	0.542	0.489	0.594	0.598	0.653	0.692	0.671	1.000	1.000	0.666
Tianjin	0.309	0.336	0.349	0.329	0.397	0.444	0.608	0.796	1.000	0.649	0.766	0.544
Shijiazhuang	0.245	0.293	0.288	0.309	0.318	0.334	0.393	0.304	0.463	0.36	0.405	0.337
Tangshan	0.360	0.438	0.438	0.465	0.469	0.472	0.521	0.287	1.000	0.64	1.000	0.554
Qinhuangdao	0.404	0.422	0.391	0.452	1.000	0.444	0.515	0.661	1.000	1.000	1.000	0.663
Handan	0.267	0.314	0.300	0.250	0.247	0.250	0.274	0.263	0.368	0.381	0.577	0.318
Xingtai	0.219	0.252	0.219	0.216	0.217	0.226	0.245	0.188	0.345	0.315	0.473	0.265
Baoding	0.209	0.225	0.199	0.219	0.206	0.245	0.233	0.234	0.290	0.299	0.384	0.249
Zhangjiakou	0.230	0.263	0.249	0.244	0.257	0.260	0.301	0.271	0.313	0.291	0.297	0.271
Chengde	0.329	0.427	0.468	0.400	0.408	0.456	0.499	1.000	1.000	0.405	0.442	0.530
Cangzhou	0.251	0.266	0.262	0.276	0.282	0.311	0.356	0.137	0.516	0.453	0.508	0.329
Langfang	0.267	0.255	0.256	0.254	0.284	0.314	0.355	0.092	0.804	0.951	1.000	0.439
Hengshui	0.210	0.232	0.225	0.222	0.227	0.227	0.275	0.285	1.000	0.844	1.000	0.432

of the central city and the hinterland city to the central city's own gravitational strength to describe the relative degree of economic connection transformation between the central city and the hinterland city of the urban agglomeration. related indicators.

(3) Control variables. This paper selects control variable indicators from six perspectives: industrial structure, scientific and technological progress, economic development level, degree of opening to the outside world, government behavior, and human capital accumulation. Among them, the industrial structure (IN) selects the proportion of the secondary industry in the regional GDP as an indicator to measure the industrial structure; the scientific and technological progress (TECH) uses the proportion of employees in the scientific research comprehensive technology service industry in the total urban employees as a substitute; The level of economic development (ECO) uses per capita GDP to measure the economic development level of each city, and the data is processed logarithmically; the level of opening to the outside world (OP) uses the proportion of FDI to GDP to measure the level of a region's opening to the outside world; government behavior (GOV) is measured by the proportion of government fiscal expenditure in each city to GDP; human capital accumulation (HUM) is measured by the number of college students in each city, and the logarithm is taken.

4.3 Construction of Panel Threshold Model

In order to verify whether there is a nonlinear relationship between the circle structure of the Beijing−Tianjin−Hebei urban agglomeration and the energy eco−efficiency, a panel threshold model is added in this paper. This model is suitable for testing whether there is a nonlinear relationship between the independent variable and the dependent variable. Such independent variables are also called threshold variables. When the threshold variables are located in different value ranges, the two have different effects. At the same time, the regression model can also avoid errors caused by artificial grouping. The specific form is as follows:

$$EE_{it} = a_1 G_{RCit} I\left(G_{RC_{it}} \leqslant \lambda\right) + a_2 G_{RCit} I\left(G_{RC_{it}} \geqslant \lambda\right) + a_3 D_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

Among them, EE_{it} is the energy ecological efficiency; G_{RCit} is the urban agglomeration circle structure, which is also the threshold variable of this study; D_{it} is a set of control variables; $a_1 - a_3$ is the coefficient of the parameter to be estimated; $I(\bullet)$ is the expression of the indicative function, and the indicative function takes the value 1 when the condition in the parentheses is established, and 0 otherwise; λ is the threshold to be estimated, ε_{it} is a random disturbance term, and μ_i i represents an individual fixed effect that does not change with time.

5 Empirical Results and Analysis

5.1 Hausman Test

Because the time span of the selected panel data is short, the number of sections 13 is greater than the number of time points 11, so the panel unit root test is no longer performed. Before performing panel data model estimation, a hausman test should be performed to determine the applicability of the random−effects model and the fixed−effects model. It can be seen from the test results that the hausman test p value of the model is 0.000, indicating that the model rejects the null hypothesis of random effects at the 1% significant level, so a fixed effect model is selected for estimation.

5.2 Threshold Effect Test

Before establishing the panel threshold effect model, the threshold effect test should be carried out first. The test consists of two parts. First, to test whether the threshold effect exists, that is, whether the parameters are significant after dividing different threshold intervals can be judged by the p value of the coefficient estimate; secondly, to test whether the estimated threshold value is equal to the true value, here the Bootstrap method is used for consistency test, which can be determined by the likelihood ratio LR value. This paper uses stata15.0 for testing and estimation. Table 3 shows the test results with the "circle layer" structure as the threshold variable. The results show that at the 5% significance level, there is a single threshold effect in the labor transfer model, and there are no double thresholds and triple thresholds. Therefore, this paper uses a single threshold model to study the impact of the "circle layer" structure of the Beijing−Tianjin−Hebei urban agglomeration on energy eco−efficiency.

The above test verifies the existence of the threshold effect, but a second−step test is still needed to determine whether the estimated threshold value is equal to the true value. Table 4 presents the estimated thresholds and estimated intervals at the 95% confidence level. Figure 2 is a graph of the likelihood ratio statistic function of the threshold value, where the dotted line is the critical value at the 95% confidence level. In the figure, the estimated value of LR corresponding to the threshold value

Table 3 Self−sampling test of threshold effect

Threshold	Fstat	Prob	Crit10	Crit5	Crit1
Single	20.46	0.042**	16.263	19.6094	30.9871
Double	3.25	0.947	19.7289	23.7448	34.3191
Triple	7.1	0.628	19.3502	24.0832	31.434

Note * ,*** ,*** * represent the significance levels of 10%, 5%, and 1% respectively

Table 4 Threshold estimation results and confidence intervals

Model	Threshold	Lower	Upper
Th−1	0.0030	0.0028	0.003

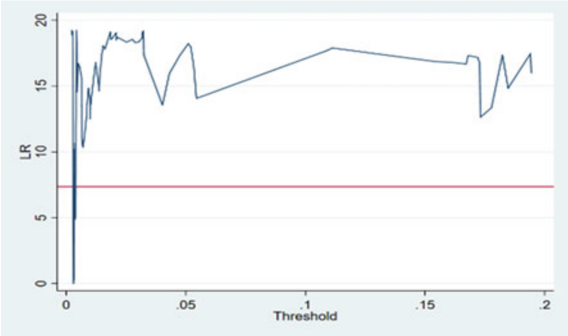

Fig. 2 Single threshold LR estimation

falls below the critical value, indicating that the estimated threshold value is valid and the estimated value is equal to the true value.

Therefore, according to the above test results, build a model:

$$EE_{it} = a_1 G_{RCit} I(G_{RCit} \le 0.003) + a_2 G_{RCit} I(G_{RCit} \ge 0.003) + a_3 D_{it} + \mu_i + \varepsilon_{it} \quad (6)$$

The threshold value of the "circle layer" structure is 0.003, which divides itself into two intervals: $G_{RCit} \le 0.003$ and $G_{RCit} \ge 0.003$.

5.3 Regression Results of Panel Threshold Model

Based on the research data, use stata15.0 software to empirically analyze the threshold effect between the "circle layer" structure and energy eco−efficiency. Table 5 shows the estimation results of the panel threshold model. The regression results show that the "circle" structure of the Beijing−Tianjin−Hebei urban agglomeration has a single threshold effect on energy ecological efficiency. When the "circle" structure strength is less than the threshold value of 0.003, the "circle" structure It has a significant positive impact on energy eco−efficiency, but when the "circle layer" structural strength exceeds the threshold value of 0.003, it has a significant negative impact on energy eco−efficiency. This shows that once the scale of the Beijing−Tianjin−Hebei urban agglomeration reaches a relatively crowded state, the urban economy cannot make up for the negative effect of reducing energy ecological efficiency caused by overcrowding. Due to the over−concentration of factor density, the too tight "circle" structure is likely to cause problems such as overloaded operation of infrastructure and relative scarcity of factors, resulting in accelerated energy consumption,

Table 5 Panel threshold regression results

	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
IN	−1.463	0.465	−3.150	0.008**	−2.476	−0.451
OPEN	−0.086	0.054	−1.580	0.140	−0.204	0.033
GOV	−1.250	0.719	−1.740	0.007**	−2.816	0.315
TECH	0.035	0.020	1.760	0.004**	−0.078	0.008
ECO	0.536	0.189	2.840	0.015**	0.124	0.948
HUM	0.055	0.050	1.100	0.091*	−0.054	0.164
$G_{RC} \leq 0.003$	105.266	23.950	4.400	0.001***	53.083	157.449
$G_{RC} \geq 0.0003$	−0.735	0.392	−1.880	0.085*	−1.588	0.118

Note * ,*** ,*** * represent the significance levels of 10%, 5%, and 1% respectively

serious environmental pollution and rising factor prices, resulting in distorted factor allocation, leading to energy Eco−efficiency declines.

From the control variables, we can see that the influence of various variables on energy intensity is basically consistent with the conclusions of the current representative literature. The regression coefficient of industrial structure to energy eco−efficiency is −1.463, which reflects that the urban industrial structure inhibits the improvement of energy eco−efficiency. Since the secondary industry is an industry with high energy consumption and the energy utilization is not sufficient, the increase in the proportion of the secondary industry will To reduce energy ecological efficiency, it is still necessary to continue to promote industrial upgrading and optimization; the regression results of the degree of opening to the outside world in each model are not significant enough, indicating that the introduction of foreign capital in the Beijing−Tianjin−Hebei urban agglomeration has only a limited impact on energy ecological efficiency; the government The regression coefficient of intervention on energy eco−efficiency is −1.25, indicating that in the Beijing−Tianjin−Hebei urban agglomeration, when the government intervenes too much in the market, it hinders the improvement of energy eco−efficiency; technological progress is positively correlated with energy eco−efficiency, that is, technological progress It is an important factor to promote the improvement of carbon emission efficiency. The introduction of advanced technology to improve the efficiency of energy utilization and the treatment of exhaust gas can minimize the pollution of carbon dioxide emissions, and technological progress will promote the use of clean energy and improve energy ecological efficiency. There is a significant positive correlation between the level of economic development and the eco−efficiency of energy. This paper believes that the Beijing−Tianjin−Hebei area underwent industrial transformation and upgrading earlier, the industrial structure is relatively advanced, the service industry is relatively complete, and the management and technical level of the relatively developed areas are relatively high. High, it has a promoting effect on energy ecological efficiency; human capital has a positive role in promoting energy efficiency, and talents are the key to technological innovation. Renewal plays an important role and thus contributes to the improvement of energy eco−efficiency.

6 Conclusions and Policy Recommendations

This paper comprehensively draws on the existing relevant research results, links the "circle" structure of the Beijing−Tianjin−Hebei urban agglomeration with the energy ecological efficiency, and studies the impact of the "circle" structure of the urban agglomeration on the energy ecological efficiency. In the specific research, the agricultural technology level is used as the threshold variable, the panel data of 13 cities in Beijing, Tianjin and Hebei from 2010 to 2020 are selected, and the undesired SBM−DEA model is used to measure the energy ecological efficiency, and the "circle layer" structure is used as the core explanation. The variables construct a panel threshold model, and empirically conclude that the impact of the urban agglomeration "circle layer" structure on energy ecological efficiency is non−linear. The specific performance is as follows: the continuous increase of the scale density within the urban agglomeration can achieve the effect of improving the energy eco−efficiency, but the overcrowding of the urban agglomeration will lead to a decrease in the energy eco−efficiency. Based on the conclusions drawn from the empirical research in this paper, the following policy recommendations are put forward:

First, we must firmly implement the urbanization and regional economic development strategy of urban agglomerations or urban belts centered on core cities, take big cities as leaders, give play to the driving and radiating role of core cities, and continuously strengthen surrounding cities and core cities within the urban agglomeration. It is recommended to try a public transportation−oriented development (TOD) development model, focusing on the large cities of the urban agglomeration, paying attention to the comprehensive development of land along the public transportation corridor, the integration of stations and cities, and the development of comprehensive hubs, so as to realize the intensive use of land, In this way, it will help realize a reasonable urban agglomeration structure and a reasonable transportation structure, promote the rational division of labor and complement each other in industries, improve the overall resource allocation efficiency and economic efficiency, and reduce energy consumption and carbon emissions.

Second, different size and density of urban agglomerations have different effects on the total factor energy efficiency of cities. The central government should formulate a reasonable urban agglomeration development strategy according to local conditions. It cannot limit the development density and scale of urban agglomerations, thereby restricting the rational allocation of resources, complementary industrial advantages and functions of each city. The formation of a rational division of labor should not overly increase the development scale and density of urban agglomerations, and avoid a series of problems such as crowding, traffic congestion, environmental pollution, and insufficient infrastructure caused by excessive urban agglomerations.

The third is to further encourage and support energy technology innovation. In order to achieve the goal of carbon neutrality as soon as possible and promote energy transformation, it is necessary to make great efforts in technological innovation and accelerate the integration and development of related industries, especially in the context of the rapid development of Internet +, big data and artificial intelligence, it is necessary to The traditional energy industry is combined with information technology to explore the development path of the new energy industry including the energy Internet, and realize the green, low−carbon and intelligent development of the energy system.

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Analysis and Forecast of Carbon Emission Reduction Effect in China's Carbon Trading Market

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Abstract The carbon emission trading market is an important policy tool for emiasion reduction, and seven carbon trading pilot markets have been established in China to achieve the goal of carbon peaking and carbon neutrality. In this regard, this paper measures the carbon trading market situation from the market dimension perspective with the carbon price, relative market size, and market activity as indicators, and uses the BP neural network model to predict the emission reduction rate in 2025 under different carbon trading market scenarios in each region based on the data of seven pilot regions from 2008−2019 to analyze the emission reduction effect of carbon trading market. The results of the empirical study show that, in general, the launch of the carbon trading market will reduce the carbon emissions of each pilot region, but due to the differences in the emission control subjects, launch time, and trading policies of each pilot carbon market, resulting in the changes in market conditions have different emission reduction effects on each pilot, therefore, this paper recommends accelerating the construction of the national carbon trading market and formulating a scientific carbon market mechanism according to the actual situation of each region, to achieve the carbon emission reduction target.

Keywords BP neural network · Carbon trading market · Carbon emission reduction

1 Introduction

Since the industrial revolution, the massive consumption of fossil energy by businesses has led to the accumulation of carbon dioxide emissions, which have contributed to global warming. In the Kyoto Protocol signed in 1997, it was proposed

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for the first time that countries could adopt "emissions trading" to reduce emissions. In this context, China attaches great importance to addressing climate change, actively implementing emission reduction strategies, and promoting low-carbon economic transformation. In September 2020, China put forward the goal of striving to achieve carbon peaking by 2030 and carbon neutrality by 2060 at the United Nations General Assembly. Drawing on the experience of developed countries and regions such as the EU, the carbon trading market is one of the most effective tools to reduce emissions at a low cost, Therefore, China has carried out carbon emission trading pilot projects in seven provinces and cities, including Beijing, Shanghai, Guangdong, and Hubei, since 2011. In July 2021, China's carbon emission trading market was officially launched online, and by the end of October, the cumulative volume of carbon emission allowances (CEA) traded in the national carbon market exceeded 20.2 million tons, and the cumulative turnover exceeded 900 million yuan. Therefore, as an important policy tool for China to achieve the goal of carbon peaking and carbon neutrality, it is of great theoretical and practical significance to study the emission reduction effect of China's carbon trading market.

The existing literature mainly focuses on studying the economic and environmental impacts of carbon trading markets [1–7], with research methods such as system dynamics and double-difference methods; the research scales cover countries [1, 3–6], regions [2, 8], and enterprises [9–12], and industries including industry [9], construction [10], and electricity [12]. The research results concluded that carbon trading can effectively promote carbon emission reduction and reduce carbon intensity through technological, economic, and energy consumption [3] and green innovation [6] paths to achieve green development [1, 2], and the better the economic development of a city, the greater the impact of carbon trading on its sustainable development [4], but some scholars believe that carbon trading will have some negative impact on the economy [5]; From the perspective of carbon trading pilot regions, the launch of the carbon market significantly improved the efficiency of carbon emissions in each region [13], and there was regional heterogeneity in the emission reduction effect [14], in addition to the limited effect of market mechanisms to promote carbon emission reduction, based on the synergy between government administrative intervention and market mechanisms can significantly enhance the emission reduction effect of the market [8]; At the firm level, it has been argued that carbon trading significantly increases the total factor productivity of firms and that this effect is stable without lags [11], and in terms of influencing factors, it has been argued that an increase in the volume of carbon trading can effectively promote carbon emission reduction and that a high carbon price can inhibit the emission reduction effect of carbon trading [10]. However, some scholars believe that increasing the carbon price will promote carbon emission reduction and aggravate the negative impact on the economy [15], and the penalty system suggests a graded penalty mechanism according to the size of enterprises and the degree of participation in the carbon market [12]; By industry, the emission reduction effect of increasing carbon price on coal power supply chain increases first and then decreases, and the reduction of free quota proportion and carbon trading subsidies will enhance its emission reduction effect [9]; in terms of research methods, scholars have used BP neural network method to predict carbon price [16] and carbon emissions of Chinese industry and construction [17–19].

Taken together, the existing studies have laid a good research foundation in exploring the impact of carbon trading on carbon emission reduction and predicting carbon emissions, but there are also the following shortcomings: On the one hand, no study has considered the emission reduction effect of carbon trading market when predicting the future carbon emissions in China; on the other hand, most of the existing studies on the impact of carbon market mechanism on carbon emission reduction are based on the existing small amount of data, without considering the time lag of the influencing factors. Therefore, this paper sets four carbon trading market scenarios to further explore the impact of different carbon trading market mechanisms on China's emission reduction rate in 2025 and to provide a reference for the construction and development of China's carbon trading market.

Given the limited historical carbon emission data, and the BP neural network model has no special requirements on the number of training samples and better prediction results, BP neural network models have been used in the literature to predict the peak time of industrial carbon emission in China [17], the carbon emission intensity of the construction industry [18], and the price of carbon emission trading [16], as well as the peak time of carbon in China under different scenarios [19]. Therefore, based on the BP neural network model, this paper predicts and analyzes the impact of different carbon trading market scenarios on the emission reduction rate of China's current pilot regions in 2025, and provides policy recommendations for the future development of China's carbon trading market.

2 BP Neural Network-Based Carbon Emission Prediction Model Construction

2.1 BP Neural Network Model Construction

BP neural network is a typical nonlinear algorithm, which is suitable for dealing with complex factor problems and has self-learning capability, and is theoretically capable of approximating any nonlinear continuous function with arbitrary accuracy. BP neural network consists of the input layer, several hidden layers, and an output layer. In this paper, the influencing factors of carbon emission in each region are taken as input values, and the carbon emission in the corresponding region is taken as the output value. The tansig function is chosen for the implicit layer nodes. The data of seven pilot regions from 2008−2017 were selected as training samples, and the data of each region from 2018−2019 were used as test samples, and the data were normalized, and the BP neural network trained with the training samples was used to simulate the output and inverse normalization to obtain the prediction results compared with the actual carbon emissions. As shown in Fig. 1, the calculated average accuracy is 83.7%, which shows that the BP neural network has a good prediction

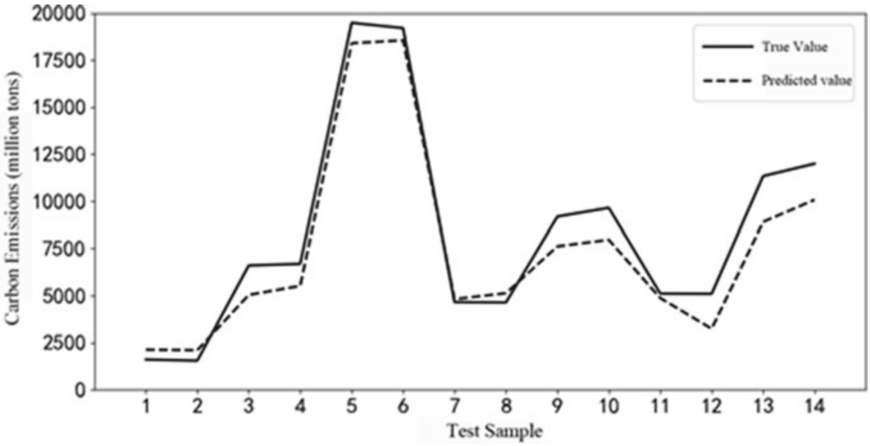

Fig. 1 Predicted versus true values of CO_2 emissions for 2018−2019 for the seven pilot regions in China

effect. Further, we set the scenario values of carbon emission influencing factors in each region in 2025, use the trained BP neural network model to predict the carbon emission in each region in 2025, and study the influence of different carbon trading market situations on the carbon emission reduction effect.

2.2 Sample Data and Indicator Selection

The sample data selected in this paper are the relevant data from 2008−2019 for the provinces (Beijing, Shanghai, Guangdong, Chongqing, Fujian, Tianjin, and Hubei) that have initiated carbon trading pilot projects in China. Data from *China Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Industrial Statistical Yearbook*,*China Regional Statistical Yearbook*, *China City Statistical Yearbook*, China Carbon Trading Website (www.tanpaifang.com).

The explanatory variable in this paper is carbon dioxide emissions, and the carbon emissions of each province are calculated by using the energy consumption of each province according to the carbon emissions calculation formula in the 2006 IPCC guidelines. To study the impact of the carbon trading market on emission reduction effect, three core explanatory variables are selected to measure the carbon trading market situation: (1) Carbon trading price: Carbon price is determined by the supply and demand of carbon emission rights, which affects the emission reduction strategy of enterprises in the market operation, and then affects the emission reduction effect. This paper uses the average of the first day of the month carbon trading price in the region. (2) Market activity: The market activity reflects the effectiveness of carbon quota allocation and the participation of emission control entities, which is a key factor affecting the emission reduction effect. In this paper, the total number of trading days in the regional carbon trading market is used. (3) Market size: The market size is a reflection of the size of the carbon market to play a role in emission reduction. In this paper, the ratio of total annual carbon trade to annual carbon emissions in the region is used. Referring to the existing literature on the influencing factors of carbon emissions, combined with the focus of this paper's research, the selected control variables are (1) population: the increase in population will increase energy consumption and have an impact on carbon emissions, expressed in terms of total regional year-end population (million people) (2) GDP per capita: representing the level of economic development of each region, economic growth is the main driver of carbon emissions from energy consumption, expressed in terms of total regional GDP and the total population at the end of the year in the region (yuan) (3) Market development degree: carbon emissions generated by the energy consumption of industrial enterprises account for about 85% of the total carbon emissions in China, according to which the number of industrial enterprises above the scale at the end of the year in the region is used to indicate the degree of market development. (4) Industrial structure: The main source of carbon dioxide emissions is the burning of fossil energy in the secondary industry, so this paper adopts the regional secondary industry output value as a proportion of GDP to indicate (5) Science and technology investment: Science and technology investment can promote enterprises to develop low-carbon technologies, improve energy use efficiency and reduce carbon dioxide emissions, so this paper adopts the regional R&D expenditure to indicate. Where the values of control variables in 2025 are derived by the exponential smoothing method using historical data.

3 Analysis of the Emission Reduction Effect of the Carbon Trading Market

3.1 Emission Reduction Effect of Carbon Trading Market

Based on historical data, the trend of carbon emissions before and after the launch of the carbon trading market in each pilot region is shown in Fig. 2, and the triangular marked points in the figure are the time when the carbon trading market was launched in each region. As shown in the figure, except for Guangdong and Fujian, all other provinces have a significant downward trend in carbon emissions, with an average emission reduction rate of 24%, and Fujian Province has not yet achieved the emission reduction effect due to the late start of the carbon trading market, which did not trade during the carbon quota allocation period, but Guangdong Province, although there is no downward trend in carbon emissions, ranks first in the country with 38% of its carbon trading volume, and it is estimated that the carbon trading policy has improved carbon dioxide emission reduction in the emission control industry in Guangdong Province by about 10% [20]. Therefore, the carbon trading market is an effective tool for emission reduction, and the next paper will predict the impact of different

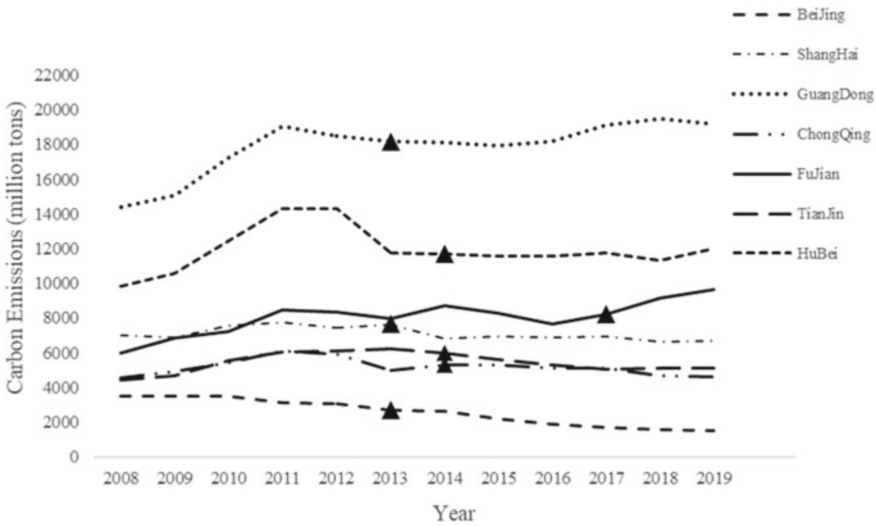

Fig. 2 Carbon emissions in the seven pilot regions of China, 2008−2019

market scenarios on the emission reduction effect of each pilot region in 2025 from the market dimension.

3.2 Scenario Setting

To study the impact of different carbon trading market situations on carbon emission reduction effects, this paper sets up the classical scenario S0 and four simulation scenarios A1–C4: A1–A4 is the carbon trading price scenario, B1–B4 is the relative market size scenario, and C1–C4 is the market activity degree scenario. Based on the historical trading data of the seven carbon trading pilot regions, the carbon trading price fluctuates from ¥15 to ¥60/ton, setting the carbon prices under the A1−A4 scenarios at ¥20, ¥30, ¥40, and ¥50, respectively. The relative market size fluctuates from 0.01 to 0.05, and the market activity fluctuates from 30 to 200 days. Considering that the carbon trading market has just started, and with the gradual expansion and improvement of the industry coverage and trading methods, the relative market size under B1−B4 scenarios are set at 0.01, 0.03, 0.05, and 0.07 respectively; the market activity under C1−C4 scenarios are set at 60 days, 140 days, 220 days, and 300 days. are set to 60, 140, 220, and 300 days. The specific scenario design is shown in Table 1.

Table 1 Scenario setting for carbon trading market situation

Influence variables	Scenario	Scenario setting		
		Carbon trading price (Yuan/per ton of carbon emissions)	Relative market size	Market activity
Classic scenarios	S0	35	0.04	180
Impact of carbon trading price	A1	20	0.04	180
	A2	30	0.04	180
	A3	40	0.04	180
	A4	50	0.04	180
Impact of relative market size	B1	35	0.01	180
	B2	35	0.03	180
	B3	35	0.05	180
	B4	35	0.07	180
Impact of market activity	C1	35	0.04	60
	C2	35	0.04	140
	C3	35	0.04	220
	C4	35	0.04	300

3.3 Emission Reduction Effects Under Different Carbon Trading Market Scenarios

3.3.1 Carbon Trading Price

Figure 3 shows the effect of carbon trading price on carbon emissions of carbon trading pilot provinces in 2025. As shown in the figure, different carbon trading prices will reduce the carbon emissions of each province, and the higher the carbon price, the more significant the carbon emission reduction effect of each pilot province. When the carbon price rose from 20 to 50 yuan/ton, the best emission reduction effect of the pilot provinces is Fujian Province, the emission reduction rate rose from 4 to 56%, followed by Hubei Province and Shanghai rose 52 and 22% respectively, Beijing, Tianjin, Chongqing, although the emission reduction rate rose only about 10%, the average emission reduction rate of 53%, the emission reduction effect is worse in Guangdong Province, the emission reduction rate of about 1%. The main reason why the increase in carbon price has a greater impact on the emission reduction rate is that some provinces currently have carbon market policies with penalties linked to the carbon price, if the emission control enterprises fail to complete compliance will be fined about 4 times the average price of market quotas, so it will bring greater cost pressure on enterprises, thus increasing investment in emission reduction technology, and the emission reduction effect is more significant, while Guangdong Province only needs to pay 2 times the quota, and in addition, because Guangdong Province has larger carbon emissions, energy supply is insufficient, the rise in carbon prices will

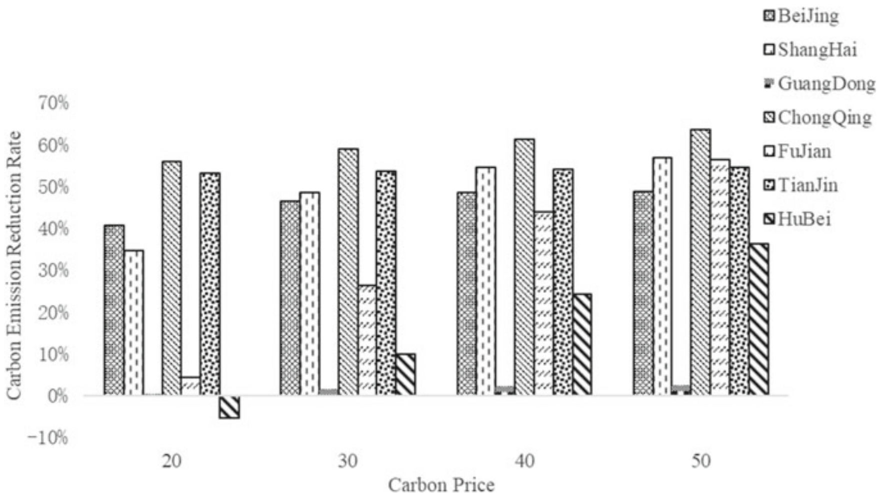

Fig. 3 Impact of carbon trading market on emission reduction rate in 2025 in pilot regions under scenarios A1−A4 (%)

increase the cost of coal use, thereby reducing the demand for coal, so the decline in coal prices instead promote the consumption of coal, inhibiting the carbon reduction effect of higher carbon prices.

3.3.2 Market Activity Level

Figure 4 shows the impact of market activity on carbon emissions in 2025 in the carbon trading pilot provinces. As can be seen from the figure, in most of the provinces and cities with the increase in market activity, the emission reduction rate then decreases, mainly because at the early stage of carbon trading market establishment, enterprises may worry about the negative impact of purchasing carbon allowances to the government and the outside world for excessive emissions, even if the return of emission reduction investment is less than the return of directly purchasing carbon allowances, enterprises prefer to choose emission reduction investment, which inhibits the carbon trading activity and also increases the emission reduction rate. However, overall, the market activity has a more significant effect on the emission reduction of each province, except for Guangdong Province, the emission reduction rate of all other provinces reached about 50%, for example, Chongqing City because of the current oversupply of carbon quotas, compared to other pilot areas the smallest market size, resulting in a very low level of market activity in Chongqing, so when the market activity increases, it indicates that the lack of carbon credits for enterprises need to develop energy-saving and emission reduction technologies, making Chongqing City emission reduction rate as high as 60%, while the carbon trading volume in Guangdong Province in 2018 accounted for 56% of the total national

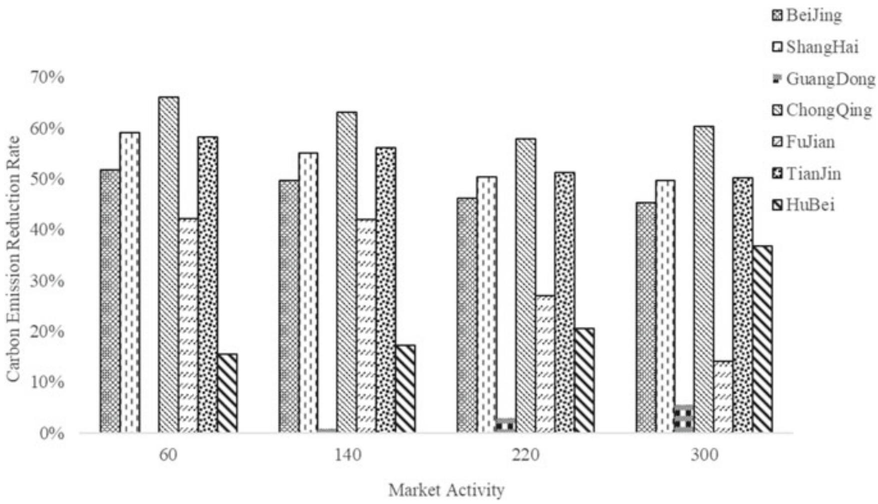

Fig. 4 Impact of carbon trading market on emission reduction rate in 2025 in pilot regions under B1–B4 scenarios (%)

trading volume, indicating that the energy-saving technology of each enterprise has become mature and the development of low-carbon space has been significantly reduced, so the emission reduction rate of Guangdong Province by the increase in market activity is only about 3%.

3.3.3 Relative Market Size

Figure 5 shows the effect of relative market size on carbon emissions in 2025 in the pilot carbon trading provinces. As shown in the figure, different carbon trading volume shares will reduce the carbon emissions of each province, because the increase in carbon trading volume indicates a greater demand for carbon credits from producers, which motivates other enterprises to develop low-carbon technologies to profit from them, thus achieving the effect of emission reduction. When the share of carbon trading volume increases from 0.01 to 0.07, the best emission reduction effect is in Shanghai and Chongqing, with emission reduction rates rising by 45% and 40% respectively, followed by Beijing, Tianjin, and Hubei, with emission reduction rates rising by 26%, 25%, and 11% respectively. Since Guangdong Province has the highest carbon emissions among the pilot cities, the number of emission control entities is small, and the number of high energy-consuming and high-emission enterprises is relatively high, the increase in carbon trading volume has less impact on the emission reduction effect in Guangdong Province.

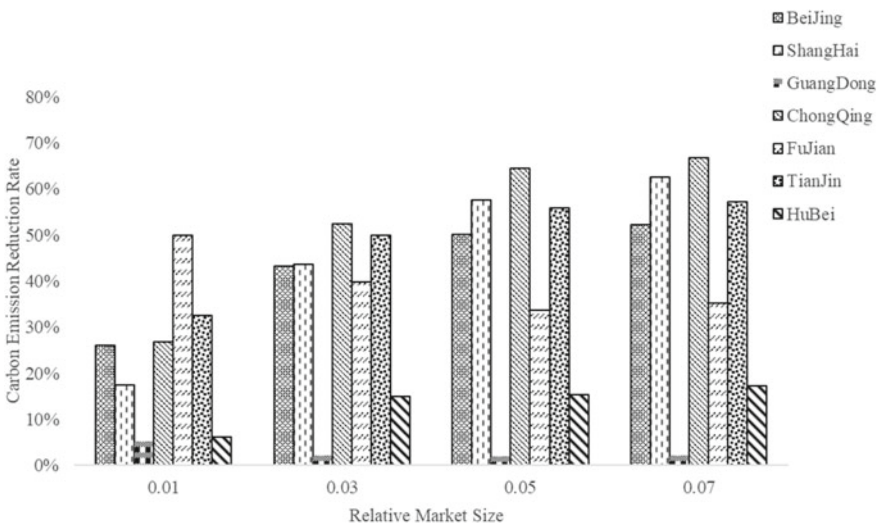

Fig. 5 Impact of carbon trading market on emission reduction rate in 2025 in pilot regions under C1−C4 scenarios (%)

4 Conclusion

Based on the BP neural network model, this paper constructs a carbon emission prediction model for pilot regions and studies the impact of different carbon trading markets on the emission reduction effect by setting up simulation scenarios, which provide guidance and suggestions for the establishment of a unified carbon emission trading market in China. According to the prediction results of the model, this paper draws the following conclusions: (1) Overall, the launch of the carbon trading market will significantly improve the emission reduction rate of each pilot region, although the total amount of carbon emissions in some regions does not change, the carbon emissions of the emission control subjects in the market have significantly decreased, in addition, due to the differences in regional carbon trading policies and carbon market launch time, the emission reduction effect also shows obvious regional heterogeneity. (2) Increasing the carbon price will promote a reduction of carbon emissions by about 20% in the pilot areas, and the effect of emission reduction will be more significant for the pilot areas linked to the carbon price in the penalty policy, while the effect of carbon price changes on carbon emissions will not be significant for provinces with higher energy demand. (3) The increase in market activity will lead to a significant increase in emission reduction rate in regions with the excessive allocation of carbon allowances but will have little impact on carbon emissions in regions with early carbon market start-ups and perfect carbon trading policies. (4) Expanding the scale of the carbon market will help increase the emission reduction rate in pilot regions but will have less impact on regions with more high energy-consuming and high-emission enterprises among the main emission control bodies.

In this regard, this paper gives the following suggestions: (1) accelerate the construction of a national unified carbon trading market. The current carbon trading policy in the pilot areas has led to a significant decline in carbon emissions in some regions, but the market activity in the fledgling pilot areas is low, and the emission reduction effect is not significant. Therefore, to achieve the goal of carbon peaking and carbon neutrality, China needs to promote the construction of a national carbon market as soon as possible and make preparations for the transition from the pilot areas to the national carbon market. (2) Improve the design of the carbon trading mechanism. Allocate carbon quotas scientifically according to the actual situation of regions and industries, so that carbon prices can truly reflect the cost of emission reduction, increase the pressure of emission reduction on emission control subjects, and avoid excessive carbon quotas resulting in low market activity. In addition, government regulators should flexibly adjust carbon pricing and penalty policies, make full use of the regulating ability of the market, motivate enterprises to participate in carbon emissions trading, and bring into play the potential of low-carbon technology innovation. (3) Expand the scope of trading subjects. At present, only the electric power industry is included in the national carbon trading market. In the future, we can increase the investment in R&D of low-carbon technologies, attract more high-emission enterprises to join the carbon trading market, gradually enrich the trading methods and trading varieties, and give play to the market mechanism of emission reduction, and help China achieve the double carbon target.

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Research on Channel Construction Under Green Marketing

Margaret Kho

Abstract In the twenty-first century, with the rapid development of global science and technology and economic productivity, the harmonious relationship between human and natural environment has undergone subtle changes. However, development is more based on unreasonable resource exploitation and excessive resource use, global warming, deterioration of "waste" pollution, further deterioration of the ecological environment and a series of problems. In this context of social green demand, green marketing, as a kind of social green demand management that can meet the sustainable development of consumers and enterprises and create common interests, has grown rapidly under the green marketing model to protect the ecological environment. "sustainable" has become the consensus of more and more people. Green marketing has become an important marketing means for sustainable economic development that can not be ignored by enterprises. Meanwhile, green channel is a necessary path for enterprises to produce green products and finally reach consumers with green demands. The concept of green marketing channel is a unified whole, which requires the whole marketing channel process to meet the requirements of sustainable development, channel members need to maintain a high degree of unity to establish green concept. It is of great significance to green enterprises at both micro and macro level.

Keywords Green marketing · Channel construction · Demand factors · Green consumption

1 Introduction

By exploring the problems found in the current channel environment of green research, the author compares the channel operation environment of the current green market with the combination of qualitative analysis and quantitative analysis. Macro background, domestic and foreign research present situation analysis, according to

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the paper green channel demand factors research, green marketing channel effect factor analysis, suggestion to solve the green marketing channel trouble discusses the logical thinking, selected by using SPSS software to the following four factors affecting the effects of green marketing channels: the green product price sensitivity, environmental awareness, awareness of green products and credibility of green products were analyzed, and the price sensitivity of green products, environmental awareness, awareness of green products and the effect of green marketing channel brought by the credibility of green products were summarized. Green enterprise wants to gain a foothold in the green market, the enterprise must according to the characteristics of the green marketing in the marketing channel to analyze the development trend of product and business strategies [1], build their professional marketing channels for green products, to strengthen the technical and quality of green product protection, optimize the structure of green marketing channels, ensure that the "five flows" clear, Assemble and form marketing channel strategic alliance with green enterprises as the core, so as to realize the real value and significance of the choice of green marketing channel.

2 Channel Environment Analysis of Green Marketing

2.1 Analysis of Political Environment

In the country and the development of the green macro strategy and concrete policy, according to the National Development and Reform Commission in March 2020 of the rules for establishing the green production and consumption policy system of opinion "pointed out that the systematic aspects in the green production, the existing laws and regulations policy is not perfect, there is a lot of room to improve, such as respect, adapt to and protect the nature [2], Development and protection are unified. As the saying goes, "Gold and silver mountains are clear waters and green mountains", mountains, rivers, forests, fields, lakes and grass are a continuation of the concept of a community of life. In terms of the legal system of green production and consumption, the coordination and integration of environmental pollution prevention and control, and the exploitation and utilization of natural resources have formed a relatively systematic system. In terms of coordination, the legal system of green production and consumption has not yet formed a coordinated and universally recognized incentive and constraint mechanism. On the operational side, the concept and principles of green production and consumption are not only problematic, but vary in form and degree of mismanagement. The 14th Five-year Plan clearly states that the future development of green economy can focus on the following points: responding to the government's call to develop green urbanization, guiding the implementation of green infrastructure, green buildings and green transportation, and promoting the all-round development of all types of green real economy; Establish green GDP accounting and enterprise environmental cost accounting system; To establish and improve the system of property rights and use of natural resources assets; Seize the opportunity of the technological development of emerging industries to promote the technological upgrading and industrial structure adjustment of traditional industries; We will promote green consumption throughout society. The important goal of China's economic and industrial development is to develop green finance, support the technological reform of green industry, and upgrade the green development of key fields and industries. Green industry will become an important goal of economic development [3].

2.2 Economic Environment Analysis

With the rapid development of world economic integration, consumer demand and consumption level is rising. According to the 2019 Statistical Bulletin on National Economic and Social Development released in 2019, the per capita disposable income of Chinese residents was 15,294 yuan in the first half of 2019, up 8.8% year-on-year in nominal terms. Per capita wage income was 8,793 yuan, a nominal increase of 8.7% year on year. As shown in Fig. 1, even in 2020 when the epidemic was rampant, the global economic growth slowed down and the market fluctuated, China's per capita GDP still grew steadily (China's GDP in 2020 was 10,1598.6 billion yuan). Clearly, Chinese consumers have more spending power. Behind the growth of consumption power, consumers are increasingly demanding higher and higher quality of consumer goods. When the consumption capacity is limited, people pay more attention to the practicality of the product, the high cost performance; When the consumption level enters a higher level, consumers will naturally change their consumption concept and pay more attention to healthy, natural and ecological green consumption.

In recent years, The annual contribution of China's final consumption to global consumption growth has ranked first in the world. From 2013 to 2018 [4], China's final consumption contributed an average of 23.4% to the world's consumption growth, with an average annual growth rate of 7.5%, based on constant DOLLAR

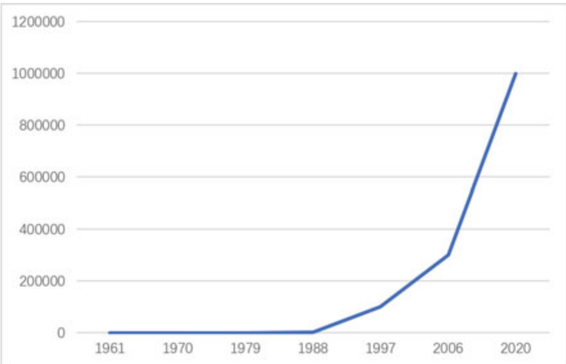

Fig. 1 Growth of China's GDP (100 million yuan) (1952–2020)

Table 1 Engel coefficients of Chinese urban and rural households from 2005 to 2018

Year	Urban resident	Rural resident
2005	36.7	45.5
2006	35.8	43.0
2007	36.3	43.1
2008	37.9	43.7
2009	36.5	41.0
2010	35.7	41.1
2011	36.3	40.4
2012	36.2	39.3
2013	30.1	34.1
2014	30.0	33.5
2015	29.7	33.0
2016	29.3	32.2
2017	28.6	31.2
2018	27.7	30.1

prices, while the world's consumption market grew at an average annual growth rate of 2.4%. The boost to personal economic conditions and willingness to consume is strongly driving consumption growth. With the change of social public consumption concept and consumption mode, consumption structure is also changing further. This is mainly reflected in the steady growth of subsistence consumption and the gradual release of the huge potential for the development of green ecological consumption. At present China's consumption structure is in the new stage, residents' Engel's coefficient declining, food consumption gradually consumption gradually shift from the quantitative just need to type to quality, quality consumption, more people seeking pay attention to the quality of green product, show the pay for the interest, the pursuit of green consumption trends and characteristics of high quality life (Table 1).

2.3 Social Environment Analysis

Social environment is a huge system, population, geography, local conditions and practices are subsystems of the system. Due to the historical development of each region, urban construction foundation and development orientation are not the same, the construction of China's social environment presents the characteristics of regional differentiation. Ecological financial research center, Renmin University of China on the basis of human comfort, green transportation, air quality, water management, energy consumption, waste recycling, noise effects, health, environment and citizen education, urban economic development and financial management indicators, divided into 10 aspects, to score 25 subdivision index coefficient, compared with calculate weight summary, The 169 cities monitored by the Ministry of Ecology and Environment are put forward as green indicators, and the "TOP50 China green city index 2020" is sorted according to the size of the index. The TOP50 cities in the green city index are selected as follows and the indicators that can represent the green city index are selected as follows: Per capita GDP, per capita public outside the city government infrastructure investment, park green land area per capita (green area), air quality index, urban sewage emissions per capita, per capita energy consumption, per capita living garbage harmless treatment, environmental noise impact grade and the city government has quantity (per capita) public toilets and so on nine big coefficient. Generally speaking, large cities have the population siphon effect, but the continuous concentration of population in large cities leads to the "urban diseases" such as urban housing, transportation and environment becoming more and more serious when the population size of large cities exceeds a certain level. Therefore, in comparison, the first and second-tier cities with dense population have more significant effects on the construction of green marketing channels.

3 Scale and Questionnaire Design

3.1 Scale Design

(1) Green price sensitivity Based on existing studies and combined with the characteristics of green marketing, this paper refers to Zhang et al. [5]. In the scale of green price sensitivity, three questions are set for green price sensitivity, as follows (Table 2).
(2) Based on existing studies and combined with the characteristics of green marketing, this paper refers to Yi [6]. In the scale of green product awareness, two questions are set for green product awareness, as follows (Table 3).
(3) Green product credibility based on existing studies, this paper refers to Porter [7]. The credibility scale of green products is prepared, and three questions are set for the credibility of green products, as follows (Table 4).
(4) Green consumption Consciousness Based on existing studies and UNEP's definition of green consumer consciousness, this paper sets four questions for green consumption consciousness by referring to the scale of green consumption consciousness compiled by Porter, as follows (Table 5).

Table 2 Green price sensitivity scale

Coding	Variable	Coding	Item content
A	Green price sensitivity	A11	I'm willing to pay more for green products
		A12	I'm willing to pay twice as much for a green product
		A13	The price of green food affects my buying decisions

Table 3 Green product awareness scale

Coding	Variable	Coding	Item content
B	Green product awareness	B21	I have some understanding of the concept of pollution-free agricultural products, green food and organic food
		B22	I know that the use of chemicals, pesticides and fertilizers is an important factor in the pollution of farmland
		B23	I know a lot of green badges
		B24	I understand the basic standards of green products

Table 4 Green product credibility scale

Coding	Variable	Coding	Item content
C	Green product credibility	C31	I think green food is safer to eat than regular food
		C32	I believe in home appliances or electronics on the market that claim to be environmentally friendly
		C33	I'm happy with the green products on the market

Table 5 Scale of green consumption awareness

Coding	Variable	Coding	Item content
D	Green consumption consciousness	D41	I am very concerned about whether the products I buy are environmentally friendly in the manufacturing process
		D42	I think the current environmental pollution problem is very serious
		D43	In the process of consumption, I will consider that my consumption may cause pollution to the environment
		D44	It is very important to me whether the lamp is energy-saving

(5) Effect of green marketing channel Based on existing studies and combined with the characteristics of green marketing, this paper sets three questions for effect of green marketing channel by referring to the scale of effect of green marketing channel prepared by Longjun et al., as follows (Table 6).

Table 6 Effect scale of green marketing channel

Coding	Variable	Coding	Item content
E	Effect of green marketing channel	E51	I prefer to buy green products offline rather than online
		E52	I think the market potential for green products is huge
		E53	I trust green rating agencies more than recommendations from friends and family

3.2 Analysis of Formal Survey Data

3.2.1 Descriptive Statistical Analysis of Formal Survey Questionnaires

This paper sorted out and analyzed the basic information data in the formal survey questionnaire, as shown in Table 7. In the sample data collected from the formal questionnaire, first of all, from the perspective of gender, there are 207 males, accounting for 50.74%, and 201 females, accounting for 49.26%, with only a difference of 6 persons. It can be seen that there is a small gap in the proportion of males and females in the sample, indicating that the sample has good representativeness and universality.

Secondly, in terms of age, there are 33 people under 20 years old, accounting for 8.08%, 185 people between 21 and 30 years old, accounting for 45.34%, and 162 people between 31 and 40 years old, accounting for 39.70%. In general, the age structure is widely distributed. Moreover, in terms of educational background, bachelor/junior college degree accounts for 67.9%, master's degree accounts for 17.89%, and other levels of education are involved and account for a relatively small proportion. Finally, from the perspective of monthly income, the number of people with less than 2,500 yuan and more than 10,000 yuan accounts for a relatively small number, 7.84 and 13.43% respectively. The monthly income of most people is concentrated between 5000–10,000 yuan, and the income of all levels is involved, which objectively and truly reflects our income situation.

3.2.2 Reliability Analysis of Formal Survey Questionnaire

In order to ensure high reliability and validity, we need to check the reliability of the questionnaire before conducting formal empirical analysis. In this paper, SPPS25.0 software is used to test the reliability of the data collected from the formal survey. The Cronbach α coefficient is used to observe the reliability test. Generally speaking, if the Cronbach α coefficient is greater than 0.7, it indicates good reliability and can be used for observation. The reliability test results of the formal questionnaire are shown

Table 7 Descriptive analysis of formal survey samples

The title	Options	The number of	Accounted for (%)	The title	Options	The number of	Accounted for (%)
Gender	Male	207	50.70	Record of formal schooling	Junior high and below	11	2.69
	Female	201	49.26		High school, technical secondary school	51	12.5
Age	Under the age of 20	33	8.08		College	98	24.01
	21–30	185	45.34		Undergraduate course	175	42.89
	31–40	162	39.70		Master degree or above	73	17.89
	41–50	19	4.65	Average monthly disposable income	RMB 2000 or less	32	7.84
	50 years of age or older	9	2.25		2000–4000 yuan	107	26.22
Professional	Students	127	31.11		4000–6000 yuan	156	38.03
	Employees in enterprises and institutions	154	37.74		6000–10,000 yuan	59	14.46
					More than 10,000 yuan	54	13.43
	Soho	77	18.8				
	Other	50	12.2				

Table 8 Reliability test of formal survey measurement scale

The variable name	The title number	Cronbach alpha coefficient
Price sensitivity	3	0.738
Green product awareness	4	0.832
Green product credibility	3	0.785
Environmental awareness	4	0.735
Effect of green marketing channel	3	0.788

in Table 8. From the Cronbach α coefficient values, the Cronbach α coefficients of the five variables are all greater than 0.7, which can be used for observation [8].

3.2.3 Validity Analysis of Formal Survey Questionnaires

On the basis of testing the reliability of the questionnaire, we also need to test the validity of the formal questionnaire to ensure the validity of the questionnaire. In this paper, factor analysis in SPSS software is used to test the validity of the questionnaire, and KMO and Bartlett spherical test is used to determine whether the sample data of factors affecting green consumption channel can be used for exploratory factor analysis. The inspection results are shown in Table 9.

As can be seen from the analysis results in Table 9, the KMO value of each variable is greater than or equal to 0.6, and the Bartlett sphericity test value is significant under the condition of $P < 0.005$, indicating that the measure index of each variable meets the requirements of validity test. According to the principle of eigenvalue greater than 1 and the maximum variance method, all the measurement indicators of price sensitivity [9], green product awareness, green marketing channel effect, environmental awareness and green product credibility are put together to test whether five common factors can be extracted. The specific results are shown in Table 10.

Table 9 KMO values and cumulative explanatory variances of variables in formal investigation

The variable name	Item number	KMO value	Sig value	Cumulative explanatory variance (%)
Price sensitivity	3	0.684	0	65.64
Green product awareness	4	0.664	0	67.96
Green product credibility	3	0.678	0	64.15
Environmental awareness	4	0.757	0	55.86
Effect of green marketing channel	3	0.679	0	64.44

Table 10 Exploratory factor analysis of formal survey

The variable name	Item name	Factor load after rotation	The eigenvalue	The reliability
Price sensitivity	A11	0.828	1.969	0.738
	A12	0.808		
	A13	0.794		
Green product awareness	B21	0.719	2.719	0.832
	B22	0.932		
	B23	0.679		
	B24	0.934		
Green product credibility	C33	0.858	1.876	0.785
	C32	0.772		
	C31	0.738		
Environmental awareness	D41	0.775	2.236	0.735
	D43	0.770		
	D44	0.723		
	D42	0.721		
Effect of green marketing channel	E52	0.799	1.924	0.788
	E51	0.818		
	E53	0.785		

Table 10 results of exploratory factor analysis show that all measurement indexes can extract 5 common factors, and factor load of each measurement index is greater than 0.6, indicating that all variable measure indexes have good validity. Therefore, it indicates that the formal questionnaire meets the requirements of validity and can be further analyzed. On the basis of the existing relevant research, referring to the mature scale, the design of the price sensitivity, green product awareness, green marketing channel effect, environmental awareness, green product credibility of the five main variables of the measurement scale. At the same time, the basic information of respondents and other items were added to form the questionnaire of this paper. In order to ensure the reliability of the questionnaire and the validity of the study, the questionnaire distribution was carried out twice, including pre-survey and formal survey. In the pre-survey, the reliability and validity of the questionnaire were tested [10], indicating that formal investigation could be carried out. After the formal survey, a total of 487 valid questionnaires were received, and then descriptive statistical analysis and reliability and validity test were carried out on the data collected by the formal survey. The results showed that the requirements of the empirical analysis below were met, laying a solid foundation for the subsequent hypothesis testing.

3.3 Correlation Analysis

There are five variables in this study, including independent variable price sensitivity (A), green product awareness (B), environmental awareness (C), green product credibility (D), and dependent variable effect of green marketing channel (E). Before regression analysis, correlation analysis should be carried out on these 5 variables first to observe the magnitude and significance of correlation coefficients among variables. Generally speaking, the closer the absolute value of the correlation coefficient is to 1, the stronger the correlation between variables is, and the coefficient needs to pass the significance test.

Through the study, it is found that the Pearson correlation coefficient among the factors related to the problem on Richter scale is price sensitivity factor, green product awareness factor, environmental awareness factor, green product credibility factor, and the dependent variable green marketing channel effect factor. As shown in Table 11, Pearson's determination of the relationship between each factor and channel marketing effect is positive. This means that as a positive variable, the value of the second factor will be further reduced. In this assessment, the estimated value of Pearson's connection coefficient is low because there is no fixed relationship between these factors. The results show that four factors are positively correlated with the effect of green marketing channel marketing, including green price sensitivity ($R = 0.503$, $P < 0.5$), green product awareness ($R = -0.614$, $P < 0.5$), environmental awareness ($R = 0.511$, $P < 0.5$) and green product credibility ($R = -0.555$, $P < 0.5$). $P < 0.5$) [11].

Table 11 Correlation analysis of all variables

The correlation

		A1	B2	C3	D4	E5
Price sensitivity	Pearson correlation	1	451[a]	420[a]	546[a]	503[a]
	Sig. (double tail)		000	000	000	000
	The case number	408	408	408	408	408
Green product awareness	Pearson correlation	451[a]	1	464[a]	579[a]	614[a]
	Sig. (double tail)	000		000	000	000
	The case number	408	408	408	408	408
Environmental awareness	Pearson correlation	420[a]	464[a]	1	546[a]	511[a]
	Sig. (double tail)	000	000		000	000
	The case number	408	408	408	408	408
Green product credibility	Pearson correlation	546[a]	579[a]	546[a]	1	555[a]
	Sig. (double tail)	000	000	000		000
	The case number	408	408	408	408	408
Effect of green marketing channel	Pearson correlation	503[a]	614[a]	511[a]	555[a]	1
	Sig. (double tail)	000	000	000	000	
	The case number	408	408	408	408	408

[a] At 0.01 level (two-tailed), the correlation was significant

Table 12 Description of the total variables

	Initial eigenvalue			Sum of square loads			The sum of rotations of the square loads		
	The sum of the	Percentage difference	Cumulative percentage	The sum of the	Percentage difference	Cumulative percentage	The sum of the	Percentage difference	Cumulative percentage
1	5.740	38.270	38.270	5.740	38.270	38.270	2.190	14.602	14.602
2	1.184	7.894	46.164	1.184	7.894	46.164	2.109	14.062	28.664
3	1.167	7.780	53.944	1.167	7.780	53.944	1.940	12.934	41.598
4	1.140	7.599	61.543	1.140	7.599	61.543	1.910	12.735	54.333
5	1.112	5.409	66.952	1.112	5.409	66.952	1.893	12.620	66.952

3.4 Factor Analysis and Regression Summary

The first factor is the green price sensitivity factor, and the Total (factor characteristic value) is 5.740, which is significantly greater than 1. The percentage of its explanatory variance is 38.270%, among which the aggregation item can explain the effect factor of price sensitivity on green marketing channel is relatively heavy [12]. The second factor, the factor characteristic value of green product awareness factor, is 51.184, the factor characteristic value is greater than 1, and the percentage of interpretation variance is 7.894%. The aggregation item can explain green consumers' cognition of products. The third factor is the environmental awareness factor, and its characteristic value is 1.167, which is greater than 1. The percentage of variance of its explanation is 7.780%, which can fully explain the environmental awareness of consumers. The fourth factor, the credibility of green products, has a characteristic value of 1.140 and a variance percentage of 5.409%. Related questions can explain the credibility of green products among consumers. The fifth factor is the marketing effect factor of green marketing channel, and its characteristic value is 1.112, whose characteristic value is greater than 1, and its explanatory variance percentage is 5.409%. Related questions can explain the marketing effect of green marketing channel; As can be seen from Table 12, the Cumulative% (Cumulative interpretation variance percentage) of the above five factors is 66.952, which also means that the factor can cover 66.952% information to a certain extent. Therefore, the scale constructed in this study is reasonable and relatively valid (Tables 13 and 14).

Table 13 Rotation component matrix[a]

	1	2	3	4	5
V11	066	731	241	068	311
V12	204	838	102	086	−056
V13	142	691	067	249	213
V21	003	209	217	648	415
V22	210	089	052	807	189
V23	249	167	448	632	−044
V31	670	130	094	138	296
V32	688	144	399	118	054
V33	822	119	−007	183	064
V41	483	261	234	−014	507
V42	104	068	062	171	841
V43	256	229	099	288	587
V51	268	253	691	211	249
V52	190	265	448	363	268
V53	043	063	838	102	027

Extraction method of this table: principal component analysis method
The rotation method of this table: Kaiser normalized maximum variance method

Table 14 Summary of regression results[b]

	Nonstandard coefficient		The standard coefficient	t	Sig.	Column linear statistics	
	B	Std. Error	Beta			The tolerance	VIF
The constant C	0.309	0.023	–	0.317	0.925	–	–
Green price sensitivity factor	0.301	0.051	0.277	2.763	0.001	0.293	3.192
Green product awareness factor	0.364	0.042	0.364	3.845	0.000	0.359	3.638
Environmental awareness factor	0.154	0.036	0.381	2.094	0.001	0.308	3.774
Green product credibility factors	0.223	0.018	0.309	3.811	0.000	0.288	2.036
R	0.790	Std. error of the estimate			0.6851	Dubin–Watson	1.998
R Square	0.615	Adjusted R square			0.663	F-statistic	92.75

[a] Independent variables: green product cognition factor, green price sensitivity factor, environmental awareness factor, customer green product credibility factor
[b] Dependent variable: effect of green marketing channel

Table 15 Hypothesis test results

Assuming that	Assuming that the content	The verification results
H1	Price sensitivity has a significant positive influence on the effect of green marketing channel	Support
H2	Green product credibility has a significant positive impact on the effect of green marketing channel	Support
H3	Environmental awareness has a significant positive influence on the effect of green marketing channel	Support
H4	Green product awareness has a significant positive impact on the effect of green marketing channel	Support

In conclusion, through empirical regression analysis, it can be concluded that there is an obvious correlation between green product cognition factors, green price sensitivity factors, environmental awareness factors, green product credibility factors and the effect of green marketing channel [14]. And the four factors showed a positive correlation with it. In terms of the degree of influence of these factors, the degree of influence of green product awareness is the largest, followed by the degree of influence of green price sensitivity on the effect of green marketing channel [13]. The credibility factor of green product ranks the third, and the environmental awareness factor ranks the fourth, which has the least influence. In addition, through relevant empirical analysis, it can be confirmed that the four research hypotheses proposed above have passed the test, as shown in Table 15.

4 Conclusion

This paper firstly determines the relevant factors influencing the effect of green marketing channel, and puts forward the research hypothesis between these factors and the effect of green marketing channel. Then the variables and data statistics of the empirical study are determined and the empirical model analysis is carried out. Finally, relevant empirical results are discussed. In this chapter, SPSS25.0 software is used to conduct correlation analysis and regression analysis on the data recovered from the formal questionnaire, and KMO and Bartlett sphericity test are used to verify the hypotheses proposed in this paper [14]. First of all, through correlation analysis, it is confirmed that there is a significant correlation between independent variable green product cognition, green price sensitivity, environmental awareness, green product credibility and dependent variable green marketing channel effect. Secondly, through regression analysis, it is confirmed that green product cognition, green price sensitivity, environmental awareness and green product credibility have a significant positive impact on the effect of green marketing channel. Based on the above analysis, it can be seen that in the process of green channel marketing, it is necessary to actively consider relevant influencing factors, such as green product cognition, green price sensitivity, environmental awareness and green product credibility. It is necessary to fully integrate the above related factors into the process of green marketing channel marketing strategy optimization and marketing effect improvement, so as to ensure the development of a more scientific and feasible related management strategy, and promote the improvement of green channel marketing effect [15]. With the increasing environmental crisis of natural environment pollution, adherence to ecological priority green development has become a consensus of global economic integration. Global environmental problems have attracted more and more attention from consumers, and green marketing has become a necessary road for the construction of sustainable development ecological civilization. How to promote the rapid development of green marketing research has become one of the important directions for the country to adjust the economic structure and change the development mode, the world has set off a wave of green consumption. All green companies need to actively analyze economic trends. According to their own actual situation, to adapt to the needs of consumers, optimize the management model, innovative business philosophy, the application of modern science and technology, a variety of channels sales. Let the production, output and demand of products effectively docking, explore, use and share marketing channel resources, to provide consumers with better services, help enterprises develop in an all-round way, improve their sales profits and competitiveness.

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Research on the Impact of Information Industry Agglomeration on Regional Economic Development

Haifeng Zhang and Siwei Tang

Abstract This paper uses panel data of 31 provinces, cities, and autonomous regions from 2007 to 2016 to test the spatial correlation between information industry agglomeration and regional economic development level by plotting the spatial and temporal evolution trend, and employing a spatial econometric model to empirically prove the direct effect and spatial spillover effect of information industry agglomeration on regional economic development, draw conclusions: (1) The degree of concentration of the information industry and the level of regional economic development in each region of China show obvious spatial heterogeneity and unevenness, and there are significant spatial correlations. (2) Information industry agglomeration has a direct and significant driving effect on regional economic development and generates positive spatial spillover effects on other regions through spatial correlation. (3) From the perspective of geographical location differences, the direct effect of information industry agglomeration on regional economic development is significant in the eastern, central, and western regions, while the indirect effect varies from region to region. The above research is important for the region to promote its economic development by relying on information industry clustering and to achieve high-quality national economic development.

Keywords Information industry · Industrial clustering · Space measurement · Regional economic growth

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1 Introduction

The Fifth Plenary Session of the 19th CPC Central Committee clearly proposed to accelerate digital development, promote digital industrialization and industrial digitization, promote the deep integration of the digital economy and the real economy, and create internationally competitive digital industry clusters. The information industry is the basic industry for the development of the digital economy, and as one of the core industries of the digital economy, regions are also focusing their efforts on accelerating the construction of information industry clusters, seizing the first opportunity of the digital economy and forming competitive information industry clusters. Regional economic growth is influenced by a greater number of factors, and from the perspective of an agglomeration economy, industrial clustering is also one of the main drivers of regional economic development.

Research has shown that spatial agglomeration and economic growth arising from regional economic activity are concomitant and inseparable processes, and economists have extensively verified the close correlation between the two. Marshall attributed industrial agglomeration to natural endowments, while Alfred Weber argued that industrial agglomeration is related to both economies of scale and inter-firm collaboration, division of labor, and public access to the infrastructure [1]. Marshall [2], Arrow [3], and Rome [4] argue that vertical agglomeration of firms in an industry, i.e. specialization, will significantly contribute to knowledge and technology spillovers from firms, thus facilitating the upgrading of technological innovation. According to the economics of agglomeration, the specialized agglomeration of enterprises will form a solid labor market and increase the speed of matching labor with the market; create payoffs of scale and reduce the operating costs of enterprises; attract a large number of high-level talents and promote enterprise innovation and knowledge spillover (Jianyong Fan [5]; Sultani [6]). The specialized clustering of enterprises will promote the sharing of innovation resources, guide the rational allocation of factors, and create a good investment and development environment, which in turn will bring into play the spatial spillover effect of knowledge and technology and promote regional economic development (Yonghui Li [7]). In summary, in terms of theoretical research industrial agglomeration exists to promote the development of the regional economy.

In fact, regional economic development has always been a key and hot issue of research for scholars at home and abroad. In addition to theoretical research, empirical research has been carried out mainly in two aspects: first, research and improvement on the measurement methods of industrial agglomeration. The measurement method of industrial agglomeration domestic scholars earlier used statistical indicators such as quotient of location and E–G index [5], but they could not reflect the spatial relationship between industries in each region [5]. The Moran's I, subsequently proposed by Patrick Alfred PierceMoran [8] in 1950, is widely used in China because it can intuitively reflect the correlation between entities and measure the degree of spatial autocorrelation (Yangjun Ren [9]). Secondly, the inquiry on spatial factors affecting regional economic development. Numerous scholars have explored the factors influencing regional economic development in terms of employment density, technical efficiency, unemployment rate, and economic structure (Ciccone [10]; Mitra and Sato [11]). Liu found that regional logistics agglomeration significantly promoted regional economic development [12]; Ren studied that the agglomeration of productive service industries promoted high-quality regional economic development [9]. However, research on information industry agglomeration is less and less systematic, and what kind of spatial relationship exists between information industry agglomeration and regional economic development has become an urgent question to be answered.

Compared with previous literature, the contribution of this paper may be: firstly, it studies the influence of information industry agglomeration on regional economic development from the perspective of the information industry agglomeration, providing a new perspective for regional economic development. Secondly, the Moran index is used to measure the degree of information industry agglomeration, and the spatial and temporal evolution trend of information industry agglomeration and regional economic development is plotted to visually analyze the spatial and temporal relationship existing between the two. Finally, a spatial econometric model is used to empirically explore the direct effects and spatial spillover effects of information industry agglomeration on regional economic development, and geographical location heterogeneity is incorporated into the research framework of information industry agglomeration affecting regional economic development.

2 Research Hypothesis

During this critical period of transition from a traditional economy to a digital economy, we need to understand what relationship exists between information industry clustering and regional economic development. Zhang found that too high a degree of specialization can produce a crowding effect, resulting in convergence, leading to increased competition costs and inhibiting the enthusiasm for enterprise innovation, that is, there is an inverted U-shaped relationship between specialization agglomeration and innovation activities that are first promoted and then inhibited [13]. Deng found that high-tech industry agglomeration in the early stage of factor dispersion agglomeration economic externalities on economic development is not significant, high-tech industry in the later stages of increasing the level of specialization, enterprises have more specialized talent knowledge spillover more easily, economic externalities give full play to achieve scale payoffs in favor of economic development, that is, high-tech industry and economic development is first inhibited and then promoted by a positive U-shaped relationship [14]. Based on the above study, the following hypothesis is proposed:

H1: There is an impact and a U-shaped relationship between information industry agglomeration and regional economic development.

There has been a problem of unbalanced economic development in the eastern, central, and western regions of China, and there is a question as to whether there is a difference in the interaction between information industry agglomeration and regional economic development in the context of different geographical locations. Li found that the specialized agglomeration and diversified agglomeration of productive service industries are not significant for technological innovation in coastal cities, while there is a driving effect of specialized agglomeration of productive service industries and a positive spillover effect of diversified agglomeration on technological innovation in inland cities, and there are geographical location differences in the influence of specialized agglomeration and diversified agglomeration of productive service industries on urban technological innovation [7]. In his study, Ren found that high-end productive service industry agglomeration promotes high-quality economic development in the eastern region, low-end productive service industry agglomeration promotes high-quality economic development in the central and western regions, and there are differences in the geographical location of productive service industry agglomeration on high-quality economic development [9]. Based on the above study, the following hypotheses are proposed.

H2: There are differences in the role of information industry agglomeration in influencing regional economic development in the eastern, central, and western regions.

3 Models, Variables and Methods

3.1 Model Setting

The purpose of this paper is to examine the impact of information industry agglomeration on regional economic development, drawing on a study by Su [6], which set the basic econometric model as:

$$y_{kt} = \alpha_0 + \alpha_1 agg_{kt} + \beta \vec{X} + u_t + \varepsilon_{kt} \tag{1}$$

where the subscripts k and t denote region and time, respectively; y is the explanatory variable of this paper, denoting regional economic growth; agg is the core explanatory variable of this paper, denoting information industry agglomeration; $\vec{X}$ are other control variables; u_t are time fixed effects; ε are random disturbance terms.

3.2 Variable Selection and Description

(1) Explanatory variable: regional economic development (Y). The existence of regional economic development itself is not directly observable and measurable,

so GDP per capita is used as a proxy variable to represent regional economic development.

(2) Core explanatory variables: Information Industry agglomeration (agg). This paper draws on Yuan's study to analyze the degree of information industry agglomeration without considering the scale of enterprises, and selects the number of enterprises in the information industry as a proxy variable, concerning existing literature practices for logarithmic treatment [15].

(3) Control variables: Based on a further review of the relevant literature, the following control variables were selected for this study:

   (a) Human resources (Emp): Economic theory states that human resources are a direct determinant of economic development, drawing on Ren [9], using the number of people employed in each region [9].
   (b) Industrial structure (Ic): In Lewis' (1954) dual structure economic theory, it is stated that when the labor force shifts from the traditional agricultural sector to the modern sector with higher productivity, i.e. the transformation of the industrial structure to upgrade the tertiary sector will also drive economic growth, drawing on the approach of Jia using the logarithm of the ratio of tertiary output to secondary output [16].
   (c) Financial structure (Fs): What dominates the financial system in China is indirect financing dominated by bank loans, drawing on the approach of Feng using the ratio of provincial deposit and loan balances to GDP [17].
   (d) Level of technological innovation (Pat): From the perspective of innovation output, the regional patent situation can truly reflect the level of regional technological innovation, drawing on the approach of Li [7] to use the logarithm of the number of patents filed by the region in the current year [7].
   (e) Knowledge spillover (Poe): To reflect inter-regional interactions, the logarithmic value of total passenger traffic is used, drawing on Ji [18].
   (f) Education level (Edu): Drawing on Fan's study, a formula is used: where yi is the proportion of the population corresponding to a given level of education and pi is the number of years of education corresponding to a given level of education [19].
   (g) Marketization degree (Mi): In his study, Wang points out that market-oriented reforms promote accelerated economic growth [20]. The marketization degree is adopted from the Marketization Index Report of China by Provinces compiled by Wang [21].

3.3 Data Sources and Descriptive Statistics of Variables

This paper selects the period 2007–2016 as the observation period, and the sample is 31 provinces, cities, and autonomous regions across China. The number of information industry lawmakers is from the China Information Industry Yearbook, and

Table 1 Variable definitions and descriptive statistics

Variables	Definition	N	Mean	Sd	Min	Max
Regional economic development (Y)	GDP per capita (million yuan)	310	4.007	2.261	0.692	11.82
Information Industry agglomeration (agg)	Logarithmic value of the number of enterprises in the information industry (pcs)	310	8.355	1.263	3.714	11.03
Human resources (Emp)	Employed persons (billion)	310	0.254	0.175	0.0154	0.680
Industrial structure (Ic)	Tertiary industry/secondary industry	310	−0.0946	0.383	−0.695	1.424
Financial structure (Fs)	Provincial deposit and loan balances/GDP	310	2.917	1.293	0.558	8.131
Level of technological innovation (Pat)	Number of invention patent applications (pieces) log value	310	8.326	1.895	0	11.89
Knowledge spillover (Poe)	Total number of passengers (million) log value	310	10.90	1.094	6.308	13.26
Education level (Edu)	Years of schooling per capita (years)	310	8.674	1.175	4.222	12.30
Marketization degree (Mi)	Marketability index	310	6.126	2.069	−0.230	11.71

the degree of commercialization is from the China Sub-Provincial Marketization Index Report. The rest of the variables were obtained from the China Statistical Yearbook as well as various local statistical yearbooks. To eliminate the problems of volatility and potential endogenous in the data of information industry agglomeration, technological innovation, and knowledge spillover indicators, the above three indicators are logarithmically processed in this paper. The specific definitions and data characteristics of the main variables are shown in Table 1.

3.4 Spatial Autocorrelation Test Model

In this paper, the global Moran's I measure of spatial autocorrelation is used to explore the degree of similarity possessed by the spatially adjacent regional units of the information industry, and the spatial weight matrix is adopted as the geographical proximity matrix, and the test results are shown in Table 2.

As can be seen from Table 2, Global Moran's I is all greater than 0, increasing from 0.095 in 2007 in constant change to 0.372 in 2016, while the p-value in the significance test decreases from 0.141 to 0.003, i.e. it passes the 1% significance test. This

Table 2 Number of companies in the information industry global Moran's I index 2007–2016

Variables	Year	Moran's I value	Z value	P value
Information Industry Agglomeration	2007	0.095	1.108	0.141
	2008	0.189	1.803	0.05
	2009	0.144	1.4737	0.075
	2010	0.19	1.8236	0.049
	2011	0.217	2.0386	0.032
	2012	0.227	2.1310	0.024
	2013	0.12	1.5322	0.081
	2014	0.193	2.0173	0.04
	2015	0.269	2.6082	0.012
	2016	0.372	3.5349	0.003

indicates that China's information industry does not present a completely random state and that information industry activities are significantly influenced by neighboring regions. It provides logical support in the statistical sense for the construction of a spatial panel model to study the spatial relationship between information industry agglomeration and regional economic development.

4 Time Evolutionary Characterisation

4.1 The Spatial and Temporal Evolution of Information Industry Clusters

From Fig. 1, it can be seen that there are obvious characteristics of agglomeration in the development of the information industry, and the national information industry showed a trend of year-on-year growth from 2007 to 2016, with significant spatial heterogeneity and unevenness. The number of enterprises in the information industry is highly distributed in areas with a trend of increasing from west to east. As time goes by, the coastal areas have further increased their advantages and the level of the information industry has also shown an upward trend. From the above differences in spatial distribution characteristics, it can be seen that the development of the information industry in inland areas is slower than in coastal cities.

From the evolution trend of the LISA agglomeration map of the information industry in Fig. 2, we can see that in terms of spatial structure, the types of agglomeration presented by the eastern region and the central and western regions are completely different, and the development is more uneven over time. 2007–2016 the eastern region's agglomeration type for high–high agglomeration is constantly changing, indicating that there is a positive promotion in the neighboring regions in the process of self-reinforcement and upgrading of the information industry. From

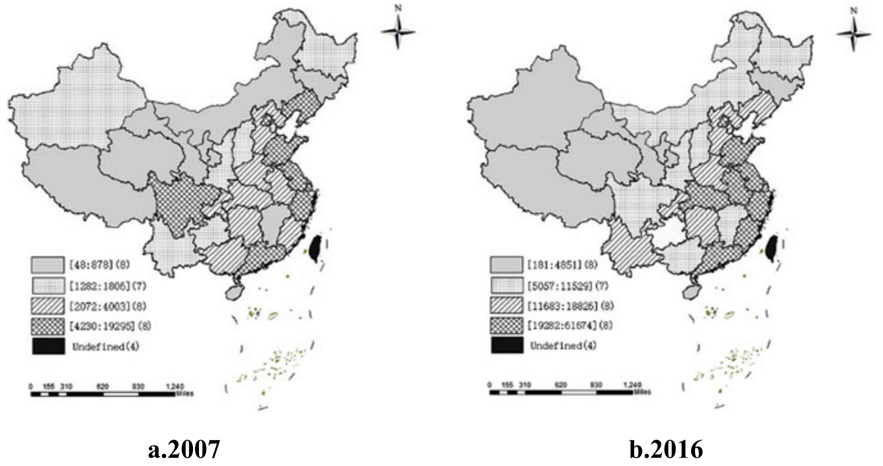


Fig. 1 Quartile map of the number of enterprises in the information industry

2007 to 2016, the development of the information industry in the central and western regions was significantly lower than that in the eastern regions, and the regions with low–low agglomeration in 2007 were Xinjiang, Inner Mongolia, and Ningxia, which increased to Xinjiang, Inner Mongolia, Ningxia, Gansu, Qinghai, Sichuan and Yunnan in 2016, indicating that the spatial dependence of each region with low–low agglomeration gradually increased.

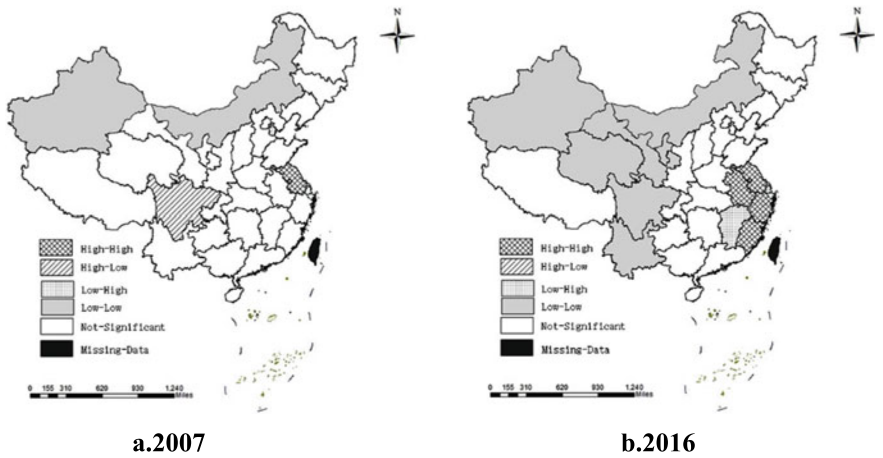


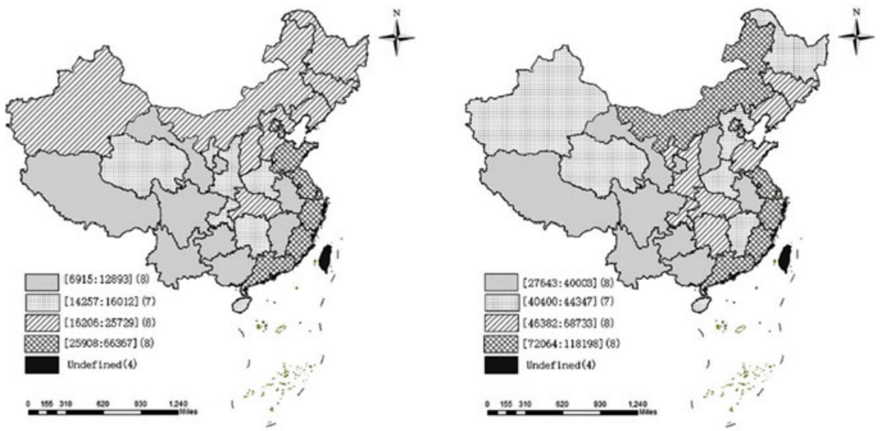
Fig. 2 LISA agglomeration map for the information industry

4.2 Spatial Evolution of the Regional Economy Over Time

Looking at the spatial and temporal evolution of China's regional economic development, as shown in Fig. 3, there are also significant spatial distribution differences and spatial unevenness in the economic development of the regions. In terms of spatial structure, the level of regional economic development in the eastern region is significantly higher than that in the central and western regions, and the difference between the development of the western region and the eastern region becomes greater as time goes by. The figure shows that there is a correlation between the spatial distribution of regional economic levels and the distribution of the information industry.

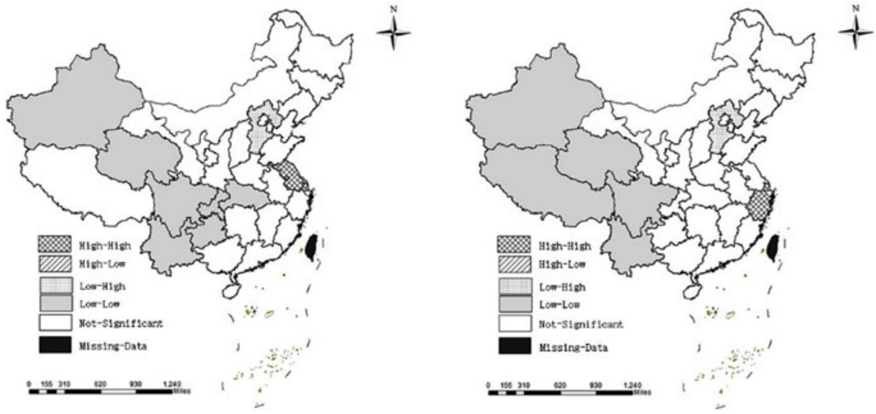
It can be seen from Fig. 4 that the regional economic development among the regions is also influenced by the neighboring regions and combined with Fig. 3, it can be concluded that, in terms of spatial structure, the regional economic level of the eastern region is significantly higher than that of the central and western regions, and, over time, presents the spatial characteristics of high agglomeration; the regional economic level of the western region presents the spatial characteristics of low agglomeration and radiation expansion over time. Although there are not many high agglomeration areas between the development of economic levels in the eastern region, it still shows that there is a positive influence of regional economic development levels on adjacent regions.

To sum up, the spatial distribution of information industry agglomeration and regional level development is spatially correlated and varies from one geographical location to another, and the spatial distribution of regional economic development shows obvious adsorption characteristics.



a.2017 **a.2016**

Fig. 3 Regional economic level quartile chart



a.2007 **b.2016**

Fig. 4 LISA agglomeration map of regional economic levels

5 Empirical Results and Analysis

5.1 Space Panel Selection and Settings

The dual fixed effects spatial Durbin model was selected as the optimal model through the Hausman test, LR test, and the construction of a spatial Durbin model for regression, and the output is shown in Table 3.

The regression results from Table 3 show that the coefficient of the quadratic term of information industry agglomeration is significantly positive, indicating a positive U-shaped relationship between industrial agglomeration and regional economic development, which also verifies the validity of the hypothesis three. In terms of the direct effect, for every 1% increase in information industry agglomeration, the regional economy improves by 0.029%. In terms of the indirect effect, the spatial spillover coefficient is significantly positive and the coefficient value is also greater than that corresponding to the direct effect. This indicates that there is a positive spatial correlation between economic activities in neighboring regions, i.e. regional economic growth not only depends on local information industry agglomeration, but also its neighboring regions' information industry agglomeration will form a positive spatial spillover effect on regional economic growth in the region through spatial correlation, and the spatial spillover effect is also greater than the direct effect, which indicates that the formation of a good domestic industrial agglomeration environment to promote information industry agglomeration enables the region to The formation of a labor resource market, enabling enterprises to obtain scale payoffs to reduce costs and attract high-level talents are the keys to promoting regional economic development.

Table 3 Decomposition of the spatial effect of information industry agglomeration on the total factor of regional economy

Variables	Direct	Indirect	Total
agg2	0.029*** (0.00)	0.070*** (0.00)	0.099*** (0.00)
Emp	−0.431 (0.74)	1.165 (0.78)	0.734 (0.87)
Ic	−0.237 (0.30)	1.506** (0.04)	1.269 (0.13)
Fs2	0.002 (0.79)	0.106*** (0.00)	0.108*** (0.00)
Pat	−0.126 (0.15)	−0.021 (0.91)	−0.147 (0.45)
Poe	0.007 (0.93)	0.593** (0.03)	0.600* (0.05)
Edu	0.257* (0.06)	−0.123 (0.80)	0.134 (0.81)
Mi2	0.009*** (0.01)	0.004 (0.58)	0.013 (0.11)
Observations	310	310	310
R-squared	0.509	0.509	0.509
Number of code	31	31	31

Note: ***, **, * denote significant at 1%, 5%, 10% statistical levels, respectively; values in parentheses are t-values

The estimation results of the control variables are generally consistent with the findings of previous studies. The regression results of human resources (Emp) are not significant, indicating that with the transformation of China's economy and the change in labor supply and demand, regional economic growth no longer relies on the increase in the labor force, which is also consistent with the findings of Zhang's study [22]. The "human capital dividend" has replaced the "population dividend" as the new driver of economic growth. Industrial structure (Ic) does not promote regional economic growth but has a positive spillover effect on neighboring regions. The reason for this is that there is a phenomenon of "premature de-industrialization" in the process of industrial structure transformation in China (Qunhui Huang [23]; Houkai Wei [24]). The rash "de-industrialization" of the manufacturing sector before the efficiency of innovation has been fully exploited, and the reduction of the share of manufacturing in the economy will lead to the "hollowing out" of the economy. The result is an industrial structure that is not supportive of the regional economy and is oriented towards the tertiary sector. Financial structure (Fs) does not have a significant direct effect on regional economic development, but there is a positive spillover effect due to the uneven development of the financial sector, which is mainly indirect financing, in each region, and the promotion of neighboring regions by the radiation of the better developed financial sector. The direct and indirect effects of technological innovation (Pat) on regional economic development are insignificant but do not negate the role of technological innovation in driving regional economic growth. The application of intellectual property rights (IPR), which is the source of the driving force of innovation, is currently at a bottleneck, and the application of IPR is currently facing a lack of conversion efficiency and use capacity, which also indicates that the promotion of regional economic growth requires promoting the actual conversion rate and use capacity of IPR, and breaking through the bottleneck of IPR application. The direct effect of knowledge spillover (Poe) is not significant but there is a positive spatial spillover effect. Technology spillovers have a catalytic effect on the economic development of neighboring regions. Education level (Edu) has a catalytic effect on the regional economy. At present, the country needs high-level, high-quality knowledge, and technical talents and the increase in the labor force does not have a significant effect on economic development, so there is a need to improve the education environment and vigorously promote the development of education level. The degree of marketization (Mi) has a significant impact on regional economic development, and a good market environment and fair market competition in the region have a significant role in promoting regional economic development.

5.2 Tests Based on Geographical Location Differences

The differences between regions are reflected in two aspects: the level of economic development and the degree of concentration of the information industry. From the perspective of economic development, the eastern coastal region has many ports for foreign trade and has certain advantages in creating conditions for the concentration of the information industry and promoting regional economic development. In terms of information industry agglomeration, compared with the central and western regions, the eastern region is more mature in terms of education, marketization, and talent and technology reserves, which is more conducive to promoting information industry agglomeration. The full sample was divided into eastern, central, and western regions based on geographical location differences, and regressed using a spatial econometric model, and the results are shown in Table 4.

From the spatial effects based on geographical location differences in Table 4. Whether in the eastern, central, or western regions, the information industry agglomeration has a significant direct effect on regional economic development, and the indirect effect differs from region to region, which also verifies the validity of hypothesis 2. The reason for this is that the eastern region has a higher degree of information industry agglomeration based on policy support and abundant resources, which attracts high-level technical talents from neighboring regions and forms a negative spillover effect; the central region does not have a spatial spillover effect on neighboring regions; the western region has a significant positive spillover effect on the economic development of other regions through spatial correlation. The reason for this is that the regional economic development level and resources are different from those of the central and eastern regions, resulting in a positive spillover effect due to the loss of resources. In general, the formation of a good agglomeration environment

Table 4 Decomposition of the spatial effects of information industry agglomeration on geographical location differences in regional economic development

	Direct			Indirect		
Variables	Eastern	Central	Western	Eastern	Central	Western
agg2	0.039*** (0.00)	0.026*** (0.00)	0.037*** (0.00)	−0.049*** (0.00)	−0.001 (0.91)	0.055** (0.02)
Emp	−0.043 (0.98)	−2.009 (0.20)	4.358** (0.05)	−13.729*** (0.00)	−5.179* (0.06)	14.863*** (0.00)
Ic	1.157* (0.10)	−1.400*** (0.00)	−0.386 (0.20)	−0.536 (0.65)	−0.002 (0.99)	1.574** (0.01)
Fs2	0.003 (0.81)	−0.159*** (0.00)	−0.028** (0.03)	−0.026* (0.06)	0.003 (0.95)	0.037 (0.12)
Pat	0.119 (0.63)	−0.299*** (0.00)	0.006 (0.94)	−0.211 (0.37)	−0.046 (0.67)	0.193 (0.20)
Poe	0.483*** (0.00)	0.068 (0.62)	−0.133 (0.22)	−0.185 (0.30)	−0.525*** (0.00)	0.435** (0.03)
Edu	1.012*** (0.00)	0.028 (0.83)	−0.041 (0.72)	−1.424*** (0.01)	−0.559*** (0.00)	0.013 (0.97)
Mi2	0.006 (0.19)	−0.028*** (0.00)	0.012* (0.06)	−0.003 (0.64)	0.035*** (0.00)	0.048** (0.02)
R-squared	0.115	0.023	0.003	0.115	0.023	0.003
Number of code	10	9	12	10	9	12

Note: ***, **, * denote significant at 1%, 5%, 10% statistical levels, respectively; values in parentheses are t-values

in the region promotes the agglomeration of the information industry, so that the knowledge, technology, information, and talents in the industry can converge and form a scale effect, which is the key to promoting regional economic development. For the control variables, their significance on regional economic development varies due to the different levels of economic development in each region.

5.3 Robustness Tests

To ensure the reliability of the regression results, this paper conducts robustness tests on the relationship between information industry agglomeration and regional economic development in the following aspects.

(1) Ensuring causality. Referring to the estimation results in the previous paper, considering the problem of possible lags between the explanatory and explained variables, and drawing on Li's approach this paper incorporates the time lag term of information industry agglomeration into the model for regression [7]. The results are shown in Table 5. The core variables in the spatial lagged models for

fixed and random effects are still significant and the conclusions of this paper still hold.

(2) Dealing with endogenous. This paper uses a core variable and seven control variables in the benchmark econometric model. Due to various reasons such as potential inverse relationship and measurement bias, some of the explanatory variables used in this paper inevitably have endogeneity, which leads to biased results. To address the issue of possible endogeneity in the regression results of the core variables, the information industry agglomeration was estimated in a spatial Durbin panel model alone by removing all control variables, drawing on the approach of Cao Xiang and Li [25]. From the empirical results shown in Table 5 the core explanatory variables remain significant and the model fit is high, and the conclusions of this paper still hold.

(3) Adjusting the study sample. To control the impact of the explanatory variable information industry agglomeration outliers on the regression results, the sample with the largest and smallest 1% of information industry agglomeration was shrunk by drawing on the practice of Guo [26]. The results are shown in Table 5. The information industry agglomeration is still significant for regional economic development, and the results of the control variables do not differ significantly, which shows that the key results of this paper still hold after adjusting the sample.

From the above results, it can be found that the regression results of the robustness test remain largely consistent with the regression results of this paper, and thus the conclusions of this paper are robust.

6 Conclusions and Policy Recommendations

This paper uses spatial measurement to explore the impact of information industry agglomeration on regional economic development in a more systematic manner. The research results show that: firstly, the degree of information industry agglomeration and the level of regional economic development of each region in China reflect obvious spatial heterogeneity and unevenness, and there are significant spatial correlations. Secondly, information industry agglomeration has a direct and significant role in promoting regional economic growth, and through spatial correlation, it has a positive spatial spillover effect on other regions and improves the level of regional economic development. Thirdly, from the perspective of geographical differences, the direct effect of information industry agglomeration on regional economic development is significant whether in the eastern, central, or western regions, while the indirect effect differs between regions.

Overall, the findings of this paper are of great significance in promoting the development of China's regional economy, facilitating the transformation of China's economy from a traditional economy to a digital economy, and creating an economic and trade powerhouse. To further improve the development of the regional economy

Table 5 Robustness test regression results

	Spatial lag model		Spatial Dubin regression models for core variables			Tailoring		
Variables	Fixed effects	Random effects	Direct	Indirect	Total	Direct	Indirect	Total
agg2	0.036*** (0.00)	0.034*** (0.00)	0.031*** (0.00)	0.048*** (0.00)	0.079*** (0.00)	0.029*** (0.00)	0.070*** (0.00)	0.098*** (0.00)
Observations	279	279	310	310	310	310	310	310
R-squared	0.874	0.855	0.446	0.446	0.446	0.490	0.490	0.490
Number of code	31	31	31	31	31	31	31	31

Note: ***, **, * denote significant at 1%, 5%, 10% statistical levels, respectively; values in parentheses are t-values under the concentration of the information industry, this paper puts forward the following policy recommendations.

Firstly, give full play to the information industry agglomeration dividend to promote regional economic development. Information industry clustering has a positive driving effect on regional economic development. Regional governments should strengthen the planning and management of information industry clusters, clarify the development goals of information industry clusters at various stages, establish benign interaction between various regions of the information industry, give full play to the low-cost advantage and innovation effect generated by information industry clusters and other agglomeration economies, and promote regional economic development.

Secondly, vigorously support the information industry and promote the formation of a competitive information industry cluster. All regional governments should actively promote the integration of information-based enterprises into the information industry agglomeration, actively guide the coordinated development of enterprises up and down the information industry and supporting enterprises; strengthen the education and training of high-level talents required by the information industry, build an effective platform for knowledge exchange and talent collaboration, promote the training and exchange of talents, further create and optimize a fair and competitive market environment, promote the healthy development of the industrial structure and improve the transformation efficiency and use capability of patents, while continuously improving the intellectual property protection system to form good internal conditions for promoting the agglomeration of the information industry.

Thirdly, the eastern, central, and western regions should pay attention to the spatial dependence of the regional economy on the information industry agglomeration characteristics, and choose the way suitable for the agglomeration development of the information industry in the region according to the different characteristics of the industrial structure, marketization degree and resource endowment of each region. While giving full play to regional advantages and promoting information industry agglomeration, it is also necessary to focus on cross-regional cooperation in the information industry in the east, central and west, break down regional barriers, eliminate local protection, promote inter-regional factor flow, knowledge exchange and talent collaboration, and the central and western regions should strengthen interaction with the information industry in the east, actively introduce the advanced experience and actively improve the development level of the information industry in the region, which is conducive to promoting Information industry clustering and synergistic cross-regional economic development efficiently.

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Forecast of Income Gap Between Urban and Rural Residents in Central China

Fan Decheng and Xiong Wei

Abstract Based on the grey neural network model combined with grey prediction and BP neural network optimized by genetic algorithm, the income gap between urban and rural residents in central China and its provinces from 2021 to 2023 was predicted and analyzed. It was found that 2021–2023, the central region has a slight increasing trend, urban and rural residents income gap is mainly due to the two Henan, Anhui provincial this three years of income gap in urban and rural residents increased, Henan may be because of inadequate education development in rural areas, probably because the city of Hefei city circle in Anhui high speed development of the regional development; From 2021 to 2023, the income gap between urban and rural residents in Shanxi Province has a significant trend of narrowing, which may be due to the improvement of rural financial development level and the promotion of rural economic development; The income gap between urban and rural residents in Hubei, Hunan and Jiangxi has not changed significantly from 2021 to 2023, which may be due to the coordinated pace of urban and rural development in these three provinces.

Keywords Grey neural network · Income gap · Central region · Predict

1 Introduction

Since the 1980s, China's economy has developed rapidly, and the significant improvement of national living standards is obvious to all. However, the social equity problems brought by the rapid economic development are particularly prominent. The most significant problem is the widening income gap between urban and rural residents. In 1998, the per capita income of urban residents in China was 5425.1 yuan,

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and the per capita income of rural residents was 2162 yuan, with a difference of 3263.1 yuan. By 2020, the per capita income of urban residents in China is 43833.8 yuan, and the per capita income of rural residents is 17131.5 yuan, with a difference of 26,702.3 yuan. The ratio of per capita income of urban and rural residents in China shows a continuous downward trend, but the income gap between the two is still high. This shows that the per capita income of rural residents still lags behind that of urban residents for a long time, and the absolute amount of the gap is still large. In the long run, it will inevitably affect China's economic development and easily intensify social contradictions, which is not conducive to social harmony and national stability. Therefore, it is of great theoretical and practical significance to study and predict the income gap between urban and rural residents in the future for maintaining the harmonious and healthy development of China's economy and society. In addition, the central region is China's population area, economic home and important market, is about 20% of the country's GDP source, in China's regional division of labor plays an important role, so select the region as the research object of this paper.

2 Literature Review

In academia, scholars usually use Gini coefficient, Dalton index and coefficient of variation to measure the income gap, so as to obtain the gap index [1]. However, the most intuitive is the Gini coefficient, which will directly show the income gap of residents. Soltow first gives its decomposition formula, and its specific method is to decompose the data into two parts: inter-group inequality and intra-group inequality [2]. There are also different scholars at home and abroad through the impact on the income gap between urban and rural residents, issued a large number of papers and research, especially in recent years, with the expansion of the urbanization process of economic development, scholars have also issued more discussion on the income gap between urban and rural residents. Chen Binkai et al. found that the main reason for the widening income gap is that education expenditure is more inclined to cities [3]. Some scholars have proposed that the overall planning method should be added to it. For example, the research results of Xu Jing, Li Fang and other scholars show that on the basis of China's fiscal and social security expenditure level, we should focus on narrowing the regional gap and coordinating the expenditure level between urban and rural areas [4]. Some scholars believe that the more effective way is to increase the proportion of financial support for agriculture, such as Luo Lili, Peng Daiyan's research conclusion on narrowing the gap between urban and rural areas [5]. Another part of scholars from different perspectives analyze the income gap between urban and rural residents through regions. Hou Zhenmei is through the research and research in some parts of the western region, it is concluded that the technological innovation has a great effect on narrowing the gap between urban and rural areas in the western region [6]. Zhao Huijuan pointed out that in the Beijing–Tianjin–Hebei region, from the perspective of relative income gap, the income gap of residents has a narrowing trend [7]. From the content point of view, at this stage of China's urban–rural income gap prediction research is rare. However, in recent years, some scholars have used other methods of grey model. In order to explore the intuitive problem of income gap, Tu Xiongling uses ARIMA model, grey model and quadratic polynomial model to predict. By using the quadratic polynomial prediction model with the lowest mean absolute relative error (MAPE), the corresponding countermeasures and suggestions are also given [8]. Some scholars directly use the grey model to predict. For example, Zhang Yi directly uses the GM(1,1) model to predict and analyze the urban–rural income gap in Hebei and gives suggestions [9].

On the basis of previous studies, this paper selects five factors as influencing factors of urban–rural income gap, including economic development level, urbanization level, social security, degree of opening-up and human capital level, and uses relevant data of six neighboring provinces in central China from 1998 to 2020. The combined prediction model of grey prediction model and BP neural network was established to predict the income gap between urban and rural residents in central China and its provinces in 2021–2023 and analyzed. This article main contribution lies in the urban and rural residents income gap of the five factors influencing data generation into the grey prediction model, the predicted results again as the neural network prediction model of input variables, and finally through the genetic algorithm to optimize the BP neural network model to predict the final results, a grey prediction model of the hybrid forecasting model can reduce error rate, make more accurate prediction results; And this paper mainly analyzes the income gap between urban and rural residents in the central region and its provinces, which makes the research more targeted and helps the local government to formulate corresponding policies to improve the income gap.

3 Research Design

3.1 Grey Prediction Model

Grey prediction refers to the quantitative prediction of the time series of the system by using the dynamic GM model, that is, the prediction of the main behavior characteristic quantity of the system or the value of a certain indicator that develops and changes to a specific moment in the future. The grey prediction model selected in this paper is GM(1,1) model. The steps are as follows:

(1) Cumulative production of original data.
(2) The first order linear differential equation is established for the accumulated sequence.
(3) The mean value of accumulated data is generated to construct the constant term vector of original data.
(4) The least square method is used to solve the grey parameters.
(5) The grey parameter is substituted into the differential equation to solve it.

(6) The grey model is tested by reduction.

3.2 BP Neural Network Model Optimized Based on Genetic Algorithm

When the BP neural network can meet the requirements of network accuracy, the single hidden layer runs faster. Therefore, the three-layer network structure is taken as the basic structure of the prediction model, as shown in Fig. 1. Input layer, hidden layer and output layer constitute the basic structure of BP neural network, where $X_1, X_2 \ldots, X_m$ is the input value, $O_1, O_2 \ldots, O_n$ is the predicted value, is the weight between the input layer and the hidden layer, and is the weight between the hidden layer and the output layer. When the accuracy requirement of BP neural network is less than the error between its output result and its expected value, the iteration continues and enters the stage of back propagation, terminating when the condition is satisfied.

In order to improve the optimization ability of the network and reduce the possibility that BP neural network is prone to fall into local optimal, GA optimization of BP neural network (GA-BP network) is selected, and the steps of GA-BP network model are as follows [10]:

(1) Single BP model establishment.
(2) Individual coding and population initialization. In this paper, individuals are encoded by real numbers, and individuals are composed of weight thresholds of each layer. The coding length is calculated as follows: $S = M * N + N + N * L + L$, where M, N and L are the number of neurons in input layer, hidden layer and output layer respectively.

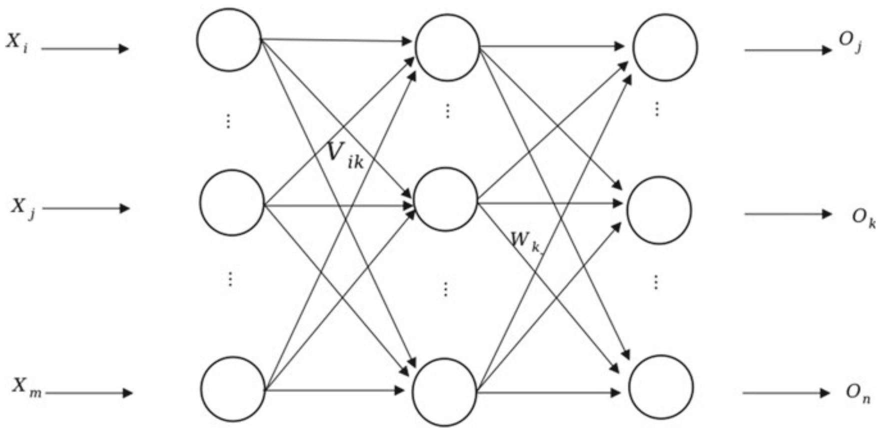

Fig. 1 BP neural network structure

(3) Calculate the fitness function. Fitness function is mainly used to evaluate the quality of the weight threshold, which reflects the gap between the actual network output and the theoretical output. The smaller the gap, the higher the individual fitness, and the individuals with higher fitness are more likely to be inherited to the next generation.
(4) Select operation, select roulette selection method, operation method is: $p_k = f(x_k)/F = f(x_k)/\sum_{k=1}^{n} f(x_k)$, k = 1, 2, …, n, Among them p_k is the probability of being selected, $f(x_k)$ is the fitness value of any individual.
(5) Interleaved operations. Using arithmetic crossover, two new individuals are generated by linear combination of two individuals as follows:

$$X_A^{t+1} = \alpha X_B^t + (1-\alpha) X_A^t$$

$$X_B^{t+1} = \alpha X_A^t + (1-\alpha) X_B^t$$

Among them, α is a parameter;
(6) Mutation operation.
(7) Optimization result output. After many training, when the termination condition is reached, the optimal solution or approximate solution is output, otherwise the step is returned (2).
(8) Optimization of BP model.

3.3 Steps of Grey Neural Network Model

(1) Grey prediction model is used to predict the input variables of neural network.
(2) Combining the known input and output data, the neural network is trained.
(3) The predicted input variable data is substituted into the trained neural network to predict the output variable.

4 Index Establishment

4.1 Index Selection

Index system for measuring income gap between urban and rural residents: The main influencing factor of income gap between urban and rural residents is the difference of real family income between urban and rural residents in essence. This paper adopts the ratio of per capita disposable income of urban residents and per capita net income of rural residents to measure. The income gap between urban and rural residents is mainly affected by national policies, economic development, industrial structure adjustment and other factors. Based on previous research results, this paper

Table 1 Index system of influencing factors of urban–rural income gap

Influence factor	Explanation of main indicators
Economic development level	Per capita GDP
Urbanization level	Proportion of non-agricultural household accounts in the total population (%)
Social security	Local government expenditure as a percentage of GDP
Degree of openness	Ratio of foreign direct investment to GDP
Human capital stock level	Average schooling year

selects the following five influencing factors for the income gap between urban and rural residents in China [11–13]. The index system is shown in Table 1.

(1) Level of economic development. The main indicator is GDP per capita. Although economic development has led to a significant increase in the income of urban and rural residents, the growth rate between the two is inconsistent, which is the direct cause of the widening income gap between urban and rural areas. Most studies show that in the early stage of economic development, the income gap between urban and rural areas will generally show a trend of gradual expansion. With the gradual balance of economic development, the income gap between urban and rural residents will tend to be stable and gradually narrow.
(2) Level of urbanization. The main indicator is the proportion of non-agricultural households in the total population. Continuous urbanization has provided a large number of employment opportunities for urban residents, and they have taken the lead in enjoying the advantages brought by urbanization, which has increased residents' property income.
(3) The social security. Measure local government expenditure as a percentage of GDP. The social security level of urban and rural residents is obviously different. For urban residents, the security level of urban residents is obviously better than that of agricultural residents. This is also a factor in the income gap between urban and rural residents.
(4) Degree of openness. Measured by the proportion of foreign direct investment in GDP. Foreign direct investment (FDI) is related to the economic development of a country or region, while FDI inflow will increase job opportunities for employees in relevant industries and provide wage income level. However, this effect will gradually fade in the later stage, and residents in eastern coastal cities with a higher level of urbanization will benefit the first.
(5) Level of human capital. Measured by the average number of years of schooling. Refer to the calculation method of Xiao et al. [14]: Formula of average years of education = proportion of primary school education * 6 + proportion of junior high school education * 9 + Proportion of senior high school education * 12 + proportion of junior college education and above * 16 [14]. Generally speaking, the education level of urban residents is higher than that of rural residents, because urban teaching resources are sufficient and the education level is relatively high, which leads to the gap in human capital level.

4.2 Data Sources

This paper selects sample data from central China and its provinces from 1998 to 2020. According to the division of China's economic regions, the central region is connected with the coast in the east and the inland in the west. According to the order from north to south and from west to east, it includes six neighboring provinces, Shanxi, Henan, Anhui, Hubei, Jiangxi and Hunan. The sample data came from China Statistical Yearbook from 1998 to 2020, the statistical yearbook of each province and the National Bureau of Statistics, and a small amount of missing data were supplemented appropriately with EPS database. Considering the price fluctuation factors, some variables will be affected by the price index, so this paper also deals with the related variables by sorting out the urban and rural consumer price index (CPI), so as to get more accurate and robust results.

5 Prediction Results and Analysis

5.1 Simulation of Grey Prediction Model

Based on the data of income gap between urban and rural residents in six central provinces from 1998 to 2020, The income gap between urban and rural residents in the central region from 1998 to 2020 was obtained by means of average value (see Fig. 2), and the data of the income gap between urban and rural residents in the central region and Shanxi, Henan, Anhui, Hubei, Hunan and Jiangxi from 2021 to 2023 were obtained by using the grey prediction model for simulation. The results are shown in Table 2.

As can be seen from Fig. 2, the ratio of urban disposable income to rural per capita net income in central China and its provinces fluctuates between 2 and 3, showing an inverted U-shaped change from 1998 to 2020. Rising stage may be due to the region in the phase of the process of urbanization faster, provided a large number of employment opportunities for urban residents, while rural residents will also be increased because of the rate of urbanization and obtain more opportunities for labor, but the urban residents and urban residents itself diathesis and the enterprises pay the difference, can lead to employment opportunity inequality, urban and rural residents, the income gap between urban and rural areas is obviously different, which leads to the widening of the income gap between urban and rural residents. Can also be found in Anhui's urban and rural residents income gap obviously lower than other provinces, the possible reason is that Anhui is an agricultural big province, non-agricultural population, though rising, but the proportion is still low compared to other provinces, the Anhui province industrial base is relatively poor, so the income of urban residents and rural residents income gap is relatively small.

It can be seen from the gray prediction results in Table 2 that the income gap between urban and rural residents in the whole central region will decrease from

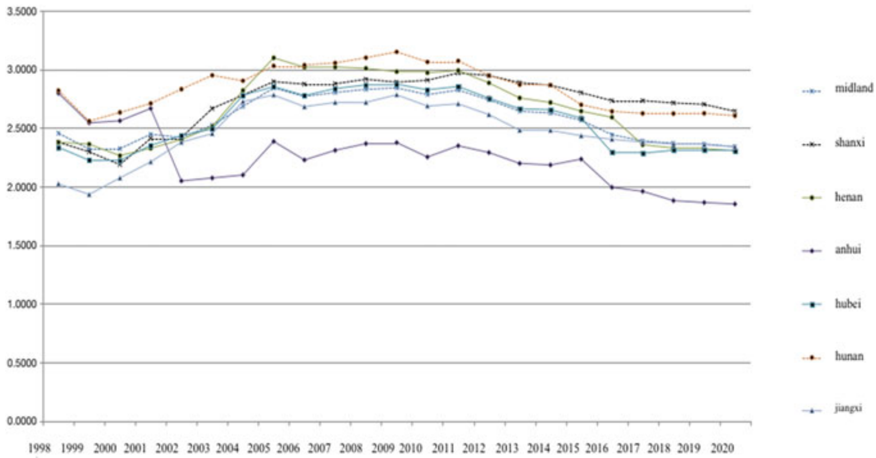

Fig. 2 Income gap between urban and rural residents in central China and provinces from 1998 to 2020

Table 2 The forecast results of the urban and rural income gap by grey forecasting model in 2021–2023

	2021	2022	2023	q	C	p
Midland	2.5482	2.5450	2.5418	0.0052	0.9841	0
Shanxi	2.9094	2.9256	2.9418	0.0046	0.8393	0
Henan	2.6219	2.6180	2.6142	0.0112	0.9753	0
Anhui	1.9429	1.9214	1.9002	0.0046	0.6201	0
Hubei	2.5246	2.5208	2.5169	0.0084	0.9745	0
Hunan	2.7631	2.7561	2.7492	0.0041	0.9698	0
Jiangxi	2.5340	2.5382	2.5425	0.0078	0.9125	0

2021 to 2023, but the improvement is not very large. The income gap between urban and rural residents in Shanxi and Jiangxi will increase from 2021 to 2023, while that in Henan, Anhui, Hubei and Hunan will decrease. According to the results of the relative error q, variance ratio C and small error probability P of the test parameters of the model, except that q values are all less than 0.02, conforming to the condition of high accuracy of the model, C values are all greater than 0.8 and P values are all less than 0.6, which do not meet the condition of high accuracy. Therefore, the accuracy of the grey prediction model is not high. Finally, the grey prediction and neural network optimized by genetic algorithm are combined to predict again to improve the accuracy of prediction.

5.2 *Grey Neural Network Model Simulation*

First, the grey prediction model is used to estimate the value of five factors influencing the income gap between urban and rural residents in 2021–2023 (see Table 3). It can be found that: for per capita GDP, the central region and its provinces have increased, which is in line with the current situation of rapid economic development in China. At the same time, it can be seen that the population growth rate is lower than the economic growth rate. As for the proportion of non-agricultural population, the value of the central region and its provinces also increased, proving that the urbanization level in the central region was constantly improving, which promoted

Table 3 Forecast results of influencing factors of urban–rural income gap in 2021–2023

		2021	2022	2023
Midland	Per capita GDP	70,175	78,720	88,305
	Proportion of non-agricultural household accounts in the total population (%)	52.1682	53.7442	55.3677
	Local government expenditure as a percentage of GDP	0.2554	0.2667	0.2785
	Ratio of foreign direct investment to GDP	0.0213	0.0211	0.0210
	Average schooling year	9.7453	9.8749	10.0062
Shanxi	Per capita GDP	58,986	64,898	71,403
	Proportion of non-agricultural household accounts in the total population (%)	62.1514	64.0569	66.0208
	Local government expenditure as a percentage of GDP	0.2944	0.3075	0.3210
	Ratio of foreign direct investment to GDP	0.0073	0.0070	0.0067
	Average schooling year	10.1069	10.2339	10.3624
Henan	Per capita GDP	67,805	75,818	84,779
	Proportion of non-agricultural household accounts in the total population (%)	56.3055	58.8583	61.5269
	Local government expenditure as a percentage of GDP	0.2149	0.2249	0.2354
	Ratio of foreign direct investment to GDP	0.0179	0.0180	0.0181
	Average schooling year	9.1975	9.2743	9.3518
Anhui	Per capita GDP	63,530	71,711	80,944
	Proportion of non-agricultural household accounts in the total population (%)	29.7635	30.4940	31.2425
	Local government expenditure as a percentage of GDP	0.2758	0.2883	0.3012
	Ratio of foreign direct investment to GDP	0.0141	0.0138	0.0136
	Average schooling year	10.1215	10.3095	10.5009

(continued)

Table 3 (continued)

		2021	2022	2023
Hubei	Per capita GDP	9273	10,511	11,913
	Proportion of non-agricultural household accounts in the total population (%)	63.4886	65.3011	67.1655
	Local government expenditure as a percentage of GDP	0.2150	0.2232	0.2316
	Ratio of foreign direct investment to GDP	0.0124	0.0119	0.0115
	Average schooling year	9.9163	10.0644	10.2147
Henan	Per capita GDP	73,920	83,129	93,485
	Proportion of non-agricultural household accounts in the total population (%)	42.5783	43.1827	43.7957
	Local government expenditure as a percentage of GDP	0.2327	0.2422	0.2521
	Ratio of foreign direct investment to GDP	0.0350	0.0356	0.0363
	Average schooling year	9.7658	9.8950	10.0259
Jiangxi	Per capita GDP	64,843	72,969	82,114
	Proportion of non-agricultural household accounts in the total population (%)	60.2382	62.4976	64.8416
	Local government expenditure as a percentage of GDP	0.3000	0.3150	0.3307
	Ratio of foreign direct investment to GDP	0.0429	0.0429	0.0429
	Average schooling year	9.3908	9.5062	9.6230

the optimization of the industrial structure in the central region to a certain extent. As for the ratio of local fiscal expenditure to GDP and FDI to GDP, there is little change in the values of central region and its provinces, Proved in 2021–2023 in central region by increasing spending pull domestic demand to drive GDP growth effect is not obvious, low degree of opening to the outside world and has no big improvement shows that the central region is not very good use of foreign capital and technology to play a regional market, the comparative advantage of resource and labor force, so as to improve the quality and efficiency of economic growth; For mean by education period, and the value of the provinces in central China are increased, central regions of the human capital level is higher and higher, which are in conformity with the situation of the present employment pressure big, before considering to go abroad for further study because of the international situation is not good to stay in the domestic employment, make more people choose to read a master's, doctorate, thus raising the average education fixed number of year.

Then, taking the five influencing factors from 1998 to 2020 as input and the income gap between urban and rural residents as output, the BP neural network optimized by genetic algorithm was trained and tested. The number of iterations of neural network was set as 10,000, the learning rate was set as 0.025, the minimum target error was set as 0.00001, and the number of nodes of hidden layer was set as

5. Then, the predicted influencing factor values from 2021 to 2023 are put into the trained BP neural network for simulation, and the final results are shown in Table 4. It can be found that the average relative error of the prediction of the central region and its provinces is less than 3%, and the determination coefficient R^2 is greater than 0.8, indicating that the model has very high prediction accuracy, which indirectly indicates the applicability and reliability of the grey BP neural network prediction model selected in this paper. The difference between the real value and the predicted value of training data in the central region is shown in Fig. 3, which further proves that the model fits well.

According to the forecast data, the income gap between urban and rural residents in central China will increase slightly from 2021 to 2023, which is due to the increasing income gap between urban and rural residents in Henan and Anhui provinces in the past three years. For Henan province, the possible reason is inadequate education development in rural areas in Henan, the low degree of resident's emphasis on education, and makes the low level of education, which leads to low income, and income level is low, in turn, reduces the popularity of education, farmers

Table 4 Prediction results of urban and rural residents' income gap in 2021–2023 by grey neural network model

	2021	2022	2023	Decision coefficient R^2	Average relative error
Midland	1.9994	1.9880	2.0044	0.9446	0.0199
Shanxi	2.5380	2.4080	2.2717	0.9448	0.0140
Henan	2.4339	2.7948	3.3301	0.9916	0.0043
Anhui	2.0035	2.1914	2.6738	0.8110	0.0289
Hubei	2.8381	2.8376	2.8369	0.9693	0.0137
Hunan	2.6164	2.6158	2.6150	0.8963	0.0084
Jiangxi	2.3584	2.3573	2.3556	0.9962	0.0046

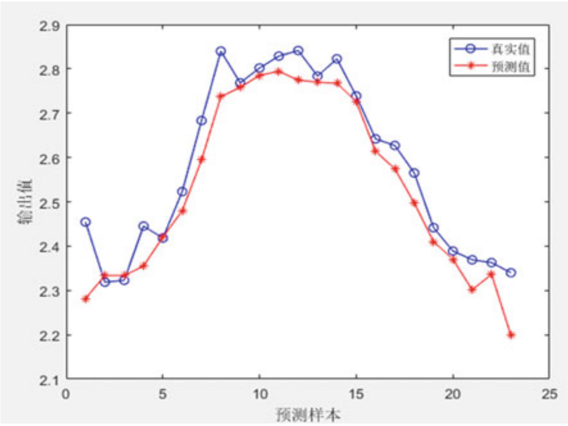

Fig. 3 The difference between the real value and the predicted value of training data in central China

find it hard to get rid of this kind of vicious circle of “low level” [15], and the town’s development speed is faster, This increases the income gap between urban and rural areas. In Anhui province, the possible reason is Anhui province to realize the rise of central China strategy, establish and gradually improve on Hefei, Hefei, Huainan, Luan, Chuzhou, Tongcheng, Maanshan, Wuhu city, 7 linkage development of Hefei city circle, economic resources in Anhui province tilt, made in Hefei city to realize high speed development of city circle, the move to make [16] regional development imbalances, This has increased the income gap between urban and rural residents. From 2021 to 2023, the income gap between urban and rural residents in Shanxi Province will be significantly reduced. The possible reason is that Shanxi Province has increased the support of financial institutions for rural credit construction, and the development level of rural finance has been improved [17], and vigorously developed the rural economy, thus shortening the income gap between urban and rural residents. The urban–rural income gap in Hubei, Hunan and Jiangxi provinces does not change significantly from 2021 to 2023, which may be because the urban–rural development speed in these three provinces is relatively coordinated, or it may be related to the influencing factors of urban–rural income gap selected in this paper.

6 Conclusions and Recommendations

This paper analyzes the income gap between urban and rural residents in central China by combining grey prediction and BP neural network optimized by genetic algorithm, and finds that there are regional differences in urban–rural integration development in central China. The forecast results of Hubei, Hunan and Jiangxi provinces show that the urban–rural income gap will remain stable in 2021–2023, while the gap of Anhui and Henan provinces will gradually expand, which may be due to the lack of rural education development and insufficient policy preference. Only In Shanxi will the urban–rural income gap gradually narrow, thanks to financial institutions that have introduced many financial policies to benefit farmers. According to the research conclusions of this paper, the following policy recommendations are put forward:

(1) Adhere to the basic goal of narrowing the urban–rural income gap. Specific measures to narrow the gap between urban and rural areas are: Firstly, improve the infrastructure construction in rural areas and increase investment to improve the level of industrial development in rural areas. Secondly, strengthen the support for rural enterprises, stimulate the innovation vitality of rural enterprises, and accelerate the migration of rural enterprises to increase the per capita income of rural areas. Lastly, improve the urban and rural social security system, the government to strengthen the investment subsidy policy, improve the educational conditions and medical conditions in rural areas, to help farmers and people in rural areas to improve their living standards.
(2) Deal with the relationship between urbanization and urban–rural income gap, to achieve urban–rural linkage development. First of all, improve the necessary

infrastructure construction, reduce the gap between the surrounding rural cities, so that rural areas are more likely to accept the impact of urban culture. Secondly, strengthen the investment in the implementation of knowledge-based, increase the competitiveness of the rural labor market, so as to broaden rural employment opportunities, improve urban and rural income levels, and form a development pattern of urban and rural linkage. Finally, create a good employment atmosphere, actively develop new industries, and broaden rural employment opportunities.

(3) Coordinate the pace of urbanization and industrial structure upgrading to achieve mutual promotion and mutual assistance. Firstly, strengthen technological innovation, use new technologies to help industrial upgrading and promote industrial restructuring. Secondly, we should promote the allocation of resources, enrich the financial funds of the region, improve the local investment environment, and provide sufficient financial support for enterprises and technological upgrading, so as to promote economic and social development. Finally, we should speed up urban and rural construction and equip infrastructure that meets the needs of market development, thus creating good conditions for the coordinated development of urbanization and enterprise structure adjustment.

(4) We must deepen the reform of the financial support system for agriculture and improve the efficiency of financial support for agriculture. First of all, to strengthen the coordination of fiscal and agricultural policies, the government should fully consider the needs of agricultural development and improve the efficiency of fiscal expenditure on agriculture. Secondly, the government should take favorable policies and measures to do a good job in the construction of new agricultural industrial organizations, introduce new agricultural technologies, and promote technological transformation. Finally, the government should increase investment in agriculture, improve facilities, technology, technical services, finance and other aspects, so as to promote the development of agricultural economy and improve the efficiency of fiscal expenditure on agriculture.

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An Improved Genetic Algorithm Based on Reinforcement Learning for the University Course Timetabling Problem

Xia Pan, Zhiming Duan, and Yuzhen Hu

Abstract To address the impact of increased walking distances for students between lectures, this paper focuses on the university course timetabling problem considering students' walking distance (UCTP-WD) and proposes a reinforcement learning-enabled genetic algorithm with free-conflict iteration (RLGA-FI). The algorithm achieves conflict-free genetic algorithm iterations through the spatiotemporal tables and intelligently adjusts the parameters by reinforcement learning. Its performance was tested and validated by a dataset of undergraduate students at Harbin Engineering University. The results show that RLGA-FI proposed in this paper has superior performance compared to other algorithms in solving the UCTP-WD problem and effectively improves students' walking distance between lectures.

Keywords University course timetabling problem · Reinforcement learning · Genetic algorithm · Combinatorial optimization

1 Introduction

Timetabling problem is one of the main tasks of the university's Academic Affairs Office. With the increase in the number of students and the variety of courses, it has become more complex. This has driven academic researchers to make further explorations. University timetabling problem can be classified into two categories: the university course timetabling problem and the examination timetabling problem [1]. In this paper, we focus our attention on the university course timetabling problem (UCTP).

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University course timetabling problem (UCTP) is a multi-dimensional assignment problem in which students and lecturers are assigned to courses and courses are assigned to classrooms and timeslots [2]. The solution of UCTP in this paper is based on a known student–lecturer assignment plan and subject to various hard and soft constraints. The former are so important that the violation will lead to the infeasibility of the timetable. And the latter represent the demands of lecturers and students and determine the quality of the course timetable. They will be improved only if all the hard constraints are satisfied. In the context of the expansion of university campuses, the distribution of classrooms in multiple teaching buildings and campuses has become the norm. The time cost for students to switch classrooms between lectures is increasing. Kirby-Hawkins [3] also pointed out the impact of distance factors on student attendance. But students' walking distance was rarely considered in previous scholars' mathematical models and only the number of students' classroom transitions is mentioned [1]. In order to further improve the quality of the course timetable and increase student satisfaction, this paper includes the distance students walk between lectures as one of the constraints, which further increases the complexity of the problem.

Genetic Algorithm (GA) has been widely used in solving UCTP problems due to its superior performance and versatility [4–8]. But conflict detection and the choice of key parameters in the original genetic algorithm affect the efficiency of the algorithm. It is necessary to implement conflict-free iterations and parameter control designs for genetic algorithms. In the current research, the way to determine the parameters is usually fixed by a certain rule [9] or an adaptive method that adjusts according to the fitness [10]. Reinforcement learning algorithm uses a scalar reinforcement signal or a reward to interact with a complex environment. It can realize the intelligent adjustment of parameters [11, 12]. But the existing literature rarely uses reinforcement learning to improve the parameters of genetic algorithms. Thus, this paper proposes a new problem of UCTP-WD and designs a Reinforcement Learning-enabled Genetic Algorithm with free-conflict iteration (RLGA-FI). The effectiveness of the algorithm is verified by five examples and a comparison with the algorithm in other literature.

Section 2 introduces the UCTP-WD problem and discusses a mathematical formulation for the problem. The proposed RLGA-FI is described completely in Sect. 3. Experimental verification is carried out in Sect. 4. Finally, the conclusion and outlines of future research are given in Sect. 5.

2 Problem Description

2.1 Objectives and Constraints of the Problem

In the UCTP-WD problem, the allocation of timeslot and classroom resources needs to be completed. Each lecture needs to have a corresponding timeslot and classroom. In this paper, 20 timeslots per week and classrooms of different capacities need to be assigned to different lectures. First, it is necessary to introduce the assumptions adhered to by the UCTP-WD problem studied in this paper

(A1) Lecturers and students have been assigned to the lectures.
(A2) Students in the same class have the same lectures.
(A3) Sufficient timeslot and classroom resources are allocated for lectures.

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In the UCTP-WD problem, the constraints are classified into two types, one of which is called hard constraints. Any timetable must satisfy these constraints. For the UCTP-WD problem, these constraints are:

(H1) A lecturer can only take one lecture at the same time.
(H2) A classroom can only arrange one lecture at the same time.
(H3) A class can only take one lecture at the same time.
(H4) Classroom capacity must be greater than the number of students.

Another type of constraints is known as soft constraints. The satisfaction of these constraints determines the quality of the timetable. For our problem, these constraints are:

(S1) ICD: More important lectures should be assigned to more preferred timeslots for students.
(S2) CUD: The time interval between the two lectures of each lecture should be more reasonable.
(S3) SC: Two sessions of a lecture should be in the same classroom as much as possible.
(S4) WD: The classroom transfer distance of students who attend consecutive lectures should be as small as possible.

2.2 Problem Formulation

In this paper, all notations are defined in Table 1. And the objective function is a weighted sum of four demand satisfaction. The problem is:

$$maxF = \sum_{k=1}^{4} \omega_k f_k \tag{1}$$

Subject to

$$\forall t \in T, \forall m \in M, \sum_{r \in R} \sum_{l \in L} Y_{mtrl} \leq 1 \tag{2}$$

$$\forall t \in T, \forall r \in R, \forall c \in C, \sum_{l \in L} X_{ctrl} \leq 1 \tag{3}$$

Table 1 Notations used in the paper

Notations	Definitions
s	Total number of students attending lectures
b	Number of students changing classrooms between lectures
p_r	The capacity of room r
q_c	The student number of class c
$d_{r_1 r_2}$	The distance between room r_1 and room r_2
α_t	The score of timeslot t
β_l	The score of the lecture l; $l_1, l_2 \in l$: each lecture has two sections a week
γ_o	The score of time interval o
ω_k	The weight of demand k. The weights can be determined by managers
X_{ctrl}	Equals 1 if, at time t, class c is in lecture l in room r, 0 otherwise
Y_{mtrl}	Equals 1 if, at time t, lecturer m is taking lecture l in room r, 0 otherwise

$$\forall c \in C, \forall l \in L, \forall t \in T, \sum_{r \in R} X_{ctrl} \le 1 \tag{4}$$

$$\forall r \in R, \forall t \in T, \sum_{c \in C} \sum_{l \in L} X_{ctrl} * q_c \le p_r \tag{5}$$

Equations (2), (3), (4) and (5) are mathematical expressions of hard constrains (H1), (H2), (H3), and (H4), respectively. A solution is feasible if the above constraints are satisfied. Equations (6), (7), and (8) are mathematical expressions of soft constrains (S1), (S2), and (S3), respectively. Equations (9) and (10) are expressions of constraint (S4). In order to integrate the demand of WD into the objective function of satisfaction, we use the Z function of fuzzy set to convert the distance into a satisfaction value from 0 to 1.

$$f_1 = \sum_{c \in C} \sum_{t \in T} \sum_{l \in L} X_{ctrl} \alpha_t \beta_l q_c / 2s \tag{6}$$

$$f_2 = \sum_{c \in C} \sum_{l \in L} \gamma_{t_2 - t_1} \left| X_{ct_2 r_2 l} t_2 - X_{ct_1 r_1 l} t_1 \right| q_c / s \tag{7}$$

$$f_3 = \left(L - \sum_{l \in L} \sum_{c \in C} \sum_{t \in T} \sum_{r \in R} \left(X_{ctrl_1} - X_{ctrl_2} \right) \right) / L \tag{8}$$

$$z = \sum_{c \in C} \sum_{i \in T/2} X_{c2ir_2 l_2} X_{c(2i-1)r_1 l_1} q_c d_{r_1 r_2} / b \tag{9}$$

$$f_4 = \begin{cases} 1 & z \le a \\ 1 - 2 * ((z-a)/(b-a))^2 & a < z \le (a+b)/2 \\ 2 * ((z-b)/(b-a))^2 & (a+b)/2 < z \le b \\ 0 & b < z \end{cases} \tag{10}$$

3 Solution Approach

3.1 A Genetic Algorithm with Free-Conflict Iteration

Genetic algorithm starts from a population solution consisting of a certain number of individuals and finds the optimal solution by updating and iterating the population through selection, crossover, and mutation operators according to the fitness function. The design of these operators is shown below.

First, the generation of the initial feasible solution is achieved through the spatiotemporal tables to ensure its feasibility and reduce the time in the conflict detection process. As shown in Table 2, m classrooms and n timeslots constitute an m*n spatiotemporal matrix. Each assignment to a lecture will pad the lecture number into the corresponding space. The satisfaction of the hard constraint (H2) is achieved through the uniqueness of the timeslot and classroom correspondence.

Tables 3 and 4 show the attributes of timeslot and classroom. The former contains the unassignable lectures for that timeslot due to the hard constraints (H1) and (H3), which achieve the satisfaction of these two constraints. The latter represents the lectures that satisfy the capacity of that classroom, thus achieving the satisfaction of the hard constraint (H4). Then the generation of the initial feasible solution is realized through the constraints of the above spatiotemporal table and its properties. But the ordinary crossover and mutation operators will be destructive to the feasible solution. So the operator design that implements iterations of the feasible solution is needed. This paper establishes a spatiotemporal table screening mechanism and only performs crossover and mutation operations that do not affect the feasibility of the solution, to guarantee the feasible iteration.

The design of other parts of the genetic algorithm also has an impact on the performance of the algorithm. For the selection operator, the roulette wheel method is combined with elite selection to ensure the iteration towards the optimal solution and the protection of the superior solution. In the process of generating offspring, selecting the optimal parent individuals to generate the offspring population will reduce the diversity of the population and make it easy to fall into a local optimum.

Table 2 Spatiotemporal table

	Classroom 1	Classroom 2	…	Classroom m
Timeslot 1	3	2		
Timeslot 2	15	12		
…				
Timeslot n				

Table 3 Timeslot property table

Timeslot 1	1, 3, 5
…	

Table 4 Classroom property table

Classroom 1	2, 4, 6
…	

Therefore, this paper gives priority to the diversity of the population. And the optimal individuals are selected for duplication based on ensuring the retention of non-duplicated individuals.

3.2 A Reinforcement Learning-Enabled Genetic Algorithm

In order to improve the solution performance of the genetic algorithm, we chose to use a parameter controller based on reinforcement learning, which can select the optimal values of the parameters at different stages of the algorithm's operation. The principle is to learn sufficiently to make decisions based on the feedback of the reward values obtained from the environment. We choose SARSA ($state_t - action_t - reward_{t+1} - state_{t+1} - action_{t+1}$), which is iteratively improving on-policy method where the transitions are considered from one state-action pair to another with a rewarding process [13].

The elements of RL need to be designed to adapt to the problem in order to achieve control of the parameters. We define the fitness in the genetic algorithm as the state and the combination of crossover probability and mutation probability (p_c, p_m) as the action selection. Thus, a Q-table (S, A) consisting of fitness and probability is formed to support the update session of RL. The interval division and scale size of action and state affect the efficiency of reinforcement learning. Therefore, we divide the states and each probability into 10 equal parts, thus forming a 10*100 Q-table with 100 combinations of probabilities. In order to reduce the interval range of states and probabilities, the author chose the minimum and maximum values of fitness during the iterative process of the genetic algorithm as the state interval and the general selection range of crossover and mutation as the action interval.

The reward value function determines the reward from taking an action. The reward value setting here is designed by the fitness of the best individual and the average fitness of the population, as shown in (11) and (12). Their weighted sum is used as the formula for calculating the reward value. If the best individual in generation t is better than that in $(t-1)$ or the average fitness in generation t is better than that in $(t-1)$, then the current action selection is valid and a certain positive reward value will be returned. Conversely, a negative reward value is returned.

$$r_c = \left(\max f\left(x_i^t\right) - \max f\left(x_i^{t-1}\right)\right) / \max f\left(x_i^{t-1}\right) \tag{11}$$

$$r_m = \left(\sum_{i=1}^{N} f\left(x_i^t\right) - \sum_{i=1}^{N} f\left(x_i^{t-1}\right)\right) / \sum_{i=1}^{N} f\left(x_i^{t-1}\right) \tag{12}$$

$$r = w_1 r_c + w_2 r_m \tag{13}$$

Table 5 Pseudocode of RLGA-FI

```
Algorithm 1: RLGA-FI
Input: Pop_init (t = 0)
Output: Pop *_RLGA (t = 500)
Parameters: S, A, p_c, p_m, t=0, α, γ, ε
Q (S, A) ← 0
While Is Not Terminated (t) do
    Pop (t+1) ← Pop (t). selected (elites)
    p_c ← S (t). set Crossover Prob ()
    p_m ← S (t). set Mutation Prob ()
    Pop (t+1) ←Pop (t). RLGA-FI (p_c, p_m)
    S (t+1) ← S (t). transition (A (t))
    A (t+1) ← S (t+1).π () // ε − greedy
    Reward (t) ← Pop (t+1). reward ()
    Q (S (t), A (t)) ←Q (S (t), A (t)) + α [Reward (t) + γQ (S (t + 1), A (t + 1) − Q (S (t), A (t)))]
    Pop (t) ← Pop (t+1)
    S (t) ←S (t+1)
    A (t) ←A (t+1)
    t←t+1
end
Pop*RLGA-FI (t = 500) ←Pop (t+1)
```

Based on the above design of conflict-free iterative and reinforcement learning parameter controller, the RLGA-FI pseudocode is shown in Table 5. In each iteration of the state-action process, the ε-greedy strategy is used to select the action. This strategy selects random actions from the Q-table with probabilities or selects the action with the highest Q-value so that the action selection tends to obtain higher reward values and achieves the tuning of the genetic algorithm parameters. A mature Q-table needs repeated training to accurately guide the selection of parameters for solving the optimal solution. Reinforcement learning also includes the selection of parameters, including training generations, learning rate, and discount factor. In this paper, the parameters with the best results will be selected for practical application based on the observation of the results of different parameters.

4 Experimental Results

This chapter describes the data of Harbin Engineering University used in the design of the example and analyzes the results of the example obtained by the improved genetic algorithm. All of the computational tests presented here are performed on Intel Core i5-9400F CPU@2.90 GHz with 16 GB of RAM.

4.1 Date

The teaching tasks of part undergraduate students at Harbin Engineering University include 110 lectures, 121 classes, 77 lecturers, and 50 classrooms distributed in four teaching buildings. In this paper, we divide them into 5 cases according to the

Table 6 Description of the instances tested

Instance	Number of lectures	Number of classes	Number of classrooms	Number of lecturers
Test 1	25	20	16	23
Test 2	55	43	28	41
Test 3	62	51	34	48
Test 4	91	82	44	63
Test 5	110	121	50	77

faculties, as shown in Table 6. The distance matrix between all classrooms can be calculated from the electronic map. Due to the large amount of data, distance data is not shown here.

4.2 Results

In order to verify the effect of RLGA-FI, the optimal choice of all parameters is obtained experimentally. We analyzed the improvement effect of the algorithm by a small calculation example. And the results are shown in Table 7. Among them, RLGA-FI improves 29.1% on the average optimal solution compared to the original GA and achieves a huge improvement in the running time from 207 to 1.6 s to reach the target fitness. The initial feasible solution and the design of the feasible iterative operator improve the solution results and efficiency significantly.

To further verify the improvement of reinforcement learning and the performance of the algorithm in the large-scale case, the results of GA-FI and RLGA-FI under different scale cases are analyzed. And the results are shown in Table 8. RLGA-FI can achieve a 1.3–1.8% improvement over GA-FI in the average optimal value and a 20% improvement in the running time excluding the results of Test 1. Taking Test 5 as an example, Fig. 1 shows the change in fitness during the iteration. It shows that reinforcement learning accelerates the iteration speed of fitness optimization by intelligent selection of crossover and mutation probability. Especially in the late iteration, due to the mature training process of reinforcement learning, the genetic

Table 7 Results for the several algorithms. 'GA' refers to the original genetic algorithm. 'GA-FI' refers to the genetic algorithm of feasible solution iteration is improved. 'RLGA-FI' refers to the reinforcement learning improved 'GA-FI'

	Ave. number of conflicts	Ave. value	Ave. gap (%)	CPU (s) [0.57]
GA	27.3	0.567	0	207
GA-FI	0	0.729	28.6	3.8
RLGA-FI	0	0.732	29.1	1.6

algorithm still has a strong exploratory nature. Therefore, the intelligent adjustment of crossover and mutation probability of reinforcement learning achieves the improvement of running efficiency in larger-scale cases.

Additionally, a comparison has been made between the computational time required to run the five cases using the RLGA-FI and AGA algorithms [10]. Under the condition of enough iterations, the optimal solution of the algorithm AGA still does not show obvious improvement. Therefore, only the computational time of the two algorithms is compared, as shown in Table 9. The results show that except for the test 1, RLGA-FI has achieved significant improvement compared to AGA.

Table 8 Comparison between GA-FI and RLGA-FI

Instance	GA-FI		RLGA-FI		Ave. value gap (%)	Ave. time gap (%)
	Ave. value	CPU (s)	Ave. value	CPU (s)		
Test 1	0.720	17.2	0.732	16.4	1.6	4.7
Test 2	0.683	78.0	0.692	56.2	1.3	27.9
Test 3	0.668	79.7	0.680	54.6	1.8	31.5
Test 4	0.649	124.2	0.661	87.1	1.8	29.9
Test 5	0.648	161.5	0.657	124.0	1.3	23.2

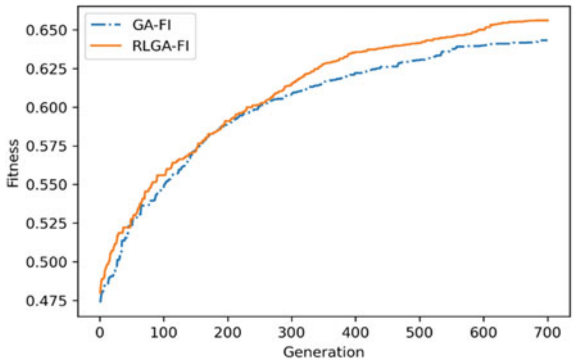

Fig. 1 Comparison of the fitness of GA-FI and RLGA-FI

Table 9 Computational time comparison between AGA and RLGA-FI

Instance	AGA	RLGA-FI	Ave. time gap (%)
Test 1	15.5	16.4	−5.9
Test 2	76.3	56.2	26.3
Test 3	72.1	54.6	24.3
Test 4	113.4	87.1	23.2
Test 5	167.2	124.0	25.8

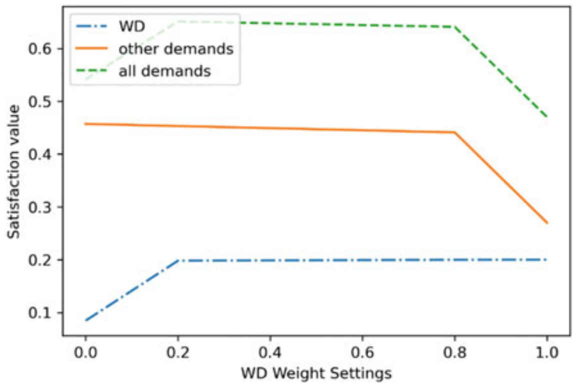

Fig. 2 Comparison of WD, other demands, and all demands satisfaction values under different weight settings of RLGA-FI

Finally, this paper analyzes the improvement effect of the WD demand under different weights. 0, 0.2, 0.8, 1 are chosen as the weight of its objective function respectively. Because the larger the classroom size, the more likely it is to produce long-distance classroom transfer among students. Taking Test 5 as an example, the average value of students' walking distance satisfaction is shown in Fig. 2. Here we still use the above-mentioned demand weighting settings to compare the satisfaction value of different demands. Thus the maximum value of satisfaction of WD demand is 0.2 and the maximum value of satisfaction of other demands is 0.8. When the weight is 0, RLGA-FI can achieve an average satisfaction value of 0.085 on WD's demand. But with increasing weights, an approximate maximum can be reached at a weight of 0.2. And the satisfaction value of all demands will rise significantly. A greater weight setting will result in a decrease in all demands' satisfaction. This shows that the demand of WD has a lot of room for improvement and has the necessity of improvement. Only a small weight is needed to obtain a larger improvement. The weight of 0.2 given to it in this paper is consistent with the demand of maximizing the target value.

5 Conclusion

In this paper, a UCTP-WD problem considering students' walking distance between lectures is proposed for the current realistic demand of university expansion. To solve the problem, an improved genetic algorithm based on reinforcement learning is adopted. The conflict-free iteration of genetic algorithms and intelligent adjustments of parameters are achieved. The results of the experiments show that the proposed method outperforms the original genetic algorithm and the given method AGA. In the future, the design of parameter selection methods for reinforcement learning will be further explored.

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The Research on the Influence of Digital Inclusive Finance on Residents' Consumption Structure

Mingye Ai, Lingjing Peng, and Minghui Ai

Abstract From the perspective of micro-family, this paper studies whether and by what means digital financial inclusion can affect the consumption structure of residents. Based on the 2014–2018 CFPS household data and digital financial inclusion index, this paper uses an individual fixed effect model to discuss whether digital financial inclusion affects the consumption structure of residents, and uses an intermediary effect model to verify the possible impact mechanism. In terms of income, the heterogeneity of its influence is explored by means of subsampled regression. The research shows that: in general, the consumption structure of residents will be optimized and upgraded with the development of digital inclusive finance; digital inclusive finance can affect the consumption structure of residents by increasing residents' income and relaxing liquidity constraints; digital inclusive finance will affect residents' consumption. The influence of structure has heterogeneity such as age, urban and rural areas, and income. Based on the research conclusions, this paper puts forward the following policy suggestions: speed up the construction of digital inclusive financial infrastructure; improve the financial quality of residents; strengthen supervision.

Keywords Digital financial inclusion · Resident consumption structure · Liquidity constraints · Income

1 Introduction

Since 2010, China's economic growth rate has been decreasing year by year. In 2020, under the influence of the Corona Virus Disease-2019 (COVID-19) epidemic, the GDP growth rate has been reduced to 2.3%, reaching the lowest point since the reform

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and opening up. As China's economy enters a new stage of development, investment, consumption and exports are the "troikas" that drive economic growth, and both investment and exports face downside risks. In terms of investment, the growth rate of fixed asset investment in the whole society has been decreasing year by year, from 20.1% in 2011 to 2.66% in 2020. In terms of exports, the huge changes in the world economic situation and the impact of the COVID-19 epidemic have greatly reduced export demand. China's economy is facing many problems. Expanding domestic demand, stimulating consumption, and promoting the upgrading of consumption structure to drive rapid economic development have become one of the paths for future social development.

Since the reform and opening up, China's economy has grown rapidly and the scale of consumption has continued to expand. At the same time, the consumption structure of Chinese residents has also changed, and the trend of transformation and upgrading is obvious. The first is the transformation from the quantity of commodities to the quality of commodities, the second is the transformation from material consumption to spiritual consumption, and the third is the transformation from subsistence consumption to development consumption. The upgrading of residents' consumption structure will affect the economic growth of the whole society through various paths, such as product structure and investment structure.

It is worth noting that although under the influence of the new crown epidemic from 2020 to the present, the often-occurring resident isolation has made the real economy incapable, but it has also made the digital economy have a brighter performance, and various e-commerce platforms are still active and even developing, and after the COVID-19 epidemic eases in 2021, the digital economy is also an important driving force for economic recovery. According to the consumption data of the National Bureau of Statistics and the Digital Financial Inclusion Index of Peking University, as an important part of the digital economy, digital financial inclusion has promoted the development of the real economy, traditional financial markets and China's P2P online lending market [1], and has a positive impact on the development of the digital economy. The optimization and upgrading of the consumption structure has a long-term impact. According to the consumption data of the National Bureau of Statistics and the Digital Financial Inclusion Index of Peking University, it can be found that from 2013 to 2020, the consumption level of Chinese residents has continued to rise, and the digital financial inclusion index has more than doubled in seven years. Although the change trend of residents' consumption structure and digital financial inclusion is similar, whether digital financial inclusion can significantly affect the consumption structure, and in what direction the effect will be produced, is the research focus of this paper.

From the perspective of micro-family, this paper studies whether and by what means digital financial inclusion can affect the consumption structure of residents. According to the research results of this paper, the development trend of digital financial inclusion and the hidden problems in the development process can be analyzed, to provide theoretical support for the formulation of relevant policies.

Foreign scholars' research on consumption structure started earlier. Stone and Rowe studied the influence of commodity consumption and commodity price on consumers' consumption behavior [2]. Stone initially proposed the Linear Expenditure System (LES) model [3], and then Lluch improved the model and proposed The "Extended Linear Expenditure System (ELES)" model [4], followed by Deaton and Muellbauer proposed an almost ideal demand system (AIDS) [5], Blundell, Pashardes and Weber added quadratic terms in the AIDS model, and got Quadratic Extended Almost Ideal Demand System (QUAIDS) [6]. On the basis of the above models, Val'tukh and Ryzhenkov constructed a theoretical utility function and tested it empirically [7], Teklu and Johnson used the AIDS model to estimate the food consumption structure in Indonesia, and Gardes et al. established the QUAIDS model to estimate the cross-section and time of food consumption. Sequence elasticity [8]. Using a systematic demand model, Zheng et al. analyzed the elasticity of tobacco consumption to price and anti-smoking advertising [9].

Regarding the relationship between financial development and consumption, the views of different foreign scholars can be roughly divided into two aspects. On the one hand, financial development can reduce consumption sensitivity [10], and provide more diverse financial services, making it possible to smooth consumption across periods, thereby increasing consumer demand [11]. At the same time, some scholars have pointed out that liquidity constraints will make residents increase precautionary savings to cope with uncertainty, and to reduce this effect requires the development of consumer credit [12, 13]. Financial development can diversify international risks and help consumers achieve smooth consumption, thereby promoting consumption growth [14]; financial development promotes consumption by easing liquidity constraints, because they find that consumption will increase with the increase of credit card limits [15, 16]. On the other hand, in order to reduce the occurrence of excessive liquidity constraints, residents will save as buffer stocks, and as such savings increase, consumption will first decrease and then increase [17]. Financial liberalization in financial development has the effect of smoothing consumption [18], which can effectively alleviate the liquidity problem of residents to a certain extent [19].

The concept of financial inclusion was first proposed in 2005 and has been extensively studied after the world financial crisis. For example, the Alliance for Financial Inclusion (AFI) has built an inclusive financial statistical indicator system, and the World Bank and the Bill and Melinda Gates Foundation cooperated with the Global Financial Inclusion Database (Global Financial Inclusion Database). As a combination of digital technology and inclusive finance, digital financial inclusion has financial characteristics, so foreigners generally believe that it will also affect consumption. The development of digital financial inclusion can alleviate the problem of inability to obtain financial services through formal channels [20], and convenient payment methods are also an important way for digital financial inclusion to promote residents' consumption [21]. The development of inclusive finance can promote the optimization and upgrading of the consumption structure [22], but in the long run to promote economic growth, we need policy support and increase the financial knowledge of residents [23].

Most of the domestic consumption structure is based on the models established by foreign scholars. Wang Wenying and Ou Xiaoli used the LES model to study the consumption needs of urban residents [24], Zang Xuheng and Sun Wenxiang used the ELES model and the AIDS model to analyze the urban–rural differences in the consumption structure of Chinese residents [25], Zhang Huanming and Ma Ruiqi used the improved LA/AIDS model to analyze the consumption structure of urban residents in my country [26]. Regarding the research on consumption structure factors, some scholars have found that changes in total consumption and relative prices of various commodities [27], income distribution and population structure [28], income level and consumption expenditure [29], urbanization [30] and other factors have had an impact on the consumption structure.

Domestic research on the relationship between financial development and consumption is relatively late. The domestic financial industry started late. Beginners believed that the lack of financial products and services increased the liquidity constraints and future uncertainty of residents, inhibiting consumption [31]. Later studies showed that the enrichment of consumer credit means, such as the promotion of credit cards, is very important. Resident consumption has a promoting effect [32]. The development of my country's financial market is not perfect, and more diverse financial services are needed to relax consumer liquidity constraints and stimulate consumption desire [33]. Financial development promotes consumption growth by alleviating liquidity constraints and providing financial services to increase residents' disposable income [34], and the development of inclusive finance reduces the cost of financial services and improves the availability of financial services, which can effectively Alleviating financial exclusion and promoting residents' consumption [35], financial development can increase residents' consumption enthusiasm through long-term sharing of consumption risks [36]. Inclusive finance is generally conducive to poverty alleviation, and there is an intermediary role of inclusive growth [37].

Finance affects the characteristics of residents' consumption structure in many ways. Domestic mainstream research believes that financial development can promote the optimization and upgrading of consumption structure. The study found that financial development can affect the consumption structure of residents in a variety of ways. The mainstream believes that there are three aspects: alleviating liquidity constraints, increasing future income expectations, and reducing financial service costs. Financial marketization can alleviate liquidity constraints through credit, insurance and other channels, thereby stimulating residents' consumption demand [38]; income and borrowing levels have a significant impact on residents' consumption and there are differences between urban and rural areas and regions [39], and financial development has Different sources of income have different effects [40], and financial inclusion affects families with different income levels in different ways [41].

Starting from the concept of inclusive finance, domestic scholars believe that the inclusive financial system is also a manifestation of financial fairness in essence, so that the huge disadvantaged groups can obtain equal financial services [42]. Optimizing resource allocation is the essence of finance, but in the Alienation under the influence of capital, the development of inclusive finance is a measure to correct this financial alienation [43]. Digital financial inclusion is further derived from the concept of financial inclusion, and its role is to provide formal and affordable financial services in a sustainable way for groups whose legitimate and legitimate financial service needs cannot be met [44]. Digital inclusive finance is the combination of inclusive finance and digital technology, which ensures the interests of financial institutions and promotes social development [45] risks and challenges [46]. Based on the reference system of financial inclusion indicators, economists have established an indicator system for digital financial inclusion. Guo Feng et al. compiled the "Peking University Digital Financial Inclusion Index" using Ant Financial's micro-data on digital financial inclusion, covering three levels of provinces, cities, and counties, and provided a multi-period index for further research on digital financial inclusion, and provided a more authoritative data basis [47].

Using the indicator system of digital financial inclusion, domestic scholars have conducted a lot of research on the impact of digital financial inclusion and consumption. At the macro level, Internet finance has smoothing, guaranteeing and value-added effects on consumption, and through these three effects, it has promoted the upgrading and optimization of residents' consumption structure, and has a greater impact on urban areas than in rural areas [48]; digital inclusive finance can improve the Resident consumption promotes economic growth [49]; Internet consumer finance mainly promotes consumption upgrades and promotes economic growth by improving development and enjoyment consumption [50]. At the micro level, alleviating liquidity constraints and facilitating residents' payment are two ways for digital inclusive finance to improve residents' consumption [51], and compared with the two, it is more effective to improve the convenience of payment [52]. By reducing the uncertainty faced by households, increasing the expected income of residents, and stimulating consumption desire [53], digital finance has stronger geographic penetration and lower cost than traditional finance, solves the problem of information asymmetry, and is effective. to promote the consumption expenditure of residents [54].

From the research status at home and abroad, we can see that: first, most scholars have studied the relationship between financial development and consumption, and domestic and foreign scholars generally believe that financial development can reduce the volatility of consumption and release consumer demand. Secondly, domestic and foreign scholars' research on the relationship between digital financial inclusion and consumption mainly focuses on the impact on total consumption. Most literatures point out the macro-promoting effect of digital financial inclusion on household consumption. Finally, the research on the relationship between the development level of digital financial inclusion and the consumption structure of residents is still insufficient, and the consumption structure of residents is an important part of consumption. Based on this, this paper will explore the impact of digital financial inclusion on the consumption structure of residents, and enrich the research in this field.

2 Theoretical Analysis and Research Assumptions

2.1 Digital Inclusive Finance and Residents' Consumption Structure

The modern form of inclusive finance has gone through four stages of "micro-credit model stage—micro-finance stage—traditional financial inclusion stage—digital inclusive finance stage" [55]. Digital inclusive finance is the combination of digital technology and inclusive finance. Digital technology can greatly reduce the threshold and cost of financial services, increase the sales of financial services, and achieve the sustainability of inclusive financial services. The definition of digital financial inclusion is widely recognized in the "G20 Advanced Principles of Digital Financial Inclusion" released in 2016, which believes that all action models that promote financial inclusion through the use of digital technology are digital financial inclusion. At present, digital inclusive finance mainly includes digital payment, digital credit scoring, online small and micro financing, micro-insurance, and digital micro-finance.

Consumption structure refers to the proportion of different types of commodities that people consume under a certain social background [56]. Consumption structure can reflect consumption content and is an important part of economic structure. According to the specific content classification of consumer goods, according to the classification standard of the National Bureau of Statistics, the consumption structure can be divided into eight categories: food, tobacco and alcohol; clothing; housing; daily necessities and services; medical care; transportation and communication; culture, education and entertainment and other. The division basis used. Engels divided consumption data into three categories: survival type, enjoyment type and development type consumption data. According to the Engels method, the consumption is divided, and the optimization and upgrading of the consumption structure is measured by the increase in the proportion of development and enjoyment consumption in the total consumption expenditure [57].

Although there are few studies on the relationship between digital financial inclusion and consumption structure at home and abroad, and there is no systematic analysis of its impact mechanism, a lot of research results have been achieved on the relationship between digital financial inclusion and consumption. Therefore, based on relevant theories and referring to the research results of other scholars, this paper systematically analyzes the mechanism by which digital financial inclusion affects the consumption structure of residents. The core of digital inclusive finance is to use digital technology to promote inclusive finance. At present, it mainly includes financial services such as digital payment, digital credit scoring, online small and micro financing, micro-insurance, and digital micro-finance. Digital inclusive finance has an impact on the consumption structure of residents. The impact of digital financial inclusion will also be realized through the services it provides. For this reason, this paper combines the three effects of smoothing, security and value-added proposed

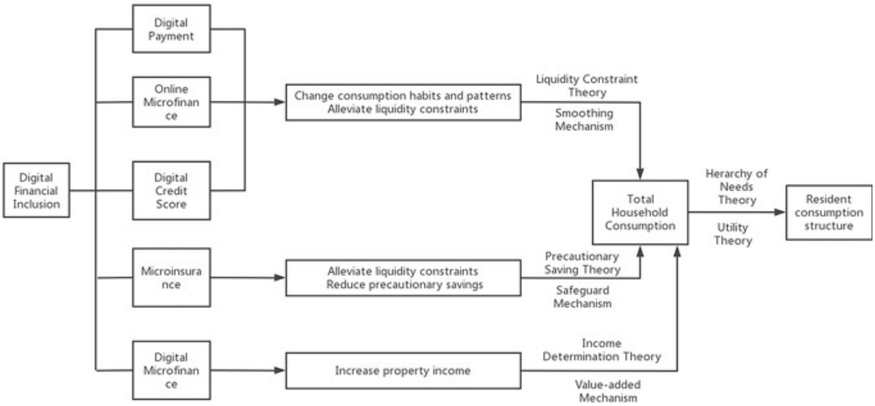

Fig. 1 Mechanism diagram of the impact of digital financial inclusion on residents' consumption structure

by Zhang Liyi and Tu Ben [48] to obtain the impact mechanism of digital inclusive finance on the consumption structure of residents as shown in the Fig. 1 shown.

The smooth mechanism that digital inclusive finance affects the consumption structure of residents is mainly realized through digital payment, online small and micro financing and digital credit scoring. With the continuous updating of digital technology, digital payment is also developing continuously. From the previous online payment to the current NFC, QR code, and face recognition payment, it has affected the consumption behavior of residents to a certain extent. First of all, digital payment has greatly shortened the time cost of transactions, which in disguise increases the leisure time of residents and increases the possibility of consumption. Secondly, digital payment eliminates the need for people to carry cash with them, reduces the situation of insufficient cash to make transactions, and increases the possibility of consumption. Thirdly, according to the theory of mental accounts, digital payment separates the process of losing funds and obtaining goods, reducing the loss of mental accounts when consuming, and stimulating their desire to consume. Finally, the development of payment methods has brought new consumption patterns, such as online pre-sale, live streaming, etc., and most of the commodities that utilize these new consumption patterns belong to development and enjoyment consumption. Digital payment allows residents to have more consumption possibilities and types of commodities. The reduced transaction costs can be seen as a drop in commodity prices. According to the utility theory, people's marginal decrease in survival consumption will use excess currency for development and development. Enjoyable consumption is a change in the consumption structure.

Based on this, this paper puts forward the research hypothesis:

H1: Digital financial inclusion has a positive effect on the upgrading of household consumption structure.

2.2 The Mediating Role of Liquidity Constraints

The theory of liquidity constraints believes that liquidity constraints are the main factor that inhibits household consumption. The high cost of a single credit in traditional financial institutions makes it difficult to meet the microfinance needs of a large number of small and medium-sized enterprises and low-income people. Microfinance is a core financial service for inclusive finance to deal with this financial exclusion, and the development of digital technology has brought not only the digitization of traditional microfinance business, but also innovative digital financing models. The cost of identifying and controlling credit risks has been greatly reduced, thereby reducing the cost of credit granting and greatly improving the availability of loans for small, medium and micro enterprises and self-employed and low-income groups. There is also the role of digital credit scoring. Compared with traditional credit reporting, digital credit scoring has the advantages of strong anti-fraud ability and wide information sources, laying a credit reporting foundation for online small and micro financing. First, the liquidity constraints of residents have been eased, which stimulated the originally suppressed consumption demand. At the same time, according to the life cycle theory, more loan products will help residents to smooth their consumption levels and achieve long-term consumption growth. According to the hierarchy of needs theory, after the basic consumption needs are satisfied, residents will naturally pursue higher-level consumption needs and adjust the consumption structure. Second, funds obtained through consumer credit have a higher marginal propensity to consume than wage income, and traditional financial institutions mostly limit high-level consumption needs such as medical care and education. Online small and micro financing will stimulate the development and enjoyment of residents. consumption.

Based on this, this paper proposes research hypotheses:

H2: Liquidity constraints have a mediating role between digital financial inclusion and household consumption structure.

2.3 Mediating Role of Income

According to the precautionary saving theory, as the uncertainty risk of future income increases, consumers reduce current consumption and save more for future consumption. In the case of limited consumption expenditure, in order to meet the basic survival consumption, people will reduce development and enjoyment consumption more, which will have an impact on the consumption structure. Insurance is an important tool to diversify uncertain risks and reduce losses, which can reduce precautionary savings and increase consumption. The emergence of micro financial management such as Yu'e Bao has broken the financial management threshold of traditional banks, making it possible for everyone to manage financial management at any time. In addition, these digital small-amount wealth management products also have the characteristics of high liquidity and stable income, which are more suitable for the general public and increase the asset income of residents. The value-added mechanism of small-amount wealth management is mainly reflected in three aspects: First, the wealth effect. The price of financial assets held by residents increases. Although it is not realized into actual wealth, people will still increase consumption. At the same time, according to the persistent income theory, people will also Increase the expectation of future income, and then increase the willingness to consume; the second is to invest in financial assets such as stocks, bonds, funds, etc., residents will expect to receive asset income such as dividends, dividends, and increase the willingness to consume; The third is that digital inclusive finance reduces investment The threshold, coupled with a variety of Internet wealth management products, effectively diversify investment risks and increase asset income. According to the income determination theory, small-amount financial management increases household consumption through the above three ways. Based on the hierarchy of needs theory and utility theory, increased consumption will affect the consumption structure to a certain extent.

Based on this, this paper proposes a research hypothesis:

H3: Income plays a mediating role between digital financial inclusion and household consumption structure.

3 Empirical Research Design

3.1 Model Design

3.1.1 Benchmark Regression Model

Based on the results of Hausmam test and F test, this paper adopts the individual fixed effect panel model for empirical analysis. The basic econometric model expression is as follows:

$$CS_{ijt} = w_0 + w_1 Index_{it} + w_2 X_{it} + c_i + \varepsilon_{it} \quad (1)$$

Among them, CS_{ijt} is the proportion of the jth type of consumption expenditure of the ith household in period t, the core explanatory variable $Index_{it}$ is the digital financial inclusion index of the province where the ith household is located in period t, and Xit is The control variables of the household head characteristics, household characteristics and regional characteristics of the i-th household in period t, c_i represents the individual effect, and ε_{it} is the disturbance term.

3.1.2 Mediation Effect Model

Combined with the previous analysis results, digital financial inclusion may affect residents' consumption structure by easing liquidity constraints, increasing income and reducing precautionary savings. Therefore, this paper constructs the mediation effect model with reference to the mediation effect test procedure proposed by Wen Zhonglin et al. [58]:

$$CS_{ijt} = w_0 + w_1 Index_{it} + w_2 X_{it} + c_{1i} + \varepsilon_{1it} \tag{2}$$

$$Med_{it} = \alpha_0 + \alpha_1 Index_{it} + \alpha_2 X_{it} + c_{2i} + \varepsilon_{2it} \tag{3}$$

$$CS_{ijt} = \beta_0 + \beta_1 Index_{it} + \beta_2 Med_{it} + \beta_3 X_{it} + c_{3i} + \varepsilon_{3it} \tag{4}$$

Among them, Med_{it} is the mediating variable, and the other variables have the same meaning as in the previous benchmark regression. In order to test whether digital financial inclusion can affect residents' consumption structure by alleviating liquidity constraints and increasing income, this paper selects property income as a variable to measure income, and household current assets as a variable to measure liquidity constraints.

3.2 Variable Selection

1. Explained variable: household consumption structure, this paper refers to the classification standard of the National Bureau of Statistics, and takes the proportion of food, clothing, housing, daily necessities, medical care, transportation and communication, culture, education and entertainment, and other eight categories of consumption in the total household expenditure. as the explained variable.
2. Explanatory variables: Digital Financial Inclusion Index. Since the development of digital financial inclusion is a regional issue, this paper uses the digital financial inclusion index of the household's region as an explanatory variable.
3. Control variables mainly include three categories: According to the life cycle theory, total household income and total household assets are important factors affecting household consumption. Therefore, this paper adds variables that measure household income and assets as control variables to the model. This paper chooses total household income as a variable to measure household income, and household net worth as a variable to measure household assets. Second, family characteristic variables and household head characteristic variables. In terms of family characteristic variables, this paper selects two indicators: family size and whether it belongs to an urban family. Among them, the family belongs to the urban area as 1, and the rural area as 0. The household head characteristic variables include the household head's gender, age, years of education, health,

the importance of the Internet as an information channel, and whether to use the Internet. Score, the higher the score, the healthier the household head, and the importance of the Internet as an information channel is also scored from 1 to 5. The higher the score, the more important the household head thinks the Internet as an information channel. Third, regional economic development variables. This paper uses the per capita GDP and financial development degree (measured by the ratio of the balance of RMB loans of financial institutions to GDP) in the area where the household is located to measure the degree of economic development in the area where the household is located.

3.3 Data Interpretation and Analysis

3.3.1 Data Sources

The data in this paper mainly include macroeconomic indicators, digital financial inclusion index and micro household data. Macroeconomic indicators are sourced from the website of the National Bureau of Statistics and the statistical yearbooks of the provinces. The Digital Financial Inclusion Index comes from the Peking University Digital Financial Inclusion Index published by the Digital Finance Research Center of Peking University. The micro-household data comes from the China Family Tracker (CFPS) data center. The CFPS project has been conducting follow-up surveys every two years since 2010, covering 25 provinces, municipalities directly under the Central Government and ethnic minority autonomous regions. Since the results of the questionnaire in 2020 have not been fully announced, this paper selected the results of the questionnaires in 2014, 2016 and 2018, and screened out the families who participated in the questionnaire three times by comparing the family numbers. Since the head of the household is not specified in the CFPS data, this paper selects the financial respondent of the household as the head of the household.

3.3.2 Descriptive Statistics

This paper excludes data with total household income less than 500 yuan, negative household net assets, zero food consumption, and zero housing consumption. Table 1 gives the descriptive statistics of each variable.

It can be seen from the table that the average value of food consumption from 2014 to 2018 was the highest, reaching 17,612.93 yuan, much higher than the intertemporal average of other types of consumption. Housing consumption is the second largest expenditure. Although the average value is only about 51% of food consumption, the standard deviation is much larger than that of food consumption. This reflects the large difference in housing consumption among households, with a difference of 1.11 million between the maximum value and the minimum value. The average value of daily necessities consumption is only 800 yuan lower than that

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Food consumption expenditure	23,214	17,612.93	16,508.37	48	600,000
Clothing consumption expenditure	23,214	2590.53	4563.72	0	250,000
Residential consumption expenditure	23,214	9088.27	29,336.8	24	1,112,280
Consumer spending on daily necessities	23,214	8270.52	33,792.93	0	2,512,800
Health care consumer spending	23,214	5684.45	15,571.85	0	500,000
Transportation and communication consumption	23,214	4589.88	5903.37	0	138,000
Culture, education and entertainment consumption	23,214	5577.22	11,729.13	0	503,000
Other consumer spending	23,214	902.92	5182.8	0	603,000
Digital financial inclusion index	23,214	237.15	54.92	154.62	377.73
Total household income	23,214	74,117.98	177,035.6	500	9,158,800
Household net worth	23,214	589,010.9	1,480,293	0	80,130,000
Family size	23,214	3.88	1.85	1	21
Whether it is an urban family(Yes = 1)	23,214	0.48	0.50	0	1
Head of household gender (Male = 1)	23,214	0.52	0.50	0	1
Age of head of household	23,214	51.79	13.57	10	95
Years of education of the head of household	23,214	6.95	4.77	0	19
Health of the head of household (very healthy = 5)	23,214	2.84	1.21	1	5
The importance of the Internet as an information channel	23,214	2.19	1.53	1	5
Whether to use the Internet (Yes = 1)	23,214	0.31	0.46	0	1
Regional GDP per capita	23,214	55,006.31	25,256.01	26,433	140,211
The level of regional financial development	23,214	1.44	0.43	0.79	2.55

of housing consumption, but it is at least 2,700 yuan lower than the other five types of consumption.

The standard deviation and maximum value are also the highest of all types of consumption. Higher living standards and the popularity of e-commerce platforms have improved the foundation for the sales of cosmetics. The average value of health care consumption and cultural, educational and entertainment consumption are similar, and the gap between different families is also large. This is mainly due to the different structure of family members. The fluctuation range of transportation and communication consumption is lower than other consumption, and the average household is only 4,589 yuan. The mean and standard deviation of clothing consumption are only higher than other consumption, indicating that the differences between different families and the same family in different years are relatively small. The standard deviation of total household income and household net assets is extremely large. The income of a single family varies greatly, and there are also large gaps between different families. The lowest total family income reaches the standard of absolute poverty, and the highest reaches tens of millions., the family sample of the follow-up survey is seriously divided between the rich and the poor. The family size varies greatly. The largest family has 21 members, with an average of about 4 members per household. It can also be seen from the descriptive statistics of urban households that the proportion of rural areas in the sample data is slightly higher than that of urban areas.

Among the 23,214 samples, the proportion of male and female heads of households is relatively balanced, with males slightly higher than females. The average age of household heads is 52 years old, but there is a wide range, with the eldest household head at 95 years old and the youngest at 10 years old. In the selected sample data, the highest education period is 19 years, that is, a master's degree, and the average is about 7 years, indicating that there are still many household heads who have not completed compulsory education. According to the statistical results of the health indicators of the head of household subjectively evaluated by the respondents, the average health level of the head of the household is 2.84, which is at a relatively healthy level. In the sample, only 31% of household heads use the Internet, and the average value of the importance of the Internet as an information channel is only 2.19, indicating that they do not pay enough attention to the Internet.

Among the two regional macro indicators, the regional per capita GDP standard deviation is very large, on the one hand, it shows that my country's economic development is very rapid, and on the other hand, it also shows that there are large differences in the economic development of different regions. The standard deviation of the regional financial development degree is small, which is mainly due to the weakening of the differences between different regions in the process of calculating the indicators.

4 Empirical Analysis

4.1 Benchmark Regression Results Analysis

An auxiliary regression model is established between the explanatory variables and the control variables, the determination coefficient of each auxiliary regression model is obtained, and then the variance inflation factor is calculated. The variance inflation factor of all auxiliary regression models is less than 10, indicating that there is no serious difference between the variables collinearity problem. This paper selects the cross-sectional data in 2014, 2016, and 2018, and thus constructs the panel data of three periods. For large amounts of data such as per capita GDP and total household income, the logarithm is taken, which reduces the dimension and reduces collinearity to a certain extent. Table 2 reports the fixed effects regression results based on model (1).

From the regression results, it can be seen that the digital financial inclusion index has a significant negative correlation with the proportion of food consumption, clothing consumption and housing consumption, and has a significant positive correlation with the proportion of daily necessities consumption. relationship. The development of digital inclusive finance will increase the proportion of health care and cultural, educational and entertainment consumption, and it will also promote other consumption, but it is not obvious enough. It can increase the proportion of development and enjoyment consumption, and promote the optimization and upgrading of consumption structure, which verifies Hypothesis 1.

Among various control variables, total household income has a negative and significant impact on the proportion of food consumption, and has a significant positive impact on the proportion of subsistence consumption of housing and daily necessities, and has no significant impact on the proportion of clothing consumption. This shows that the higher the income level, the lower the family Engel coefficient, and the higher the living standard. With the increase of household net assets, food consumption will decrease significantly and daily necessities consumption will increase significantly, which will promote the transformation of consumption structure to a certain extent. The individual characteristics of the head of household have a significant impact on the consumption structure of residents, as do family characteristics.

The proportion of food and housing consumption will decrease with the increase of family size, while the proportion of cultural, educational and entertainment consumption will increase. There will be more children in extended families, increasing education spending. The influence of urban households on the consumption structure is mainly reflected in food and medical care, which reflects that rural households can achieve a certain degree of self-sufficiency in food, but the medical system is not perfect. The gender of the head of household has a significant negative impact on the proportion of daily necessities consumption and significantly increases the proportion of food consumption, which indicates that the male head of household pays less attention to the living environment and quality of the household than the female head, but pays more attention to food quality or is less sensitive to food prices. As the age of the head of the household increases, the proportion of food expenditures continues to rise. This is because the increase in the age of the head of household will be accompanied by the increase in the age of other members of the family or the expansion of the family size, which will inevitably increase the food consumption expenditure of the family. Health care spending also increases due to health problems caused by the age of family members. The number of years of education of the head of the household has a less significant impact on the consumption structure, because the Internet has greatly reduced the cost of people's access to information and broadened the channels, which are no longer limited to school educational resources. The

Table 2 Benchmark regression results

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−4.0824*** (0.1228)	−0.6529*** (0.0238)	−1.5374*** (0.0430)	1.4494*** (0.0553)	1.8409*** (0.0579)	−0.2571*** (0.0265)	1.1415*** (0.0365)	0.4560*** (0.0101)
Total household income	−0.6001*** (0.01922)	0.1244*** (0.004601)	0.3242*** (0.01059)	0.3835*** (0.0104)	−0.2222*** (0.0069)	−0.0742*** (0.0043)	−0.1090*** (0.0048)	0.0774*** (0.0013)
Household net worth	−0.0662*** (0.0079)	0.0252*** (0.0017)	0.01663*** (0.0030)	0.0200*** (0.0021)	−0.0211*** (0.0024)	0.0144*** (0.0012)	−0.0059*** (0.0022)	0.0031*** (0.0004)
Family size	−0.3709*** (0.0205)	0.07345*** (0.0034)	−0.4594*** (0.0096)	−0.0134* (0.0077)	−0.0895*** (0.0081)	0.1759*** (0.0041)	0.4899*** (0.0093)	0.0343*** (0.0011)
Whether urban family	2.5191*** (0.1496)	−0.6756** (0.0405)	0.9424*** (0.0747)	−0.3529*** (0.0569)	−1.8840*** (0.0811)	−0.375*** 0.0367)	0.4600*** (0.0220)	−0.2259*** (0.0088)
Head of Household Gender	0.6771*** (0.0264)	−0.1809*** (0.0096)	−0.2791*** (0.0144)	−0.0622*** (0.0170)	0.1216*** (0.0160)	0.1276*** (0.0052)	−0.1348*** (0.0119)	−0.0213*** (0.0026)
Age of head of household	0.0138*** (0.0026)	−0.0087*** (0.0006)	0.0128*** (0.0012)	−0.0178*** (0.001249)	0.0256*** (0.0011)	−0.0178*** (0.0007)	0.0001 (0.0007)	−0.0002 (0.0001)
Years of education of the head of household	0.1304*** (0.0062)	0.0129*** (0.0016)	−0.0939*** (0.0028)	−0.0085*** (0.0032)	−0.0457*** (0.0033)	−0.0097 (0.0016)	0.0194*** (0.0019)	0.0202*** (0.0004)

(continued)

Table 2 (continued)

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Health of the head of household	0.2284*** (0.0107)	0.05620*** (0.0030)	0.20379*** (0.0055)	−0.06961*** (0.0058)	−0.4355*** (0.0075)	0.0400*** (0.0027)	0.0554*** (0.0038)	0.0069*** (0.0008)
The importance of the Internet	−0.0195 (0.01298)	0.0582*** (0.0027)	0.0433*** (0.0053)	0.0631*** (0.0059)	−0.1054*** (0.0045)	−0.0234*** (0.0015)	−0.0149*** (0.0043)	0.0299*** (0.0008)
Whether to use the Internet	−0.7051*** (0.0490)	−0.1517*** (0.0065)	−0.1993*** (0.0160)	0.3901*** (0.0205)	0.2108** (0.0158)	−0.1953** (0.0092)	0.2488*** (0.0153)	0.03706*** (0.0027)
Regional GDP per capita	−0.8268*** (0.1443)	−0.2808*** (0.0324)	0.3818*** (0.0502)	0.9043*** (0.0713)	−0.1003 (0.0719)	−0.0558 (0.0350)	0.2559*** (0.0434)	−0.1332*** (0.0139)
The level of regional financial development	3.0668*** (0.1258)	0.1139*** (0.0186)	0.0525 (0.0450)	−1.2515*** (0.0455)	−0.9869*** (0.05471)	0.3756*** (0.0258)	−0.2687*** (0.0339)	−0.2354*** (0.0077)
Obs	23,201	23,201	23,201	23,201	23,201	23,201	23,201	23,201
R^2	0.9962	0.9929	0.9870	0.9808	0.9921	0.9972	0.9971	0.9905

Note The standard error of the cluster file is in brackets, ***p < 0.01, **p < 0.05, *p < 0.1

coefficient of the health of the household head on the proportion of food consumption is significantly positive, and the coefficient on the proportion of medical care consumption is significantly negative, indicating that the worse the health status, the greater the demand for medical care and the smaller the demand for food. The importance of Internet information channels and whether to use the Internet will significantly increase the proportion of daily necessities consumption, and whether or not to use the Internet will also reduce the proportion of clothing consumption. Residents who attach importance to the Internet will use the Internet more, which not only broadens their horizons, and allows them to Paying more attention to the quality of life, online shopping platforms are also cheaper than offline physical stores.

In terms of regional macro variables, an increase in per capita GDP can significantly reduce the proportion of food consumption and increase the proportion of daily necessities consumption. In contrast, the level of financial development has a significant positive correlation with the proportion of food consumption, a significant negative correlation with the proportion of daily necessities consumption, and has no significant impact on other types of consumption.

4.2 Robustness Check

In order to ensure the reliability of the analysis results, this paper replaces the explanatory variables from the proportions of food, clothing, housing, daily necessities, medical care, transportation and communication, culture, education and entertainment, and other eight categories with the proportions of survival consumption and development and enjoyment consumption. The proportions are tested for robustness. The regression results are shown in Table 3.

Table 3 Robustness test: replacing explained variables

Variable	Subsistence consumption	Development and enjoyment consumption
Digital financial inclusion index	−3.7480*** (0.4706)	3.7480*** (0.4706)
Control variable	Yes	Yes
Regional economic development variables	Yes	Yes
Individual fixed effects	Yes	Yes
Observations	23,201	23,201
R^2	0.9235	0.9235

Note The standard error of the cluster file is in brackets, *** p < 0.01, ** p < 0.05, * p < 0.1; Control variables and regional economic development variables are identical to Table 2

The regression results show that the digital financial inclusion index can significantly reduce household consumption for survival and improve household development and enjoyment consumption, and has a significant positive effect on the upgrading of household consumption structure. The benchmark regression is robust.

4.3 The Results of the Mediation Model Test

4.3.1 The Results of the Mediation Effect Test of Property Income

The mediating effect model is constructed with property income as the mediating variable, and the regression results are as follows. Table 4 shows the regression results of the digital financial inclusion index on property income, and Table 5 shows the joint regression results of the digital financial inclusion index and property income on the consumption structure of residents.

It can be seen from the regression results that the regression coefficient of the digital financial inclusion index on property income is 527.7919 and is significant at the 1% level. The joint regression results of the digital financial inclusion index and property income on the consumption structure of residents are also mostly significant. This shows that there is a partial intermediary effect, which verifies Hypothesis 3. The development of digital financial inclusion affects the consumption structure through the intermediate transmission mechanism of income, but there may also be other intermediary variables.

Table 4 The mediation effect test of income (1)

Independent variable	Dependent variable: property income
Digital financial inclusion index	527.7919*** (21.5636)
Property income	–
Control variable	Yes
Regional economic development variables	Yes
Individual fixed effects	Yes
Observations	23,201
R^2	0.6466

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Compared with Table 2, the control variables and regional economic development variables do not include total household income

Table 5 The mediation effect test of income (2)

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−4.0822 *** (0.1233)	−0.6349*** (0.0269)	−1.5319*** (0.0422)	1.4479*** (0.05068)	1.8638*** (0.0592)	−0.2619*** (0.0270)	1.0713*** (0.0351)	0.4556*** (0.0101)
Total household income	-1.15×10^{-6}(1.47×10^{-6})	1.84×10^{-6}*** (4.11×10^{-7})	-1.96×10^{-6}** (8.24×10^{-7})	5.39×10^{-6}*** (7.57×10^{-7})	-4.72×10^{-6}*** (7.4×10^{-7})	-9.33×10^{-7} (6.31×10^{-7})	9×10^{-6}*** (8.72×10^{-7})	-8.85×10^{-7}*** (1.43×10^{-7})
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	23,201	23,201	23,201	23,201	23,201	23,201	23,201	23,201
R^2	0.9962	0.9920	0.9872	0.9836	0.9912	0.9973	0.9976	0.9867

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Compared with Table 2, the control variables and regional economic development variables do not include total household income

4.3.2 T the Mediating Effect Test of Liquidity Constraints

The mediating effect model is constructed with household liquid assets as the mediating variable, and the regression results are as follows. Table 6 shows the regression results of the digital financial inclusion index on household liquid assets, and Table 7 shows the joint regression results of the digital financial inclusion index and household liquid assets on the household consumption structure.

All regression coefficients of the digital financial inclusion index are significant, indicating that digital financial inclusion can significantly promote the optimization of consumption structure. The coefficient between the digital financial inclusion index and household liquid assets is 4.3083 and is significant, indicating that the development of digital financial inclusion can improve household liquid assets and ease liquidity constraints. In Table 7, the regression coefficients of total household income on the consumption structure of residents are all significant, indicating that the intermediary effect is significant, that is, the development of digital inclusive finance can alleviate liquidity constraints and optimize the consumption structure of residents; The regression coefficient of the structure is still significant, so it is a partial mediating effect, and hypothesis 2 is verified, indicating that digital financial inclusion directly affects the consumption structure of residents, or there are still other mediating variables.

Table 6 The mediation effect test of liquidity constraints (1)

Independent variable	Dependent variable: household liquid assets
Digital financial inclusion index	4.3083*** (0.1035)
Household liquid assets	–
Control variable	Yes
Regional economic development variables	Yes
Individual fixed effects	Yes
Observations	23,201
R^2	0.9574

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 7 The mediation effect test of liquidity constraints (2)

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−3.9013*** (0.1339)	−0.6584*** (0.0497)	−1.1454*** (0.0650)	1.2274*** (0.0585)	2.3622*** (0.0596)	−0.3013*** (0.0293)	1.2421*** (0.0267)	0.4179*** (0.0104)
Household liquid assets	−0.0174*** (0.0027)	0.0125*** (0.0006)	−0.0468*** (0.0015)	0.0459*** (0.0011)	−0.0276*** (0.0013)	0.0164*** (0.0006)	0.0171*** (0.0006)	0.0080*** (0.0001)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25,147	25,147	25,147	25,147	25,147	25,147	25,147	25,147
R^2	0.9950	0.9896	0.9817	0.9761	0.9922	0.9980	0.9966	0.9767

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

4.4 Heterogeneity Analysis

4.4.1 Heterogeneity Analysis of Household Head Age

The age level of the head of household will have a great impact on household consumption expenditure. Will age affect the promotion of digital inclusive finance to the upgrading of consumption structure? This paper divides household heads into young, middle-aged, and elderly household heads according to their age. Young household heads are under 45 years old, middle-aged household heads are between 45 and 59 years old, and older household heads are over 60 years old. After dividing the sample data, the individual fixed-effect panel models were constructed respectively, and the regression results in Tables 8, 9 and 10 were obtained.

The results show that digital financial inclusion has the least impact on the consumption structure of middle-aged households, and has the greatest impact on the consumption structure of young households. Among them, the proportion of food consumption has been inhibited by the digital financial inclusion index, and it has the greatest effect on the young head of household, indicating that the food consumption of the young head of household can be significantly reduced. For young and middle-aged householders, the development of digital inclusive finance will significantly reduce the proportion of residential consumption. This may be because the development of various Internet wealth management products and lending platforms has reduced the original housing cost. The daily necessities expenditure of young and middle-aged household heads has increased significantly, indicating that the development of e-commerce platforms has played a great role. The promotion of the development of digital financial inclusion on the proportion of health care expenditure increases with age, indicating that digital financial inclusion gives people more access to funds when they face the health problems caused by increasing age. Increased spending on healthcare consumption. Transportation and communication consumption in young and middle-aged households will be significantly negatively affected by digital financial inclusion. It may be that young and middle-aged householders have more free time and travel more frequently. The popularity of the Internet can significantly reduce transportation and communication. Consumption. In particular, digital inclusive finance has a very significant role in promoting the proportion of young household heads' cultural, educational and entertainment consumption, while it has little impact on household heads of other age groups, indicating that young household heads will be more engaged with digital inclusive finance. Learn to enrich yourself or immerse yourself in entertainment.

4.4.2 Heterogeneity Analysis of Urban and Rural Areas

There is still a large gap in the level of economic development between urban and rural areas in my country, and the income gap between urban and rural areas is also expanding year by year. Whether the various differences between urban and rural

Table 8 Heterogeneity analysis of age of head of household: young head of household

Dependent variable: consumption structure	Food	Clothing	Residential	Daily Necessities	Health care	Transportation and Communication	Culture, Education and Entertainment	Other consumer spending
Digital financial inclusion index	−6.8933*** (0.2491)	−1.1362*** (0.0737)	−2.6173*** (0.1130)	1.3538*** (0.1238)	−0.8625*** (0.0951)	−0.1608*** (0.0474)	8.0507*** (0.2941)	0.5715*** (0.0325)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6122	6122	6122	6122	6122	6122	6122	6122
R^2	0.9948	0.9868	0.9818	0.9947	0.9903	0.9947	0.9688	0.9664

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 9 Heterogeneity analysis of age of head of household: middle-aged householder

Dependent variable: consumption structure	Food	Clothing	Residential	Daily Necessities	Health care	Transportation and Communication	Culture, Education and Entertainment	Other consumer spending
Digital financial inclusion index	−1.7557*** (0.2678)	−0.2635*** (0.0619)	−2.0888*** (0.1087)	2.9302*** (0.0981)	2.6409*** (0.1024)	−0.3614*** (0.0458)	−0.9099*** (0.1008)	0.5856*** (0.0222)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9091	9091	9091	9091	9091	9091	9091	9091
R^2	0.9920	0.9867	0.9823	0.9799	0.9905	0.9988	0.9938	0.9836

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 10 Heterogeneity analysis of age of head of household: elderly head of household

Dependent variable: consumption structure	Food	Clothing	Residential	Daily Necessities	Health care	Transportation and Communication	Culture, Education and Entertainment	Other consumer spending
Digital financial inclusion index	−4.8501*** (0.2758)	−0.4528*** (0.0437)	−0.2610** (0.1260)	−1.1597** (0.09333)	4.3245*** (0.1423)	0.1300*** (0.0430)	0.8763*** (0.0564)	0.1952*** (0.0110)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional Economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7988	7988	7988	7988	7988	7988	7988	7988
R^2	0.9937	0.9960	0.9907	0.9868	0.9948	0.9944	0.9965	0.9773

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

areas will lead to a gap in the consumption structure of urban and rural households affected by digital inclusive finance is the concern of this paper. In this paper, the sample is divided into two parts according to whether the family belongs to urban or rural areas, and individual fixed-effect panel models are constructed respectively, and the regression results in Tables 11 and 12 are obtained.

Like the results of the benchmark analysis, the development of digital financial inclusion will significantly reduce the share of food consumption expenditures, with a greater impact on rural households. In terms of residential consumption expenditure, it has a negative impact on urban households and a positive impact on rural households. This may be due to the higher level of financial development in urban areas and more intense competition, while the phenomenon of financial inhibition in rural areas is more common, and the development of digital inclusive finance This allows urban families to reduce the cost of obtaining financial services, while rural families have more room to play in living. In terms of development and enjoyment-oriented consumption, the development of digital inclusive finance has a greater impact on the proportion of rural households' healthcare consumption than in urban areas, and has a significant role in promoting the proportion of urban households' cultural, educational and entertainment consumption, which fully reflects the urban–rural gap. With access to a wider range of financial products and digital services, urban households will spend more on education and entertainment while rural households will spend more on healthcare. In general, the development of digital inclusive finance has promoted the upgrading of the consumption structure of rural households more obviously, which may be due to the poor availability of financial services for rural households compared with urban households.

4.4.3 Heterogeneity Analysis by Income Class

Household income is an important factor affecting consumption, and digital financial inclusion can provide households with rich financial services and further increase household income. Due to the differences in consumption concepts of different income groups, the impact path and degree of digital financial inclusion may be different. In order to test the heterogeneity of different income groups, this paper divides households into low-income, middle-income and high-income families according to their total income. Income, build individual fixed-effect panel models respectively, and get the regression results in Tables 13, 14 and 15.

The results show that the degree of inhibition of the proportion of food consumption by the development of digital inclusive finance increases with the increase of household income. The development of digital inclusive finance has a weak impact on the proportion of clothing consumption, and gradually becomes less significant as household income rises. For residential consumption, the development of digital inclusive finance will increase the proportion of residential consumption of low-income households and reduce the proportion of residential consumption of high-income households. However, the impact on middle-income households is weak. The possible reason is that digital inclusiveness Some supportive financial services

Table 11 Analysis of urban–rural heterogeneity: urban households

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−2.5277*** (0.1954)	−0.0223 (0.0337)	−3.5046*** (0.1225)	0.7135*** (0.08132)	1.4854*** (0.06371)	−0.5315*** (0.0521)	2.8835*** (0.0851)	0.8445*** (0.0172)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11,315	11,315	11,315	11,315	11,315	11,315	11,315	11,315
R^2	0.9948	0.9917	0.9866	0.9804	0.9888	0.9952	0.9917	0.9887

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 12 Urban–rural heterogeneity analysis: rural households

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−5.0761*** (0.1518)	−1.4059*** (0.0467)	0.5977*** (0.0743)	2.1222*** (0.0988)	2.5060*** (0.0916)	−0.0456 (0.0435)	0.1556*** (0.0576)	0.1350*** (0.0101)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11,886	11,886	11,886	11,886	11,886	11,886	11,886	11,886
R^2	0.9940	0.9862	0.9906	0.9693	0.9939	0.9982	0.9951	0.9741

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 13 Income class heterogeneity analysis: low income

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−3.5604*** (0.2291)	−1.0852*** (0.05501)	0.6638*** (0.1236)	0.4265*** (0.0862)	2.1572*** (0.0886)	−0.05818 (0.0571)	0.4553*** (0.0566)	−0.2386*** (0.0084)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9157	9157	9157	9157	9157	9157	9157	9157
R^2	0.9946	0.9835	0.9905	0.9785	0.9986	0.9962	0.9980	0.9831

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 14 Income class heterogeneity analysis: middle income

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−3.9245*** (0.2217)	−0.2287*** (0.0426)	−2.2416*** (0.1213)	2.9337*** (0.0837)	1.0189*** (0.0690)	−0.6438*** (0.03674)	1.2068*** (0.0630)	0.7872*** (0.0214)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9379	9379	9379	9379	9379	9379	9379	9379
R^2	0.9958	0.9940	0.9848	0.9771	0.9972	0.9953	0.9930	0.9920

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

Table 15 Income class heterogeneity analysis: high income

Dependent variable: consumption structure	Food	Clothing	Residential	Daily necessities	Health care	Transportation and communication	Culture, education and entertainment	Other consumer spending
Digital financial inclusion index	−5.5563*** (0.4218)	−0.3320*** (0.1148)	−7.3021*** (0.2070)	1.7899*** (0.2692)	2.9971*** (0.1439)	−0.5762*** (0.1204)	3.9517*** (0.1777)	1.5471*** (0.05279)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional economic development variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4665	4665	4665	4665	4665	4665	4665	4665
R^2	0.9899	0.9842	0.9738	0.9514	0.9799	0.9910	0.9931	0.9521

Note The standard error of the cluster file is in brackets, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Control variables and regional economic development variables are identical to Table 2

provided by finance give low-income families the confidence to choose a better living environment, while high-income families themselves have high living expenses. The development of digital inclusive finance has further reduced the financing and wealth management channels for small and micro businesses. The original consumption amount. The impact of the development of digital financial inclusion on the proportion of health care consumption is not very different among families with different income levels, and they are all significant promoting effects. In addition, for middle- and high-income families, the development of digital inclusive finance will significantly reduce the proportion of transportation and communication consumption, and increase the proportion of daily necessities, culture, education and entertainment and other consumption. The above results show that the income difference in the impact of my country's digital financial inclusion development on the consumption structure of the situation does exist.

5 Conclusion and Suggestion

Based on the 2014–2018 CFPS household data and digital financial inclusion index, this paper uses an individual fixed effect model to discuss whether digital financial inclusion affects the consumption structure of residents, and uses an intermediary effect model to verify the possible impact mechanism. In terms of income, the heterogeneity of its influence is explored by means of subsampled regression. The research shows: First, the development of digital inclusive finance can significantly reduce subsistence consumption, improve development and enjoyment consumption, and promote the optimization of residents' consumption structure. Second, digital financial inclusion can affect the consumption structure of residents by alleviating liquidity constraints and increasing income. Third, digital inclusive finance households have significant impacts on households of different ages, but the degree of impact is different. The impact on different age groups is in descending order of young households, elderly households, and middle-aged households; digital inclusive finance The promotion effect of development on the upgrading of the consumption structure of rural households is more obvious, but some consumption categories are not significant enough; digital inclusive finance has an impact on the consumption structure of households with different incomes, but some consumption categories are not significant enough, and can effectively promote the consumption structure of low-income households optimization.

Based on the above research conclusions, this paper mainly puts forward the following suggestions:

First, accelerating the construction of digital financial inclusion infrastructure is the top priority. A good network infrastructure is not only the foundation for the development of digital inclusive finance business, but also the premise for the long-term and healthy development of digital inclusive finance. In order to make digital financial inclusion services benefit more residents, the construction of digital financial inclusion infrastructure should be accelerated, and the coverage and service quality of digital financial inclusion should be improved, especially in rural areas and the central and western regions.

Secondly, improving the financial quality of residents is the key. All financial institutions should actively popularize financial knowledge while promoting digital inclusive finance, so as to improve the financial quality of residents. By carrying out lectures on financial knowledge, playing educational videos, and distributing publicity pages, the advantages of local financial institutions and village committees will be brought into full play, so that rural residents can understand and accept new financial products such as mobile banking and online small and micro financing, allowing more Financially excluded groups benefit.

Third, increasing the supervision of digital financial inclusion is an important part. In recent years, with the rapid development of digital inclusive finance, there have been frequent occurrences of platform runaways and fraud, which have damaged the interests of investors and disrupted the industry order. At the same time, information security is also an issue that cannot be underestimated. Some platforms do not properly store users' private data, and some fraudulent platforms even collect users' private data for profit under the guise of digital inclusive finance. Regulatory authorities must not only maintain traditional regulatory mechanisms and methods, but also innovate regulatory mechanisms and explore a regulatory system suitable for digital financial inclusion. Only by building a sound legal supervision system so that residents can use digital inclusive financial services with greater confidence can digital inclusive finance develop in a more healthy and long-term manner.

Finally, improving the digital inclusive financial product and service system is the only way. Digital inclusive finance affects the consumption structure of residents through the financial products and services it provides. Therefore, it is very necessary to further expand digital inclusive financial products and services and improve the digital inclusive financial product and service system. On the one hand, Internet finance companies such as Ant Financial and Tencent Finance, as the main force in promoting the development of digital inclusive finance, should continue to play a leading role, using the massive data of their own platforms combined with digital technologies such as big data and cloud computing to build personalized, diversified An online financial service system. On the other hand, traditional financial institutions must also be brave in innovation, seize the opportunities brought by the development of digital information technology, realize the digital transformation of products and services, actively explore the field of digital inclusive finance, and strive to innovate financial services and products.

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Research on the Impact of China's Development of Fintech on Resilience of Regional Economies

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Abstract With the development of the economy, various economic shocks are arising, and the resilience of the regional economy has become an important consideration in the regional economic development. As big data, cloud computing, artificial intelligence and other technologies continue to combine with the financial industry to form financial technology, giving the development of the financial industry a new vitality, the impact of financial technology on the resilience of the regional economy should not be underestimated. By selecting the panel data of 210 prefecture-level cities in China from 2010 to 2019, this paper first conducts a theoretical analysis of the relationship between Financial Technology and regional economic resilience in China, quantifies the use of entropy law on financial technology and regional economic resilience, and then conducts an empirical analysis of the specific mechanism of financial technology affecting regional economic resilience and the factors that enhance the effect of financial technology on regional economic resilience. The main conclusions are as following: (1) During the sample period, financial technology has a significant role in promoting regional economic resilience, in addition, the scale of urban economy, government intervention and market size also have a significant role in promoting regional economic resilience, while the level of opening up to the outside world has a weak negative impact on regional economic resilience. (2) Fintech can promote regional economic resilience through the channel of industrial structure upgrading. (3) The innovation and entrepreneurship level index will positively adjust the effect of financial technology on the resilience of regional economies. Finally, based on this, this paper puts forward policy recommendations for better improving the resilience of regional economies.

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Keywords Fintech · Regional economic resilience · Industrial structure · The level of innovation and entrepreneurship

1 Introduction

Affected by the COVID-19, the global economy continues to decline, the epidemic situation in sporadic areas is repeated, China's export demand has decreased significantly, and the operation speed of the economic system has slowed down, which has had a huge impact on the economy. In the face of the uncertain epidemic, whether the regional economic system can more effectively resist external shocks and whether it can quickly restore the internal resource allocation of the system, industrial recovery, etc. all depend on the resistance and resilience of the regional economy, that is, the resilience of the regional economy, the resilience of the regional economy mainly refers to the ability of the economy to quickly switch the economic resistance mode after the impact, achieving its own risk reduction results, and ensure the stable development of the regional economy [1, 2]. In this process, the structure and elements of the economy itself are constantly changing, and new economic ecological networks may also be created to cope with new shocks [3]. How to restore the vitality of industrial economic development and improve the resilience of the regional economy is the first factor that should be considered to ensure the orderly recovery of the economy and promote the long-term and efficient development of the economy. In recent years, with the continuous development of a variety of financial technology technologies, the continuous improvement of financial tools, big data, blockchain, cloud computing, digital economy and other advanced technologies have been continuously integrated with the development of the financial economy, to a certain extent, giving economic development a certain degree of fresh vitality. Fintech refers to technology-driven financial innovation,[1] in the face of the crisis, how much will the development of fintech affect the resilience of the regional economy, and how much will its development contribute to economic development? Can it help regional economies show great resilience and vitality in the face of tests like the pandemic?

Most scholars have affirmed that fintech has a positive impact on economic development [4], and some studies have shown that fintech innovation can directly promote the development of industrial economy [5, 6], and can also promote industrial upgrading through optimized resource allocation, indirectly promoting economic development [7]. Some scholars have also found that the development of financial markets has significantly improved the effectiveness of R&D investment from the perspective of financial markets [8]. Studies have also pointed out that if a region's trade is relatively freer, then financial development is particularly beneficial to the regional economy [9]. In addition, capital freedom and financial market development are also associated with higher income and growth rates [10].

[1] *The definition of fintech from the Financial Stability Board (FSB) has now become a global consensus.*

Regarding the research on regional economic resilience, most of the research focuses on the influencing factors of regional economic resilience, and some scholars have found that scientific research innovation, unemployment rate, Gini coefficient, and industrial structure agglomeration have a great impact on urban economic resilience, and the impact of technology spillover on economic resilience is presented as a "positive U-shaped" relationship [11]. However, There are also studies believe that the level of economic development is not necessarily related to economic resilience [12]. At present, the influencing factors of China's regional economic resilience are studied from the following perspectives: social capital, labor productivity, gross domestic product, employment rate, regional economic level and policy environment [13–15].

Some scholars have also conducted research from the perspective of digital economy or digital finance, and found that the digital economy has a driving effect on market operation and resource allocation [16, 17], so as to improve regional economic resilience. In addition, most scholars have constructed the mechanism of action of digital finance development level on the upgrading of industrial institutions, so as to promote the impact of financial technology on regional economic resilience, such as: the industrialization of digital finance and the improvement of industrial informatization on regional development [18], information technology to improve the structural form of the industrial chain, and promote supply-side structural reform [19], and some scholars take the industrial ecosystem as a research point to explore the adaptability of the industrial environment [20].

It can be found that at present, most of China's research on financial technology will focus on the digital economy, and with the digital economy as the main body to explore the impact of financial technology level, while China's regional economic research for regional economic resilience is mostly concentrated in the theoretical level of analysis, and for the face of the crisis in china's economy reflected in the resilience of the research less empirical analysis, but also lack of research on the connection between financial technology and regional economic resilience. Based on this, this paper will measure the development level of financial technology in the regional economy and analyze the economic resilience of China's regional economy in the post-epidemic era. In addition, the impact of the level of financial technology on the resilience of a regional economy to cope with shocks is further studied, and the mechanism of the role of financial technology level on the resilience of the regional economy is studied.

2 Theoretical Analysis and Research Hypotheses

2.1 Analysis of the Impact of Fintech on Regional Economic Resilience

The impact of fintech on the resilience of regional economies can be analyzed from two perspectives: reducing information asymmetry, breaking down information barriers and optimizing resource allocation, improving market efficiency.

2.1.1 Reduce Information Asymmetry and Break Down Information Barriers

Fintech has been able to break down information barriers [21] and make transactions cheaper, thus greatly improving the problem of information asymmetry. For each market, the situation of information asymmetry exists to a certain extent, and with the emergence of financial technology companies, it provides a better way for most enterprises in the market, especially emerging small and micro enterprises, to obtain information, improves the lack of information, and enables both parties to the transaction to better and fairly trade, thereby reducing losses and maximizing gains. At the same time, the continuous introduction of big data and other technologies enables some enterprises to quickly obtain the information and market conditions of other enterprises, which avoids the occurrence of market risks to a certain extent and improves transaction efficiency. At the same time, with the continuous acquisition of information by enterprises, each enterprise also continuously improves its own risk management in the process of business transactions, often able to accurately judge the future development trend before the market changes, so as to take some measures to reduce or even avoid losses.

From the perspective of individual market players, with the continuous entry of financial technology companies, the way to obtain information continues to increase, and the willingness to invest is constantly enhanced, individual investors are often more confident in the development of the market and avoid misjudgments about the situation in the market, in this way promoting the stable growth of a market. From the perspective of the financial entities of the market, after data collection and data analysis, through the accurate judgment of the business status of a company, the operating conditions of the loan fund enterprise are clarified, which often makes the enterprise face a smaller risk of capital recovery, improves the matching degree of high-quality customers, reduces the number of non-performing assets in the entire industry, and avoids the occurrence of secondary risks, thereby stabilizing the entire financial industry, and the rapid rise of financial technology can also affect other financial institutions through spillover effects, and promote companies to provide better customer service [22, 23]. In the entire industry, fintech can also efficiently and accurately screen out enterprises with high investment value, while reducing the development of bad enterprises, and forming a "survival of the fittest" development situation in the market, thereby avoiding waste of resources.

2.1.2 Optimize the Allocation of Resources and Improve Market Efficiency

The development and application of financial technology has given the market a new development path and source of power, promoted the two-way opening of the financial market, improved the service quality and service effect of the financial market, improved financial efficiency, and optimized the structure of the financial market. With China's investment in scientific and technological innovation research and development, especially the continuous maturity and development of 5G technology, financial technology is also accompanied by such dividends and trends to continue to develop and innovate, to achieve from the shallow level to the deep level of cooperation between finance and technology. In the 14th Five-Year Plan, it is proposed to "steadily develop financial technology and accelerate the digital transformation of financial institutions". Its mission is to accurately and inclusively serve the real economy and local economic development by allocating financial resources more efficiently to the parts needed for economic development. Through its own advantages, fintech reduces the cost of financial resources flowing in the system and effectively improves the information efficiency of enterprises [24]. In addition, before the region suffers economic shocks, flexible economic policies are introduced through financial supervision to ensure the reliability and security of financial products. Be able to accurately judge market risks, reduce the impact of the impact, make rapid adjustments in the market, and minimize the impact of economic shocks through the trinity of cooperation between the government, the financial industry and the real economy.

Continuously improving the allocation of financial resources and improving the financial system makes financial resources more inclined to a more efficient direction, which is conducive to improving market efficiency and enhancing the industrial agglomeration effect and industrial innovation development effect in the entire economic system. In the final analysis, the problem of economic development in a region is the problem of the allocation of financial resources, and a region with a good financial structure often has more momentum and potential for development.

Therefore, this paper proposes hypothesis 1: Fintech will increase the resilience of regional economies.

2.2 Analysis of the Indirect Impact of Fintech on Regional Economic Resilience

2.2.1 Industrial Structure Optimization Perspective

Fintech can empower the real economy and promote the dynamic upgrading of traditional industries [25], thereby promoting the high-quality development of the industrial economy [6], thereby improving the resilience of the regional economy.

On the one hand, financial technology through the downgrading of the threshold of financial services in the market, improve service efficiency, so that more small and micro enterprises can participate in financial services through new ways, so as to obtain available funds, thereby improving the development of the industry, only by continuously investing new types of enterprises and funds in industrial development, industrial development can continue. Through financial technology, economic resources are more inclined to promising and efficient enterprises, so that the industrial structure is optimized and upgraded. At the same time, the application of data technology to different industrial structures will make great changes in the production structure, so that technology-intensive industries can be fully developed.

On the other hand, finance transforms into investment in the real economy by absorbing idle funds, injecting capital vitality and promoting the upgrading of industrial structure. Insufficient financial development leads to the ability to innovate and start a business is hindered, through the application of digital technology to the traditional financial industry, derived a new financial industry form, to make up for the shortcomings of the traditional industry, enhance the availability of funds, enhance the innovation of enterprises, help to open up new service areas, more effective lending so that both sides can better play the value of funds and their respective advantages, and encourage enterprises to continue to innovate and develop. The improvement of enterprise innovation ability will often make the industry change to technology-intensive and achieve the value growth of economic development.

Industrial structure is the key basis for industrial development and resource allocation, and the upgrading of industrial structure essentially refers to the upgrading of the industrial organization and industrial layout of the entire industry, thereby changing the composition of a region's economic resilience. Regions with a more diverse industrial structure tend to be better able to withstand risks and show strong economic resilience [26]. At the same time, the diversification of the industrial structure can eliminate risks and reduce losses in a timely manner, and when the economy enters the recovery adjustment period, the stronger the regional resilience of the more diversified [27].

Therefore, this paper proposes hypothesis 2: Fintech can improve the resilience of regional economies through industrial structure optimization.

2.2.2 Innovation and Entrepreneurship Perspective

The main driving force of fintech is technological innovation, which is a series of financial instruments, financial systems, financial policies and systematic and creative arrangements for promoting technological development, cost transformation and high-tech development [28, 29]. Innovation is the primary productive force of the economy, and it is also the main driving force for promoting technological progress and promoting high-quality economic development, and most studies have shown that innovation has a significant role in promoting total factor productivity [30]. At the same time, entrepreneurship can also break the monopoly pattern to a large extent, continuously inject economic vitality into regional economic development, and can also greatly improve regional productivity [31], thereby improving regional economic resilience. The development process of financial technology depends on the continuous integration of financial instruments and the real economy, and the level of innovation such as technology research and development in this process largely determines the specific degree of integration [32, 33]. Therefore, financial technology plays an important role in technological innovation in the process of empowering the economy, and the higher the level of innovation and entrepreneurship in a region, the better the absorption capacity of financial technology, so as to empower the economy to improve economic resilience.

Therefore, this paper proposes hypothesis 3: the level of innovation and entrepreneurship can enhance the effect of fintech on the resilience of regional economies.

3 Research Design

3.1 Samples and Data

Selecting 210 representative prefecture-level cities in China from 2010 to 2019. For some cities, the missing data will be made up by consulting the statistical yearbooks of various provinces, statistical bulletins, and the yearbook of China's regional economic statistics. For the individual missing data that still exists, the average growth rate of the data in each of the two years before and after is used for interpolation.

3.2 A Measure of the Level of Fintech

Clearly measuring the level of financial technology development is the focus and difficulty of this paper. At present, scholars mainly use two-stage GMM regression method, VAR model, weight assignment method, entropy value method and analytic hierarchy method to conduct research [34, 35]. With reference to the above indicator

Table 1 Fintech level indicator construction

Objective	Level 1 indicators	Level 2 indicators	Indicator directionality
Fintech level	Fintech innovation level	Fiscal science and technology expenditure (10,000 yuan)	Positive
		The number of patents granted (pcs)	Positive
		R&D population (people)	Positive
		R&D input (million yuan)	Positive
	The level of financial technology development	Financial practitioners (people)	Positive
		Technology practitioners (people)	Positive
		The total borrowing amount of the head financial enterprise (%)	Positive
		The number of fintech companies (number)	Positive
		The main business income of high-tech industries (10,000 yuan)	Positive

construction method, the construction of financial technology indicators is shown in Table 1.

The level of financial technology innovation reflects the level of financial technology development of a region, financial science and technology investment is the cost of scientific research expenditure spent by each region in the annual financial expenditure, reflects the level of investment in science and technology by a regional government, the more investment is the more developed the level of financial technology, the amount of patent authorization reflects the level of scientific research shown by a region in a year, which can show the scientific research strength of a region. The more patents are granted, the less dependent the development of a region's enterprises is on traditional production methods and means of production, the R&D population is used to measure the investment of human capital, and the total R&D investment reflects the importance of a region's economic development.

The level of financial technology development shows the current level of financial technology in a region, is a quantitative concept, the number of employees in the financial industry and technology industry reflects the investment of a region in these two industries, the more the city with more employees, the more potential and market the development of the two major industries. The total loan amount of the head financial enterprise reflects the local financial institutions for enterprise investment, as well as the demand for financing of other enterprises, the number of extreme financial technology enterprises in each prefecture-level city can better reflect the level of financial technology in a region, high-tech industries often represent the development of scientific research technology in this region, the more income, the more mature the industrial development, the greater the help for financial enterprises.

3.3 Econometric Model Building

The regression model for empirical analysis is as following:

$$RES = C + \beta_1 RV + \beta_2 GDP + \beta_3 lnMARKET + \beta_4 GOV + \beta_5 OPEN + \delta \quad (1)$$

where β1 to β5 are the parameters of the variables, δ is the residual term and C is the constant term. RES is the explanatory variable, that is, the regional economic resilience level obtained from the comprehensive evaluation in Chap. 3, the RV is the explanatory variable, that is, it represents the level of financial technology development in each region, GDP represents the economic density of each region, MARKET represents the size of the urban market, GOV represents the degree of government intervention, and OPEN represents the degree of foreign investment.

3.4 Variable Descriptions

3.4.1 The Explanatory Variable

Regarding the measurement of regional economic resilience, most scholars comprehensively evaluate regional economic resilience by constructing indicators, and at present, the construction of indicators for regional economic resilience in China is generally studied from the following perspectives: social capital, labor productivity, gross domestic product, employment rate, regional economic level and policy environment [13–15]. Based on this, the measurement value of regional economic resilience in this paper is measured according to the TOPSIS, based on the following nine data, and the explanatory variables are expressed by RES, and the index system is constructed as shown in Table 2.

Economic affordability reflects a region's ability to resist external shocks from the perspective of economic growth based on its own resources and other production factors, and the ability to restore the industrial structure and economic functions reflected in economic indicators when it suffers from external shocks. This first-level indicator mainly includes three second-level indicators, three indicators: gross national product, the number of unemployed people insured, and the total retail sales of the community. GDP is a positive indicator. The number of unemployed people insured reflects the level that migrant workers in a region can bear after suffering unemployment, reflects the affordability of unemployment in a region, and is a positive indicator. The total retail sales of society can reflect the level of economic

Table 2 Regional economic resilience indicator system

Objective	Level 1 indicators	Level 2 indicators	Indicator directionality
Regional economic resilience	Affordability	Gross National Product (10,000 RMB) [36]	Positive
		Number of unemployed persons insured (person) [37]	Positive
		Total community retail sales (10,000 RMB) [36]	Positive
	Regional resiliency	Investment in fixed assets above designated size (10,000 rmb) [36]	Positive
		Fiscal self-sufficiency rate (%) [36]	Positive
		Degree of external dependence (%) [37]	Negative
	Innovative development capabilities	Loan-to-deposit ratio of financial institutions (%) [36]	Positive
		Number of invention patents authorized (units) [36]	Positive
		Number of students per 10,000 students (persons) [36]	Positive

development of a region and more intuitively reflect the consumption capacity of residents, and is a positive indicator.

Regional resilience reflects the ability of a region to reorganize its internal structure and repair the damaged parts after suffering different shocks, while adapting to the new economic environment, gathering internal resources, and achieving economic recovery through policy guidance and internal digestion. It includes three secondary indicators: the amount of fixed asset investment above designated size, the fiscal self-sufficiency rate, and the degree of external dependence. The total investment in fixed assets above designated size is the main indicator to measure its resilience, and with the increase of fixed asset investment, it can effectively adjust the regional industrial structure, which is a positive indicator. The fiscal self-sufficiency rate measures the resilience of the region and is a positive indicator. The degree of external dependence reflects the level of opening up of a region. Due to the impact of the epidemic, excessive dependence on external funds has the effect of poor teaching, so it is a negative indicator.

The ability of innovation and development is reflected in the fact that after the economic impact, a region will seek a new path of regional development in the future through technological innovation and through various learning and experience summaries. The deposit-loan ratio of financial institutions fully reflects the capital situation owned by financial institutions in the region and the recovery of the region, so it is a positive indicator to use the deposit-to-loan ratio of financial institutions to reflect the level of financial development of the region, thereby driving the development of the real economy. The number of invention patents authorized reflects the potential and level of scientific and technological development in a region, and a strong scientific research force can improve the region's excessive dependence on traditional resources, which is a positive indicator. The number of college students per 10,000 people means innovation and is a positive indicator.

3.4.2 Core Explanatory Variables

(1) The financial technology level index also adopts the TOPSIS method, which analyzes according to 9 indicators of financial science and technology expenditure, patent authorization, R&D population, R&D investment funds, number of financial practitioners, scientific research practitioners, total loans of financial enterprises, number of financial technology enterprises and main business income of high-tech industries, and uses RV to express explanatory variables.

3.4.3 Control Variables

(1) Urban economic density [36], calculated according to the proportion of regional GDP to the area of administrative regions. Expressed in GDP.
(2) Market size [38], calculated according to the population density of each region, expressed in MARKET, due to the excessive size gap between the regional population density data and other indicator data, so the logarithmic method is taken to reduce the scale gap between the data, expressed by LNMARKET.
(3) The degree of government intervention [12], calculated according to the ratio of local fiscal expenditure to regional GDP, expressed in GOV.
(4) Foreign direct investment [12], expressed in OPEN according to the ratio of foreign capital to regional GDP in each region.

3.5 Descriptive Statistics

This paper first descriptive statistics on the data of variables, and the descriptive statistics of variable-related data are shown in Table 3, which can be seen from the following table: the regional economic resilience of each region, and the level of financial technology development vary greatly from region to region.

Table 3 Descriptive statistical results for variables

	RES	RV	GDP	LNMARKET	GOV	OPEN
Mean	7.2946	3.8048	0.3563	5.7941	1.9808	2.9218
Median	4.6108	1.0691	0.1439	5.9814	1.6511	2.0958
Maximum	86.7251	77.4138	13.4837	7.8816	23.4876	29.8952
Minimum	0.7550	0.0601	0.0013	1.6094	0.4388	0.0003
Std.Dev.	8.0454	7.9835	0.8014	0.9490	1.4122	2.9456
Skewness	3.8009	4.7645	8.3623	−1.0926	7.2249	1.9626

4 Analysis of the Current Situation and Trend of Fintech and Regional Economic Resilience

4.1 The Level of Fintech Development

This paper selects the data of 210 prefecture-level 2010–2019 and measures fintech according to the method of Chap. 3, and divides the fintech level into 3 grades according to the average score of fintech level in the past 10 years according to the stronger fintech level, medium fintech level, and weaker fintech level, and obtains the following results, there are 49 with strong fintech level, 113 fintech levels with medium fintech levels, and 48 fintech levels with weaker fintech levels, such as Beijing, Shanghai, Shenzhen's financial technology level is very high, the gap with other cities is too large, and on the whole, it presents a spindle shape with two small middles, which is also a problem in China at present, and the gap between cities and regions is too large. The results are shown in Table 4.

By dividing the prefecture-level cities in China into the eastern region, the north China region, the northeast region, the central region and the western region, the changes in the level of financial technology between various regions from 2010 to 2019 are studied.

Through Fig. 1, it can be seen that China's financial level shows a large gap between regions, the level of financial technology in the eastern coastal area is very high, while the financial technology level in the western region and the northeast region shows a poor trend, which is also a major problem in the current development of financial technology in China. The level of fintech in cities along the eastern coast is generally higher than that of inland cities, especially for the western region, showing great regional differences. The economic and trade exchanges in the eastern region are frequent, which also causes too many financial resources and other economic resources to tilt, on the contrary, the northeast region due to regional development restrictions, the solidification of the regional industrial structure, excessive dependence on the primary industry and the old secondary industry, the lack of tertiary industry development, which also leads to regional economic development backward, high-tech science and technology cannot develop, while its own traditional financial industry development is relatively weak, the foundation is poor, according

Table 4 Fintech level comprehensive evaluation score

Fintech level	Score: > 5 is stronger; >1 and <5 is medium; <1 is weaker [39, 40]
The level of fintech is strong (49)	Shanghai, Beijing, Shenzhen, Guangzhou, Suzhou, Tianjin, Wuhan, Hangzhou, Chengdu, Dongguan, Chongqing, Qingdao, Nanjing, Xi'an, Shijiazhuang, Hefei, Ningbo, Wuxi, Foshan, Changsha, Jinan, Fuzhou, Zhengzhou, Yantai, Nantong, Shenyang, Xiamen, Quanzhou, Dalian, Guiyang, Changchun, Zhongshan, Wenzhou, Shaoxing, Nanchang, Harbin, Weifang, Huizhou, Jiaxing, Changzhou, Nanning, Zhuhai, Yangzhou, Zibo, Taiyuan, Haikou, Kunming, Taizhou, Wuhu
Fintech level medium (113)	Xuzhou, Weihai, Linyi, Baoding, Langfang, Ganzhou, Jining, Tangshan, Huai'an, Lanzhou, Mianyang, Liuzhou, Xiangyang, Luoyang, Tai'an, Urumqi, Jiangmen, Dongying, Qinhuangdao, Hohhot, Lianyungang, Yichang, Dezhou, Baotou, Yinchuan, Binzhou, Suqian, Zhuzhou, Xinxiang, Heze, Xingtai, Jiujiang, Shantou, Handan, Rizhao, Xuchang, Nanyang, Cangzhou, Xianyang, Ma'anshan, Yueyang, Guilin, Daqing, Ji'an, Bengbu, Deyang, Chaohu, Ordos, Baoji, Lishui, Xiangtan, Xining, Zhangjiakou, Putian, Jiaozuo, Xianning, Xiaogan, Zunyi, Xuancheng, Shangrao, Fuyang, Jilin, Jingzhou, Changde, Zhanjiang, Pingdingshan, Ningde, Huangshi, Huanggang, Nanping, Kaifeng, Yibin, Jingmen, Weinan, Anyang, Maoming, Hengshui, Qingyuan, Yulin, Zhumadian, Shangqiu, Luzhou, Suzhou, Lhasa, Zhoukou, Huainan, Jinzhou, Siping, Sanya, Bozhou, Shanwei, Qujing, Shaoguan, Xinyang, Jinzhong, Meizhou, Changzhi, Chengde, Yulin, Chifeng, Panzhihua, Huaibei, Yuxi, Leshan, Qiqihar, Chizhou, Panjin, Luohe, Hanzhong, Huangshan, Meishan, Linfen, Pingxiang
Fintech levels are weaker (48)	Jincheng, Fushun, Sanmenxia, Yangjiang, Huaihua, Tongren, Yan'an, Mudanjiang, Wuzhou, Tieling, Hulunbuir, Yunfu, Chaoyang, Huludao, Tianshui, Suihua, Yangquan, Jiamusi, Jiuquan, Tongchuan, Xinzhou, Pu'er, Zhangye, Hebi, Shuozhou, Hechi, Ya'an, Zhongwei, Songyuan, Guang'an, Baoshan, Lijiang, Dingxi, Pingliang, Qingyang, Hezhou, Zhangjiajie, Heihe, Wuhai, Liaoyuan, Jixi, Laibin, Longnan, Shuangyashan, Linzhi, Yichun, Qitaihe, Hegang

to the natural procedures of financial development, it is not possible to achieve a good combination with science and technology. In this way improving regional efficiency. The central region and north China are generally at a medium level due to reasons such as Beijing and Guangdong, but the level of financial technology in other regions of the region is relatively low.

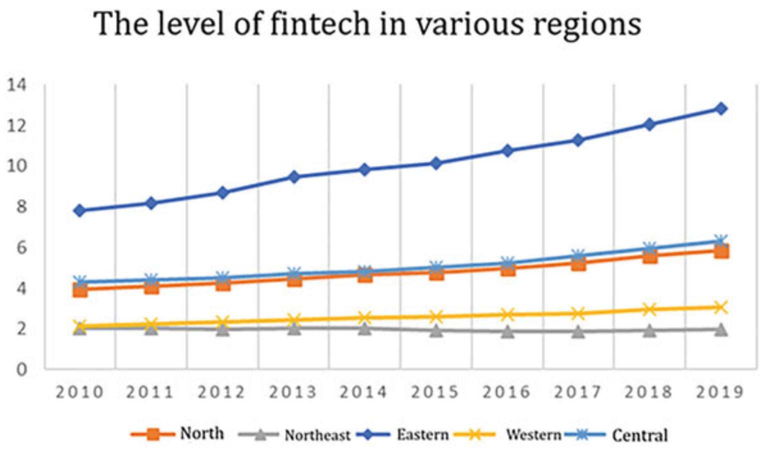

Fig. 1 The changing trend of fintech level in various regions from 2010 to 2019

4.2 The Level of Regional Economic Resilience Development

In this paper, the economic resilience levels of 210 prefectures from 2010 to 2019 are analyzed, and divided into three levels according to strong economic resilience, medium economic resilience, and weak economic resilience, as shown in Table 5.

From the data in the table, it can be concluded that there are 23 cities with strong economic resilience, 71 cities with medium economic resilience, and 116 cities with weak economic resilience, accounting for 10.95%, 33.81% and 55.24% of the total, respectively. Overall, a large proportion of cities with weaker economic resilience. Cities in the Yangtze River Delta region and the Pearl River Delta region are relatively economically resilient, and the level of major prefectures in Jiangsu and Guangdong is higher, while most provincial capitals can have strong economic resilience. Beijing, Shanghai, Shenzhen and Guangzhou ranked in the top four, showing strong regional advantages, while the subsequent other cities were mainly the capital cities of each province, the main reason is that the provinces will tilt the resource policy more in the construction of the provincial capital city, and continuously improve their economic strength at the same time, but also continuously improve the social resilience of the city, thus reflecting the overall level of development and economic resilience of the city. From the perspective of time span, in the 10 years from 2010 to 2019, the economic resilience level of most cities has maintained a stable growth trend, indicating that the national prefecture level is maintaining a good growth trend.

By dividing the prefecture-level cities in China into North China, Northeast China, Central, Eastern and Western Regions, the changes in the level of regional economic resilience from 2010 to 2019 are studied separately.

Through Fig. 2, it can be seen that the overall level of the five regions of the country is similar, after 2013, the economic resilience of North China has rapidly improved to the first position, the central and eastern regions are not much different overall,

Table 5 Regional economic resilience in prefecture-level cities

Toughness strength classification	Toughness score: >15 is stronger resilience; >5 and <10 is medium toughness; <5 is less resilient [41]
Cities with strong economic resilience	Beijing, Shanghai, Shenzhen, Guangzhou, Chongqing, Suzhou, Nanjing, Tianjin, Hangzhou, Wuhan, Chengdu, Zhengzhou, Qingdao, Xi'an, Ningbo, Jinan, Changsha, Wuxi, Hefei, Dongguan, Foshan, Harbin, Shenyang
Cities with moderate economic resilience	Fuzhou, Dalian, Quanzhou, Xiamen, Changchun, Changzhou, Yantai, Shijiazhuang, Nantong, Nanchang, Kunming, Weifang, Taiyuan, Wenzhou, Xuzhou, Zhuhai, Shaoxing, Tangshan, Jiaxing, Zibo, Zhongshan, Guiyang, Hohhot, Luoyang, Wuhu, Taizhou, Jining, Yangzhou, Lanzhou, Urumqi, Huizhou, Nanning, Linyi, Baotou, Weihai, Tai'an, Baoding, Ordos, Dongying, Handan, Xiangyang, Jiangmen, Nanyang, Huai'an, Langfang, Cangzhou, Haikou, Liuzhou, Jilin, Ma'anshan, Daqing, Yichang, Xinxiang, Shantou, Dezhou, Binzhou, Lianyungang, Jiaozuo, Qinhuangdao, Yinchuan, Zhuzhou, Yueyang, Pingdingshan, Jincheng, Jiujiang, Guilin, Xuchang, Zhanjiang, Jinzhong, Xiangtan, Yulin
Cities with weaker economic resilience	Heze, Shuozhou, Changde, Xianyang, Suqian, Anyang, Sanya, Panjin, Ganzhou, Putian, Huainan, Bengbu, Chifeng, Maoming, Rizhao, Baoji, Fushun, Jinzhou, Shangqiu, Changzhi, Xingtai, Mianyang, Kaifeng, Zunyi, Zhoukou, Xiaogan, Chaohu, Xinyang, Huanggang, Shangrao, Yibin, Zhangjiakou, Zhumadian, Sanmenxia, Linfen, Jingzhou, Songyuan, Luzhou, Nanping, Qujing, Jingmen, Xuancheng, Deyang, Mudanjiang, Chengde, Ji'an, Hengshui, Weinan, Luohe, Huaibei, Qiqihar, Lishui, Tieling, Fuyang, Hulunbuir, Qingyuan, Wuhai, Ningde, Yuxi, Chaoyang, Huangshi, Yulin, Huludao, Siping, Yangquan, Pingxiang, Xining, Huaihua, Suzhou, Meishan, Chizhou, Wuzhou, Suihua, Panzhihua, Yan'an, Yangjiang, Huangshan, Meizhou, Xinzhou, Hanzhong, Hebi, Leshan, Bozhou, Shaoguan, Qingyang, Jixi, Jiamusi, Guang'an, Yunfu, Liaoyuan, Xianning, Shanwei, Qitaihe, Lhasa, Jiuquan, Tianshui, Hegang, Shuangyashan, Heihe, Tongren, Zhangjiajie, Baoshan, Yichun, Pingliang, Ya'an, Hezhou, Pu'er, Hechi, Laibin, Tongchuan, Linzhi, Lijiang, Longnan, Zhongwei, Zhangye, Dingxi,

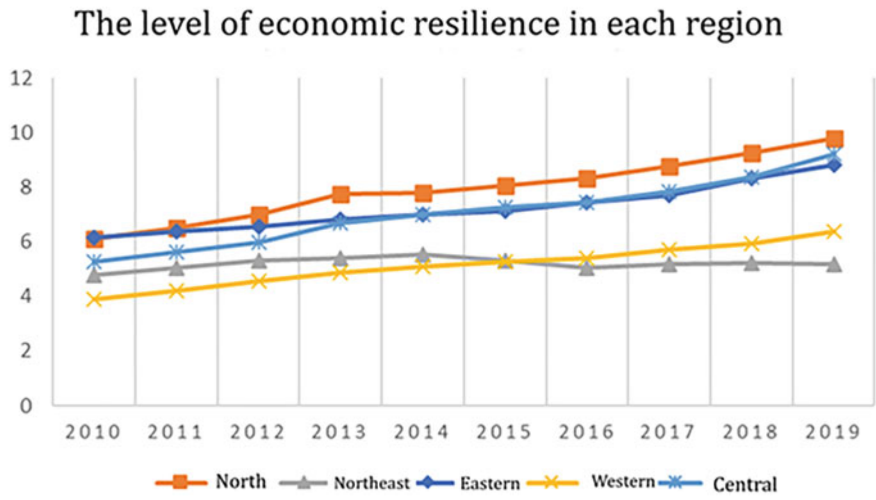

Fig. 2 Changes in the level of economic resilience in various regions from 2010 to 2019

while the western and northeastern regions are still at a low level, but the overall difference is not large. It is generally similar to the previous level of fintech. Because the industrial structure of the western region and the northeast region is solidified, the traditional industries in the region are overly dependent, and the development of the northeast region, especially Heilongjiang Province and the great northwest region, is based on the primary and secondary industries, lacks the fresh vitality of regional development, and lacks economic innovation. When suffering from economic shocks, there is often a lack of corresponding braking measures, resulting in economic losses. From the perspective of spatial distribution in cities, there are still many differences between cities in various regions of China, similar to the level of financial technology, and the overall trend of gradually decreasing from east to west is more reflected in the strong industrial base and the development of high and new technologies. On the other hand, a region with strong economic resilience can provide stronger impetus for regional development, form industrial agglomeration, and create good economic development benefits.

4.3 The Comprehensive Analysis of Fintech and the Level of Regional Economic Resilience

By studying the changes in the overall average level of fintech and regional economic resilience in 210 prefecture-level cities from 2010 to 2019, the following results are obtained, as shown in Fig. 3.

Through the chart, it can be clearly seen that the two indicators of the level of financial technology and regional economic resilience in various cities in China have

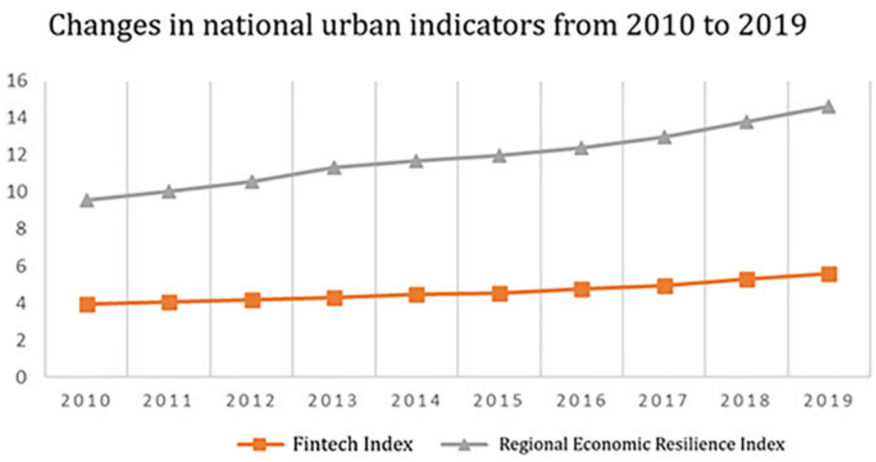

Fig. 3 Trends in indicators from 2010 to 2019

shown an overall upward trend in the past 10 years, and the development of regional economic resilience is more rapid. Especially after experiencing the financial crisis in 2008, various regions in China have gradually strengthened their attention to economic resilience, so the overall indicators of regional economic resilience in the past 10 years have risen in line with expectations. In terms of financial technology level, because big data, cloud computing, artificial intelligence and other technologies have been popularized and developed in recent years, especially in a region with relatively backward economic development, there is still a lack of financial technology development and technology, so the overall development in these 10 years is relatively stable, it is expected that in the next 10 years, with the popularization and development of financial technology, the level of financial technology in various regions will show the overall rapid development of the phenomenon.

From the change trend of fintech indicators and regional economic resilience indicators from 2010 to 2019, as well as the growth rate of fintech and regional economic resilience in various cities, it can be seen that fintech and regional economic resilience show a high positive correlation.

5 Analysis of Results

5.1 Benchmark Regression Results

This paper uses panel data from 210 cities from 2010 to 2019, and selects individual fixed-effect models based on the F-test. The results are shown in Table 6, and the regression results show that regardless of whether the control variable is added, the

Table 6 Basic regression results

Interpreted variables	RES	RES
RV	0.9575*** (139.5875)	1.07739*** (59.2566)
DGDP	–	0.5198 (0.8021)
LNMARKET	–	4.9621*** (5.9701)
GOV	–	0.0342 (0.9353)
OPEN	–	−0.0591*** (−3.6493)
C	3.6514**** (60.2024)	−25.3778*** (−5.2824)
F	19,484.66	1736.765
R^2	0.9027	0.9864

Note *** indicates rejection of the null hypothesis at a significant level of 1%, ** rejection of the null hypothesis at a significance level of 5%, and * rejection of the null hypothesis at a significance level of 10%

level of financial technology development will significantly promote the development of regional economic resilience, that is, the higher the level of regional financial technology, the higher the level of regional economic resilience. When the economy is impacted, the new technology of financial technology in the economic structure will form a role of an automatic stabilizer, quickly make the correct market response to the impact, thereby giving the market a strong economic resistance, and if the impact is too large, beyond the scope of the automatic stabilizer, the economy has been damaged, then the economy of each region will also be based on the area lost by the market, quickly allocate economic resources to achieve the effect of economic recovery, quickly restore the regional economy, and in the usual economic activities, The innovation and entrepreneurship capabilities attached to fintech can also give new path vitality to industrial enterprise development, thereby improving the resilience level of regional economies, which verifies hypothesis 1.

In terms of control variables, the scale of the urban economy reflects the relatively stable positive impact on the resilience of the regional economy, and because the variables are treated differentially, it is reflected in the degree of impact of the increase in the scale of the urban economy on the resilience of the regional economy, which has a good effect on the improvement of resilience. The market size measured by population density reflects the positive impact on the resilience of the regional economy, the market size plays an important role in regional development, the larger the market size, the wider the road of regional economic development, so that the audience of the regional economy is wider and has a wider market. At the same time, the degree of government intervention to a certain extent also has a promoting effect on the resilience of the regional economy, a market in the full play of the leading role of the market, more play the market's resource allocation function at the same time, the need for the government to activate and invest, especially in terms of funds

Table 7 Robustness testing results

Interpreted variables	RES (1)	RES (2)
IF	0.0123*** (68.4502)	0.0155*** (21.3028)
DGDP	–	10.9402*** (11.2488)
LNMARKET	–	9.8559*** (7.5735)
GOV	–	−0.1091** (−1.8658)
OPEN	–	−0.0404 (−1.5748)
C	5.1142*** (150.4046)	−52.5890*** (−6.9981)

Note *** indicates rejection of the null hypothesis at a significant level of 1%, ** rejection of the null hypothesis at a significance level of 5%, and * rejection of the null hypothesis at a significance level of 10%

and policies. The degree of opening up to the outside world reflects a weak negative correlation, too high external dependence often leads to the path dependence of regional economic development, and because the market of mature cities often has a good foreign market, while the market with poor economic development is relatively weak or lacks corresponding development opportunities in this regard, so the degree of external dependence shows a weak negative correlation.

5.2 Robustness Testing

In order to ensure the stability of empirical results, the explanatory nature of the interpretation evaluation method is guaranteed. In this paper, the digital financial inclusion index of each municipality measured by Peking University is used to replace the dependent variable. The empirical results are shown in Table 7, and the results show that the conclusions reached are consistent with the previous paragraph, indicating that the original model has a certain degree of robustness.

5.3 Mediating Effect Analysis

Based on the previous theoretical analysis, it can be seen that financial technology will promote the gradual development of the regional industrial structure in the direction of rationalization and upgrading, and the rationalization of the industrial structure is the basis for the development of regional economic resilience. Therefore, the intermediary variables in this article refer to the industrial rationalization and upgrading index of Yuan Hang and Zhu Chengliang [42], which are used as intermediary variables and are represented by the letter IC. Build the mediation model as following:

$$RES = C + \beta_1 RV + \beta_2 GDP + \beta_3 lnMARKET + \beta_4 GOV + \beta_5 OPEN + \delta_1 \quad (2)$$

$$IC = C + \alpha_1 RV + \alpha_2 GDP + \alpha_3 lnMARKET + \alpha_4 GOV + \alpha_5 OPEN + \delta_2 \quad (3)$$

Among them, RES represents the interpreted variable, that is, the regional economic resilience, the RV represents the level of financial technology, and the IC is the intermediary variable, that is, the rationalization index of the industrial structure. GDP, LNMARKET, GOV, and OPEN are the control variables, which are the four variables of regional economic density, market size, degree of government intervention, and foreign direct investment.

To test whether the rationalization of industrial structure plays an intermediary role in the relationship between the level of financial technology and the resilience of the regional economy. Table 8 lists the regression results of each model. Column (1) shows the basic regression model of fintech level on regional economic resilience, and column (2) studies the impact of fintech level RV on industrial structure rationalization index IC.

First of all, after analyzing the model (2), it can be seen that the coefficient significance of the financial technology level has passed the test, which means that financial technology has a significant positive effect on the resilience of the regional

Table 8 Mediating effects test results

Interpreted variables	RES (1)	IC (2)
RV	1.07739*** (59.2566)	0.0176*** (7.2360)
DGDP	0.5198 (0.8021)	−0.1784** (-2.0515)
LNMARKET	4.9621*** (5.9701)	0.6116*** (5.4784)
GOV	0.0342 (0.9353)	0.0442*** (8.9954)
OPEN	−0.0591*** (−3.6493)	−0.0127*** (−5.8431)
C	−25.3778*** (−5.2824)	2.8636*** (4.4365)

Note *** indicates rejection of the null hypothesis at a significant level of 1%, ** rejection of the null hypothesis at a significance level of 5%, and * rejection of the null hypothesis at a significance level of 10%

economy. According to the results of the influence of the fintech level RV on the industrial rationalization index IC in column (2), the coefficient of the fintech level RV at the significant level of 1% is 0.0176, and the t-value is 7.2360, which passes the test below the significant level of 1%, indicating that the fintech level has a certain positive effect on the rationalization of the industrial structure, and the higher the financial technology level, the higher the level of rationalization of the regional industrial structure. Thus, it is concluded that there is a partial intermediary effect between the level of financial technology and the resilience of the regional economy, which is manifested as the acceleration effect of the impact of financial technology on the resilience of the regional economy, which verifies hypothesis 2.

5.4 Regulatory Effect Analysis

When financial technology changes the market innovation structure, enhances the development and innovation of the regional economy, thus changing the level of regional economic resilience, and the level of innovation and entrepreneurship also affects the development of financial technology, which helps to promote the continuous improvement of financial technology, according to the previous hypothesis, through further regression analysis to select regulatory variables, to study whether the impact of innovation structure on financial technology and regional economic resilience has a regulatory effect. In this paper, a model of fintech on the resilience of regional economies is constructed, and empirical analysis is carried out by adding the regulatory variable innovation and entrepreneurship index IU and the interaction between the fintech level RV and the regulatory variable IU. With reference to the theoretical research of Long Jianhui [43] and Mao Wenfeng [44], the innovation and entrepreneurship level index is taken as a regulatory variable, which plays a positive role in regional economic resilience, represented by the letter IU. The moderating effect model is constructed as following:

$$RES = C + \lambda_0 IU + \lambda_1 RV + \lambda_2 IU \times RV + \lambda_3 GDP + \lambda_4 lnMARKET + \lambda_5 GOV + \lambda_6 OPEN + \delta_4 \quad (4)$$

Among them, RES indicates that the interpreted variables are regional economic resilience, RV indicates the level of financial technology, all of which are obtained from the comprehensive evaluation of Chap. 3, IU is the regulatory variable, that is, the regional innovation and entrepreneurship level index, IU × RV are interactive items, and GDP, LNMARKET, GOV, and OPEN are the control variables, which are the four independent variables of regional economic density, market size, degree of government intervention, and foreign direct investment. If $\lambda 2$ is significantly greater than 0, it means that the level of innovation and entrepreneurship can strengthen the impact of fintech level on regional economic resilience, while if $\lambda 2$ is not significant or equal to 0, it means that there is no regulatory effect.

Table 9 Modulating effect test results

Interpreted variables	RES (1)	RES (2)	RES (3)
RV	1.0773*** (59.2566)	–	2.0218*** (8.0009)
IU	–	0.2180*** (4.1651)	1.4726 *** (3.5753)
IU × RV	–	–	0.9595*** (3.7469)
DGDP	0.5198 (0.8021)	0.2576*** (2.7915)	0.6318 (0.9781)
LNMARKET	4.9622*** (5.9702)	1.1888*** (9.9372)	4.8326*** (5.8293)
GOV	0.0342 (0.9353)	0.01059** (1.9523)	0.0361 (0.9885)
OPEN	−0.0591*** (−3.6493)	−0.0052*** (−2.1690)	−0.0597*** (−3.6766)
C	−25.3778*** (−5.2824)	−5.3467*** (−7.7202)	−25.8417*** (−5.3977)

Note *** indicates rejection of the null hypothesis at a significant level of 1%, ** rejection of the null hypothesis at a significance level of 5%, and * rejection of the null hypothesis at a significance level of 10%

Table 9 lists the validation of the model (4), of which (1) is listed as the original regression analysis, that is, the impact of financial technology on regional economic resilience, and column (2) studies the regression structure of innovation and entrepreneurship level IU on regional economic resilience RES. Column (3) is the result of the addition of fintech, innovation and entrepreneurship level index, and the interaction between fintech and innovation and entrepreneurship level index.

Column (1) is the basic regression model of the financial technology level on the regional economic resilience, and it can be seen that the coefficient of the influence of the financial technology level on the regional economic resilience is significantly positive, indicating its positive effect on the regional economic resilience. Column (2) concludes from the impact of the Innovation and Entrepreneurship Index on regional economic resilience alone, which passes the 1% significant level test, which shows that the Innovation and Entrepreneurship Index has a significant effect on the increase of regional economic resilience. In column (3), the interaction term IU × RV was significantly positive at a significant level of 1%, and through the significance level test, it showed that the innovation and entrepreneurship index increased the sensitivity of the fintech level to the impact of regional economic resilience. By comparing the RV level of fintech in columns (1) and (3) and the interaction term coefficient is significantly positive, it can be concluded that innovation and entrepreneurship further strengthen the impact of fintech development on regional economic resilience, that is, the higher the level of innovation and entrepreneurship, the greater the positive effect of fintech on regional economic resilience, which can be concluded that the level of innovation and entrepreneurship has a regulatory effect on the relationship between fintech and regional economic resilience, and hypothesis 3 is verified.

6 Conclusions and Implications

Based on the data of 210 prefecture-level cities in China from 2010 to 2019, this paper conducts theoretical and empirical research on the effect and mode of effect of financial technology on regional economic resilience. The main conclusions are as following: (1) During the sample period, financial technology has a significant role in promoting regional economic resilience, in addition, the scale of urban economy, government intervention and market size also have a significant role in promoting regional economic resilience, while the level of opening up to the outside world has a weak negative impact on regional economic resilience. (2) Fintech can promote regional economic resilience through the channel of industrial structure upgrading. (3) The innovation and entrepreneurship level index will positively adjust the effect of financial technology on the resilience of regional economies.

Based on this, this article proposes the following policy recommendations:

(1) Improve the level of fintech development. The results of this paper show that fintech has a significant role in promoting regional economic resilience. Therefore, we should vigorously develop financial technology, improve the level of application of digital technology, continuously introduce relevant talents and technologies, and actively combine with local enterprises to create a good financial service system, give full play to the investment transformation function brought by finance, and lay a good foundation for economic development. Use fintech to improve the level of financial services, so that more enterprises can obtain funds, while widely publicizing financial technology and creating a good market environment. Strengthen inter-regional ties, radiate outward according to high-tech cities, achieve a good economic operation system, and provide stable economic resources for economic development.
(2) Encourage public innovation and promote the transformation of innovative achievements. The results of this paper show that the Innovation and Entrepreneurship Index will positively adjust the role of fintech in promoting the resilience of regional economies. Therefore, the market should invest more market resources into basic economic innovation enterprises based on Internet big data, and give play to its role as the main body of the market, promote the further integration of digital technology with other industries, improve the threshold for market entry, vigorously invest advanced technology in the real economy, improve the regional industrial structure and market structure, so that more new enterprises can survive smoothly in the market, so that more investors can enter the system. The addition of new investors has brought new vitality at the same time, but also brought capital and innovation, and more innovative and

entrepreneurial enterprises have joined, further expanding the positive feedback effect of financial technology in the resilience of the regional economy.

Secondly, while ensuring the innovative development of the regional economy, the government regulatory departments should always pay attention to the monitoring of financial technology, while ensuring its efficiency to serve the market, prevent greater financial risks, and provide better protection for regional economic development. Create a good atmosphere and environment for innovation and entrepreneurship, establish industrial parks, and then form a good industrial chain to enhance urban resilience.

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The Impact of Digitization on Bank Operation and Regulation

Xibo Sun and Ke Wang

Abstract At present, the digital transformation of global commercial banks is basically at the same level, and gradually expands from the focus on strategy formulation, cultural atmosphere, online business and electronic channels in the initial stage of digital transformation to various fields such as organizational structure, business channels, marketing models, risk prevention and control. Its transformation path mainly includes the following points: change the concept; Personnel transformation; The transition from a carb to an account base; The shift from the branch economy to open banking and the transformation of business models. From a global perspective, digital transformation still faces multiple challenges, mainly in the lack of talents, insufficient capital investment, and unsuitable corporate culture. From the domestic point of view, China's banking industry is still facing a series of practical problems and challenges, for example, the system is closed and isolated, and it is difficult to adapt to changes in the situation; The data foundation is weak, and the data island phenomenon is more serious under the analysis ability; There is a serious shortage of professional talents. Based on this, China's banking industry should establish a digital management system; Build a big data security defense mechanism; Introducing FinTech talent; Strengthen data security management capabilities to protect customer privacy; Implement a real-name account system.

Keywords Digital transformation · Commercial banks · Financial regulation

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1 Introduction

With the construction and development of network infrastructure, the digital economy has become an important "prescription" for economic transformation, constantly breaking down barriers and development boundaries between industries, and gradually becoming an important force related to the future direction of the world economy. According to the data, the scale of China's digital economy reached 3.92 billion yuan in 2020, accounting for 38.6% of GDP, becoming an important force supporting the national economic recovery under the epidemic.

The advent of the digital economy era has inevitably promoted the reform of commercial banks [1, 2]. First of all, digital industrialization has brought about the rapid development of big data, cloud computing, and artificial intelligence, thus providing technical support for the digital transformation of the commercial banking industry, and the application of digital technology has promoted the establishment and renewal of banks, through the use of internal resources of commercial banks for risk prevention and management, building an open platform, reducing operating costs, effective intelligent decision-making, and improving data mining capabilities [3, 4]; Second, the development of industrial digitalization has made big data a basic strategic resource for the development of digital intelligence, and big data has penetrated into all fields of society, improving the speed and efficiency of industrial innovation and development, driving the economy to achieve high-quality development, and promoting banks to carry out risk prevention and control and management; Third, the development of commercial banks should grasp the application of data, do a good job in data governance, and build an ecological governance system connecting the G-end, B-end and C-end [5–7].

2 Theory of Financial Engineering

2.1 Theory of Financial Innovation

Financial innovation is a theory of a demand-induced profit-driven financial phenomenon. However, the theory has not yet formed a systematic and complete theoretical system, usually explained with the help of theories in microeconomics. Economists argue that financial innovation is created to prevent companies from maximizing profits and utility.

The digital transformation of the financial industry refers to the use of emerging technologies to connect the various entities related to enterprises in the digital environment and transform them into the form of data, which is conducive to enterprise management decisions and realizing corporate value reshaping. Therefore, how to realize the value of the enterprise through the effective use of data has become the ultimate goal of the industry's digital transformation. At this stage, to achieve digital transformation in the financial industry, it is necessary to use digital technology, use enterprise data for product innovation, adjust business orientation and service standards, expand the scope of business services, achieve accurate market positioning and customer updates, carry out banking risk prevention and control and management, and promote profit growth. At the same time, due to the special social attributes of the financial industry, the operation of the financial industry has more financial roles and goals, and in addition to the need to provide financial services, it is also necessary to integrate and allocate resources.

2.2 The Long Tail Theory

When the demand for a product is not large or the sales volume is not high, but the amount of savings is large enough and the distribution channels are enough, its proportion of market share can be matched with some products with high sales, which is the long tail theory. In the traditional demand curve, the head is a hot product, and the long tail is a cold product, but the cold product contains the needs of more people, and when the power of the small market accumulates enough, it will also surpass the mainstream market, which is related to the sales volume of the enterprise.

With the advent of the digital age, the rapid development of digital technology, the long-tail effect has been closely related to people's lives, stimulating the renewal and reform of the industry, transformation and upgrading, of which financial services have slowly focused on long-tail customers. In commercial banks, if you want to use the long tail theory to reduce the cost of product niche, you can change the horizontal and vertical axes of the demand curve to the number of users and the value created by users, respectively, in order to achieve the extension of digital inclusive services, you must consider extending the length of the long tail or thickening the thickness of the long tail. First of all, commercial banks should use digital technology to update service content, innovate service models, attract more users, and achieve the growth of the number of users and the expansion of service scope. Secondly, banks can cross-sell, so that users can reduce the cost of search, provide customers with more levels of demand, and make the value created grow. Therefore, commercial banks should focus on the in-depth needs of "non-traditional high-quality customers", not only to pay attention to the financial service needs of large enterprises and traditional high-quality customers, but also to focus on the deep needs of a huge number of non-traditional high-quality customers and small enterprises, and how to improve their service experience, so that the competitiveness of commercial banks in the market is enhanced, so as to achieve innovation and breakthroughs in bank development.

2.3 Big Data Theory

With the development of digital technology, big data is often used to help people solve the problem of information asymmetry, the application field was initially mainly in the IT field, and now it has been widely used in the financial field, and has gradually developed into a new generation of information technology and service forms.

In the financial industry, with the help of digital technology, accurate analysis of massive amounts of big data can provide high-quality support for the daily business of banks, a deeper understanding of customers, and help each object to make more accurate and effective decisions. The use of big data to analyze customers' daily consumption data can establish a credit scoring system and risk control for individuals, accurately predict customer needs, and improve bank financial risk management capabilities. At the same time, the application of big data in commercial banks is also an effective way to solve the problem of financial inclusion. Digital inclusive finance has reached a golden age of development and has received attention from all over the world. Big data can provide technical support for solving financial inclusion, reduce the cost of pre-decision-making and post-event risks of inclusive finance, innovate financial services, and enable banks to better provide financial services and carry out operation and management. While focusing on the opportunities that big data brings to the financial industry, we must also pay attention to the risks and challenges it brings. The rapid development of the Internet has brought about information security issues, especially in the financial field, user information leakage will lead to various financial crimes, greatly harming the interests of users, so it is necessary to pay attention to risk management to ensure data security.

3 The Digital Transformation of Commercial Banks

From the perspective of the digital transformation process, the banking industry as a whole has experienced four periods: manual upgrading period, information substitution period, digital budding period and digital explosion period.

During the manual upgrade period, the main feature of this stage is the computerization of accounting. Based on the development of science and technology, banks in Europe and the United States were the first to use microcomputers on a large scale, the first bank in China to use computers was the Bank of China, in 1982, the Bank of China Embassy District had two windows to use computers to work, and slowly began to explore the computer in China's banking industry.

In the period of information substitution, computers have been practiced in banking business, and the scope of application has continued to expand. The financial derivative business of the European and American banking industry has developed rapidly, and the proportion of non-interest income has increased significantly. JPMorgan Chase & Co. and Citibank have become the forerunners of the industry, and the ratio of their derivative business amount to loan amount is as high as 130 to 1 and 110 to 1 respectively. China's banking industry combined with the actual conditions of the country, extracted the abstract concept of informatization, through the introduction, digestion, absorption and independent innovation of the combination, the introduction of IBM4300, ES9000, RS6000, AS400 and other advanced large, medium and small computer processing systems, in the counter, accounting, retail, credit, national settlement and other major business areas, and strive to achieve computer information processing, continue to carry out information construction. The main features of this period are the comprehensive promotion of inter-bank network clearing, as well as the wide application of electronic channels such as online banking, ATM, and telephone banking.

In the early stage of digitalization, the Banking industry in Europe and the United States continued to carry out the exploration of online digitalization. Especially after the 2008 international financial crisis, jpmorgan Chase and Wells Fargo, represented by the digital transformation of information technology, demonstrated excellent risk control ability and maintained a low non-performing ratio. During this period, the informatization of China's banking industry has also developed rapidly, generally increasing IT construction investment, the number of computer configuration has increased significantly, and the depth and breadth of software application has been rapidly expanded. The main feature of this period is the migration of face-to-face customer channels to digital channels, and mobile financial services such as mobile banking gradually become the mainstream.

Since 2014, the global banking industry has entered the digital explosion period. Digital transformation from disagreement to consensus, and with the banking industry strategic transformation and investment reform alternate upgrading, showing a trend of gradual acceleration. In terms of strategy, leading banks around the world have developed comprehensive digital priorities and growth strategies. Jpmorgan Chase has built a digital bank in an all-round way, formulated the strategy of "mobile first, everything digital", and continued to promote digital transformation. Citibank has put forward the transformation strategy of "mobile first" and "digital bank" successively. China's large state-owned commercial banks have also put forward digital strategies, such as E-ICBC of INDUSTRIAL and Commercial Bank of China, Agricultural Bank of China's "Fintech+", Bank of China's technology-led digital development strategy, China Construction Bank's "Most Intelligent Bank", and Bank of Communications's "Digital and Intelligent Bank of Communications". In terms of personnel and investment, the AVERAGE US banking industry invests about 20% of pre-tax profits in digital transformation and innovation every year. Jpmorgan's annual tech budget has increased to $12 billion, up from $9.5 billion in 2020. According to the China Banking and Insurance Regulatory Commission, the total investment in science and technology by China's large state-owned banks in 2021 exceeded 100 billion yuan.

4 Analysis of the Current Situation of Digital Development of China's Commercial Banks

Since the founding of the People's Republic of China, China's commercial banks from the "great unification" system, the transition to professional banks, commercial banks, especially in the reform and opening up for forty years, commercial banks operating shareholding system reform, the establishment of a market-oriented operating system and mechanism, commercial banks to achieve high-speed, healthy development, its financial field occupies an absolute weight of the share, in the economic development of the decisive role. The historical contribution and responsibility of the development of commercial banks in the process of building socialism with Chinese characteristics and promoting high-quality social economy and development are increasing. Like all economic entities, enterprises can continuously enhance their vitality in the market economy, one is from the pressure of external market competition, the other is from the internal innovation power, and since the reform and opening up, the important factors driving the rapid development and butterfly changes of commercial banks, in addition to the policy dividends of reform and opening up, technological innovation and drive is a key part of it.

The first is the universal use of PCs, so that the daily affairs of the bank can be operated electronically, employees can get rid of a large number of tedious and repetitive work, greatly improving work efficiency; The second is the use of the Internet, the use of the network, can make the distance of the physical outlets can be contacted, within the bank so that the business can be unified management, between different banks, inter-bank, cross-provincial and municipal are no longer a problem, breaking through the limitations of a single legal person system, the national network can be shared information, for customers, unrestricted regional network settings can greatly improve their service experience; The third is the emergence of the mobile Internet and the emergence of virtual service platforms, banking services can be transformed from offline to online operations; The fourth commercial bank widely uses financial technology, has changed the traditional concept of physical banking to the concept of digitalization of emerging banks, technology has not only been a tool for commercial bank managers in the traditional sense to achieve business ideas, but sublimated into a personalized manager who assists, assists or even directly manages banking business. This process of integrating big data, blockchain, artificial intelligence, Internet of Things and cloud computing with the various businesses of commercial banks as the main tools is the digital process. Technical tools have risen to become an important decision-making management tool for commercial bank managers, to a certain extent more scientific, accurate, efficient than people's subjective decision-making, play a decisive role, and in the face of fierce business competition in the same industry and external squeeze of foreign financial opening, the higher the degree of digitalization of the bank its competitiveness, therefore, digitalization has become the supreme magic weapon for today's commercial banks to compete and win.

On the whole, the digital transformation of China's commercial banks has progressed rapidly, but it cannot be ignored that the development is also facing the following challenges:

1. Strategic planning: Strategic planning can guide the direction of the bank's digital transformation and determine the development tone, but most of China's banks have not yet formulated a suitable strategic plan, there is a lack of top-level design, it is impossible to plan the financial business as a whole, the basic support of data

transformation is insufficient, and the depth and breadth of development need to be improved [8].

2. Organizational culture: the coordination mechanism between various departments of the bank is not perfect, the interests between departments are not clear, resulting in difficulties in data sharing, lack of cross-organizational coordination mechanism, insufficient cooperation power in core business, more contradictions between traditional departments and new departments, and difficulty in stimulating business practice and innovation in the organizational culture mechanism.
3. Technological innovation: The financial industry represented by banks needs to rely on the development of digital technology if it wants to carry out digital transformation, and scientific and technological innovation will help empower various financial businesses, but technological innovation will also bring risk management challenges and problems.
4. Talent investment: The digital transformation of commercial banks requires digital talents with relevant business backgrounds and excellent technical capabilities, but the current shortage of compound talents makes it difficult to promote the digital transformation of the financial industry, and it is difficult to achieve the renewal and iteration of the financial services industry. How to attract talents into the banking industry and leave talents to jointly build the digital process of the bank is an important problem.
5. Data governance: The rapid development of big data will bring about data governance problems, data openness and sharing need to protect the customer's data privacy as the premise, for data analysis and processing and mining analysis capabilities also need to be improved, reduce data management and storage costs, better make data play its role [9].

5 Regulatory Advice on the Digital Transformation of Commercial Banks

1. Establish a digital management system. In the era of digital economy, commercial banks first need to establish a management system around "digital", with the help of electronic and intelligent devices under digital technology, automatically complete most of the simple and repetitive work, and employees only need to be responsible for some personalized service work; In addition, the establishment of a management system also needs to revolve around the concept of "information", the headquarters of commercial banks as an information center, with the help of branches to collect information, so that commercial banks will be transformed into a system that collects information and processes information [10].
2. Improve the talent selection mechanism and introduce financial technology talents. In the selection of financial technology talents, it is necessary to set a good scoring system, pay attention to the financial innovation ability and business ability of talents, set up an open and transparent selection mechanism,

and prohibit the emergence of bad trends in the selection process to affect the admission of outstanding talents. The admitted talents should be trained regularly, emphasizing the safety awareness of financial personnel, doing a good job in financial supervision and information confidentiality, taking over the work content faster, and consciously improving their business level, and constantly stimulating their work potential. Encourage employees to report internally to ensure the healthy operation of the organization.

3. Strengthen data security management capabilities and protect customer privacy. As a special financial services industry, banks need to focus on clarifying the security of data, understanding data ownership and trading rights. With the accelerated development of the Internet, the total amount of data held by banks is also growing rapidly, so data management and governance have become an important mission of banks [11–13]. Because, if the bank has a management error, resulting in the leakage of the customer's personal privacy information, the impact on the whole society will be very tragic, and the bank will be difficult to repair the credibility in people's hearts.
4. Build a big data security defense mechanism. With the advancement of science and technology, banks can use evil anti-virus software to block some information infringement and theft, maintain and rectify the entire system, and regularly use antivirus software for virus scanning to prevent some potential hackers and vulnerabilities. Identity technology can help us ensure the privacy of our customers, and deferred payment technology helps customers have a buffer time when facing scams, allowing time to think calmly, reducing the number of cases in which scams occur under impulse.
5. In order to prevent the occurrence of acts that harm social interests such as online gambling and vicious money laundering, commercial banks should implement the real-name account system. And regularly check the customer's information to prevent some people from illegally stealing other people's accounts for fraud, while often passing on to customers some of the financial scams currently circulating on the market, training cardholders' self-protection awareness, so that customers can improve their self-prevention awareness, protect their account information, and ensure the security of the card.
6. Focus on risk management in digital banking. In the face of some financial scams, there are related technologies that can be prevented and controlled, but the technology is also designed by natural persons, so there may be some technical loopholes, and at the same time, in the digital age, there must be some risks [14]. However, digital banks cannot rely entirely on digital technology, and they also need to be managed and maintained by natural persons to regularly audit their operations.
7. Vigorously develop digital banking regulatory technology. The digital transformation of commercial banks will inevitably put forward new requirements and challenges for digital supervision, first of all, to enhance the technical capabilities of digital supervision in financial supervision, to formulate a feasible regulatory system in combination with the actual development of banks, and at the same time

to continuously update the concept of supervision and enhance the proportion of technology in the digital supervision of banking business [15, 16].

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Dynamic Connectedness of Financial Market Volatilities

Keqin Zhang

Abstract Based on the generalized variance decomposition, this paper measures the dynamic connectedness of financial market volatilities across four major economies, and analyzes the shock sources of China's financial market volatility. The result shows that the dynamic connectedness of financial market volatilities rose sharply during the 2008 financial crisis, the European debt crisis and COVID-19. China's financial market volatility has a high influence on other financial market volatilities in several periods while the contact with other financial markets is not close. The US and the UK are the main sources of connectedness China's financial market volatility receives. This paper provides new insights to improve China's financial risk management ability.

Keywords Dynamic connectedness · Financial market volatility · Financial risk

1 Introduction

With the acceleration of financial deepening and economic globalization, the capital flow between financial markets is becoming more and more frequent, which leads to the increasingly closer relationship between the volatility of financial markets. After the outbreak of COVID-19 in 2020, the historic four circuit breakers of the S&P 500 index in the US stock market have had a dramatic impact on other economies' financial markets (Zhang et al. 2020 [1]).

At the same time, the contagion of global financial market volatilities during the 2008 financial crisis shows that the interaction of economic variables may be not simultaneous, which is similar to the dominoes. Several studies have used the GARCH model to estimate the relationship between different variables (Kenourgios et al. 2011 [2]; Antonakakis et al. 2013 [3]), and realized volatility predictive model is also widely used to assess the impact between different variables (Chiang 2019

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[4]; Li et al. 2019 [5]). By analyzing the impact of one variable on the fluctuation of another variable, the variance decomposition model has become a new perspective to measure the connectedness between economic variables across economies (Diebold and Yilmaz 2012 [6]), in which the relationship between variables can be easily quantified and compared (He et al. 2020 [7]; Si et al. 2021 [8]). Based on the generalized variance decomposition model, Zhao et al. (2022) [9] used the proportion of variance to estimate the influencing factor on the crude oil price. However, not much scholarly attention has been paid to the shock sources of market volatility using this method.

To sum up, the existing studies have measured the connectedness between the economic variables, but have not further investigated the shock sources of China's financial market volatility based on the connectedness results. In view of this, using the extreme value method and the generalized variance decomposition model, this paper analyzes the dynamic connectedness of financial market risks across major economies and the shock sources of China's financial market volatility.

2 Methodology and Data

In this paper, we use the generalized variance decomposition based on the vector autoregression (VAR) to measure the connectedness of financial market volatilities. This method can measure the two-way connectedness between different variables and avoid the disadvantage that the traditional Cholesky variance decomposition results are easily affected by the ordering of variables (Diebold and Yilmaz 2014 [10]). In terms of sample data, we use the extreme value method to estimate the financial market volatility of global major economies.

2.1 Dynamic Connectedness Measurement Based on VAR Framework

Firstly, we construct a covariance stationary m-variable VAR(p) model:

$$X_t = \sum_{i=1}^{p} \Phi_i X_{t-i} + \varepsilon_t \tag{1}$$

Then the VAR(p) can be converted to VMA(∞) model:

$$X_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \tag{2}$$

Based on the generalized variance decomposition proposed by Pesaran and Shin (1998) [11], the proportion of the shock from variable j in the n-step-ahead error variance of variable i is:

$$\theta_{ij}^{g}(n) = \frac{\sigma_{jj}^{-1}\sum_{h=0}^{n-1}\left(e_i{}'A_h\Sigma e_j\right)^2}{\sum_{h=0}^{n-1}(e_i{}'A_h\Sigma A_h{}'e_i)} \quad (3)$$

As the sums of forecast error variance proportions are not necessarily unity, we further standardize the generalized variance decomposition results as the connectedness from variable j to variable i:

$$C_{ij}(n) = \tilde{\theta}_{ij}^{g}(n) = \frac{\theta_{ij}^{g}(n)}{\sum_{j=1}^{m}\theta_{ij}^{g}(n)} \times 100\% \quad (4)$$

Finally, in order to investigate the dynamic connectedness of financial market volatilities, we use the rolling-window approach to obtain the time series of generalized variance decomposition results (Zhao et al. 2022 [9]).

2.2 Data Measurement of Financial Market Volatility

With the highest information efficiency and the most active trading, stock market is often used as the representation of financial market (Yang et al. 2020 [12]). And the price fluctuation of the stock market can well reflect financial market volatility. Considering the market influence and location distribution, this paper selects China, the United States, the United Kingdom and Japan as the sample economies. We firstly use Shanghai Securities Composite Index (000, 001), S&P 500 Index (SP500), FTSE 100 Index (FTSE) and Nikkei 225 Index (N225) as the financial market indices of the four economies, and then use the extreme value method to measure the financial market volatility. This method can estimate the volatility of prices based on relatively little data (Parkinson 1980 [13]).

$$\sigma_{it}^2 = 0.361 \times \left[\ln\left(P_{it}^{max}\right) - \ln\left(P_{it}^{min}\right)\right]^2 \quad (5)$$

$$\widehat{\sigma_{it}} = 100 \times \sqrt{365 \times \sigma_{it}^2} \quad (6)$$

where $\widehat{\sigma_{it}}$ is the annual return variance of stock index i on day t, P_{it}^{max} is the highest price of market index i on day t, and P_{it}^{min} is the lowest price of market index i on day t. Take the calculated monthly average of $\widehat{\sigma_{it}}$ as the volatility of the stock index i of the current month, which is used to measure the financial market volatility of the economy where the stock index i is located. Finally, this paper follows the research convention and takes the logarithm for all data.

Our data begins in January 2000 and ends in May 2021. According to ADF and PP test results, all data are stationary time series, which meet the requirement for building a VAR model.

3 Empirical Results

In this section, we measure the dynamic connectedness of financial market volatilities based on Diebold and Yilmaz's (2014) [10] connectedness model. We construct a VAR(1) model according to the results of AIC and BIC and set the prediction period to 10 steps referring to previous literature. We choose 60 months as the length of the rolling window, so the time interval of the empirical results is from January 2005 to May 2021.

3.1 Dynamic Total Connectedness Analysis

Total connectedness describes the contribution of other variables' shock on the whole forecast error variance of the VAR system.

$$TC(n) = \frac{\sum_{i,j=1,i\neq j}^{m} C_{ij}(n)}{\sum_{i,j=1}^{m} C_{ij}(n)} \times 100\% = \frac{\sum_{i,j=1,i\neq j}^{m} C_{ij}(n)}{m} \times 100\% \tag{7}$$

Figure 1 shows the time-varying change of the dynamic total connectedness of financial market volatilities. The overall level of the dynamic total connectedness is relatively high and the fluctuation of it appears very obvious. After the 2008 financial crisis happened, the total connectedness rose drastically to a high level, close to 60%, which indicates that nearly 60% of the variance in the system comes from the shock of other financial markets. Affected by the following European debt crisis, the total connectedness remained above 50% until 2013. After the start of the Sino-US trade friction in 2018, the total connectedness of the system rose again. And since the outbreak of COVID-19 in 2020, the total connectedness has further increased, approaching the level during the financial crisis and the European debt crisis. One can see that major events have a great impact on the total connectedness of financial market volatilities, and the dynamic total connectedness can be used as an important indicator of systematic financial risk.

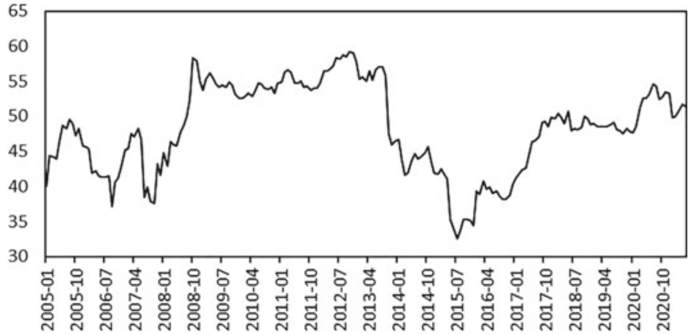

Fig. 1 Dynamic total connectedness of financial market volatilities

3.2 *Dynamic Directional Connectedness Analysis*

In order to better understand the characteristic of connectedness of the four economies in the system, we use dynamic directional connectedness to analyze the change of the total directional connectedness and the net directional connectedness. The total directional connectedness is the sum of all the received connectedness from other economies and all the generated connectedness to other economies, which describes the degree of closeness to other economies. The net directional connectedness is the difference between all the received connectedness from other economies and all the generated connectedness to other economies, which indicates the direction and the influence of the connectedness. Figure 2 shows the dynamic total directional connectedness and the dynamic net directional connectedness of the four financial market volatilities.

The change of the total directional connectedness of China's financial market volatility is similar to that of the total connectedness of the VAR system, which both reached a significantly high level during 2008–2013 and 2018–2021. In terms of the net directional connectedness, China's financial market volatility had a high and positive directional connectedness during the financial crisis and 2017–2019, but after COVID-19, China's net directional connectedness dropped rapidly. The total directional connectedness level of the United States and the United Kingdom is high and stable, while the net directional connectedness shows a downward trend. The total directional connectedness level of Japan fluctuates to some extent, but the net directional connectedness stays negative. Comparing the four economies, it can be found that the total directional connectedness of the United States, the United Kingdom and Japan is significantly higher than that of China, while the net directional connectedness of China is higher than that of others in several periods. This indicates that with the opening of China's financial market, its volatility has had a great influence on other economies' financial markets, but at the same time, the degree of closeness with other economies' financial markets is still relatively low and needs to be improved.

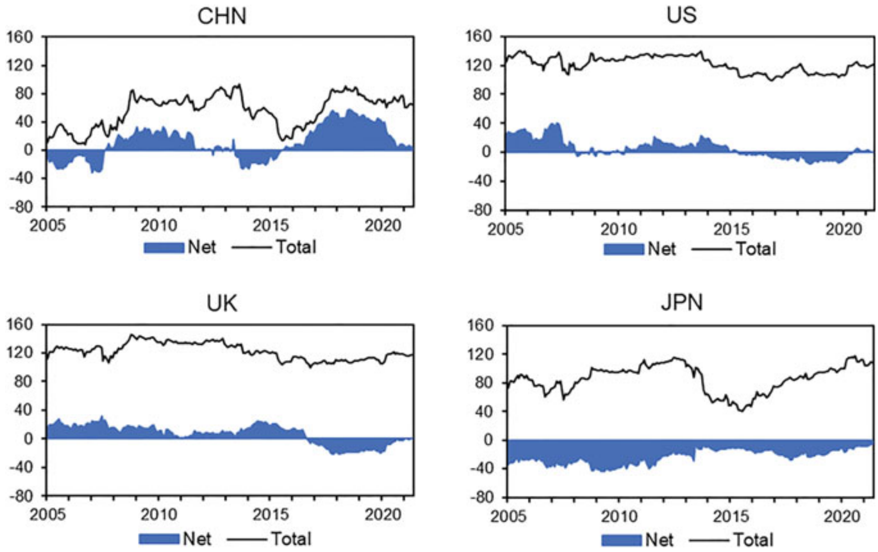

Fig. 2 Dynamic directional connectedness of financial market volatilities of China, the US, the UK and Japan

3.3 Analysis of the Shock Sources of China's Financial Market Volatility

Using the dynamic connectedness data, this paper further analyzes the time-varying situation of the shock sources of China's financial market volatility.

Figure 3 presents the dynamic connectedness that China's financial market volatility received from the United States, the United Kingdom and Japan. In general, China received a high degree of connectedness during 2008–2015 and 2020–2021. The financial market volatility of the United States and the United Kingdom generated higher connectedness to China than that of Japan, which means that the shock sources mainly concentrated on the United States and the United Kingdom. At the same time, the degree of connectedness from Japan increased significantly in the late stage of the financial crisis and after the occurrence of COVID-19, and the United States and the United Kingdom have relatively consistent changes in dynamic connectedness.

4 Conclusions

This paper assesses the financial market volatility of China, the United States, the United Kingdom and Japan by using the extreme value method, measures the dynamic connectedness of the financial market volatilities across four economies based on the rolling-window approach and the generalized variance decomposition model, and

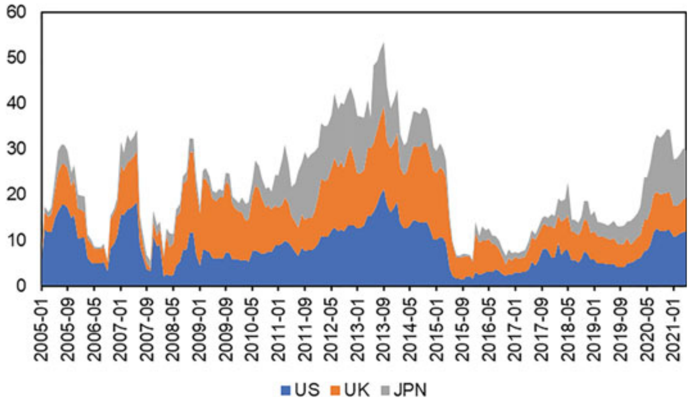

Fig. 3 Dynamic connectedness on China's financial market volatility from the US, the UK and Japan

further analyzes the risk sources of China's financial market volatility. The results show that the total connectedness of financial market volatilities is very high in general, and major events like the financial crisis, the European debt crisis and COVID-19 drove it to increase sharply. China's financial market volatility had a high influence on other economies' financial market volatilities in several periods, but the connectedness strength between China and other economies' financial market volatilities is still relatively low. The United States and the United Kingdom have a higher degree of connectedness to China's financial market volatility, while the connectedness from Japan rose sharply in the event of systemic risks. This paper provides a new perspective for developing economies to improve their financial risk management ability in the process of financial opening-up.

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Evaluation on the Effect of Green Transformation of Resource-Based Cities Under the "Double Carbon" Goal Based on the Reality Analysis of Resource-Based Cities in Heilongjiang Province

Si Wang and Hexiang Jin

Abstract Peak carbon dioxide emissions and carbon neutrality are important goals of ecological civilization construction at present. Based on the panel data of 10 resource-based cities in Heilongjiang Province from 2010 to 2019, and based on the "double carbon" goal, a new evaluation index system is constructed by using entropy method, and the comprehensive scores of economic green transformation effect and the scores of four subsystems, namely, economic development, social life, resource security and ecological environment, are calculated. The results show that: (1) The effect of economic green transformation of resource-based cities in Heilongjiang Province generally shows a development trend of first decreasing and then increasing; (2) From the perspective of systems, during the study period, the transformation effect of social life and resource security in Heilongjiang Province was good, showing a steady but rising development trend, but the transformation effect of economic development and ecological environment was poor, the economic development vitality was insufficient, the environmental pollution was serious, and the government's investment in environmental governance was relatively insufficient. It is suggested to increase government support, broaden investment channels and promote regional high-level technological progress, etc., so as to speed up the process of economic green transformation of resource-based cities in Heilongjiang Province.

Keywords Evaluation of the effect · Economic Green transformation · Heilongjiang province · A resource-based city

During the "14th Five-Year Plan" period, China's ecological civilization construction entered a critical period, which focused on carbon reduction, promoted the synergy

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of pollution reduction and carbon reduction, promoted the comprehensive green transformation of economic and social development, and realized the improvement of ecological environment quality from quantitative change to qualitative change. In June, 2022, the Ministry of Ecology and Environment and other seven departments jointly issued the Implementation Plan of Synergy of Pollution Reduction and Carbon Reduction, which is one of the important documents of the "1 + N" policy system of carbon neutrality (hereinafter referred to as "double carbon") in peak carbon dioxide emissions, and systematically planned for promoting synergy of pollution reduction and carbon reduction. Urban carbon emission is an important component of China's carbon emission [1], and how to realize the green transformation of resource-based city economy under the background of "double carbon" has attracted much attention. The green economic transformation of resource-based cities is a process in which resource-based cities gradually change from the extensive mode of relying on consumable resources to the development mode of relying on non-consumable resources in regions. Its main goal is to promote the adjustment of urban industrial structure, reduce the dependence of urban development on natural resources, improve the living standard of residents, improve the environmental problems caused by over-exploitation of resources, and finally realize all-round green development of cities [2]. In November 2013, the State Council officially implemented the National Sustainable Development Plan of Resource-based Cities (2013–2020). There are 262 resource-based cities in China, including 37 in Northeast China, accounting for 14.1% of the total resource-based cities in China [3], while 11 cities (9 prefecture-level cities and 2 county-level cities) in Heilongjiang Province are listed as resource-based cities. In the first half of 2020, the per capita GDP of Heilongjiang Province ranked first in the whole country, and in 2021, the per capita GDP ranked second in the whole country. The population decreased by 6.46 million in 10 years, ranking first in the whole country, and the birth rate was the lowest in the whole country. The natural growth rate was negative for five consecutive years. At present, there are still many obstacles in the process of economic green transformation of resource-based cities in Heilongjiang Province, such as unreasonable economic structure, serious brain drain and deterioration of ecological environment. Therefore, based on the "double-carbon" goal, it is of great practical significance to construct a new comprehensive evaluation index system to evaluate the economic green transformation effect of resource-based cities in Heilongjiang Province, and to promote the efficient allocation of regional resources and regional coordinated development.

1 Literature Review

Scholars at home and abroad discuss and study the effect evaluation of green economic transformation in resource-based cities from different aspects. Foreign scholars mainly study and explain from the theoretical perspective. De Rosa and Iootty [4] analyzed the relevant cases in Russia from 1996 to 2010, and thought that the low administrative efficiency of the government would bring long-term negative effects to the cities, thus inhibiting the development and transformation of resource-based cities and reducing their competitiveness; Zhang et al. [5] built a comprehensive index evaluation system with the low-carbon economic transformation of resource-based cities as the research object, and put forward specific implementation strategies to promote the low-carbon development of resource-based cities based on the research; Gonzalez et al. [6] think that the sustainable development of a city must comprehensively consider the aspects of economic welfare, social progress and environmental protection, and develop a multi-standard method that combines the three methods of material flow analysis (MFA), life cycle assessment (LCA) and data envelopment analysis (DEA) to evaluate the sustainable development of a city; Jing and Wang [7] think that the sustainable development of resource-based cities involves many factors such as social stability, economic growth and environmental quality.

Domestic scholars mainly construct corresponding index systems for empirical analysis from different perspectives of geography, ecology, economy, resources, etc. The main methods include AHP, quadratic relative evaluation [8], data envelopment method [9] and entropy weight-TOPSIS method [10], etc. Du and Hong [11] guided by the implementation effect of the transformation policy, analyzed the transformation policy performance of Huangshi from four dimensions: resources, environment, society and economy. Huang et al. [12] constructed the evaluation index system of the transformation efficiency of resource-based cities, calculated the transformation efficiency of 30 typical resource-based cities, and analyzed the promotion effect of innovation and government regulation on the transformation of resource-based cities. Zhang and Jason [13] used entropy method and fuzzy analytic hierarchy process to evaluate the transformation performance of 114 resource-based cities from two aspects of transformation range and development trend, and deeply explored the reasons for the differences in transformation performance among different cities. Juntao et al. [14] calculated the industrial structure transformation of 24 resource-exhausted cities from the aspects of transformation direction, speed and level, and found that the industrial structure of these resource-exhausted cities is constantly being optimized, but it is still lower than the national average level, and there are differences among the transformation effects of different cities. Wang et al. [15] used DPSIR model to build a comprehensive capacity evaluation model for sustainable development of resource-based cities.

At present, the domestic research on the evaluation of green transformation of resource-based cities' economy is based on the "double carbon" background, and there are few index systems. In this paper, the related indicators of urban green development are included, a new evaluation index system is constructed, and the effect evaluation of economic green transformation of resource-based cities in Heilongjiang Province under the "double-carbon" goal is studied.

Based on this, this study uses the panel data of 10 resource-based cities in Heilongjiang Province from 2010 to 2019, uses entropy method and comprehensive evaluation method, builds a new comprehensive evaluation index system based on the "double carbon" goal, calculates the comprehensive score of economic green transformation of resource-based cities in Heilongjiang Province and the comprehensive score of each subsystem, and then evaluates the economic green development situation of resource-based cities in Heilongjiang Province.

2 Research Methods and Data

2.1 Research Methods

In this paper, entropy method, an objective weighting method, is selected to measure and evaluate the economic green transformation effect of resource-based cities in Heilongjiang Province. Entropy method is an objective weighting method. It determines the index weight by the principle of information entropy, which can completely retain the information reflected by the original data and has high accuracy. Entropy measures the disorder degree of data. The smaller the entropy value of the index, the more obvious the data development trend and the greater its importance in the comprehensive index system, and the greater the weight of the index [16].

2.2 Construction of Transformation Evaluation Index System

2.2.1 Data Sources

This paper selects the relevant annual data from 2010 to 2019 to measure and evaluate the economic green transformation effect of resource-based cities in Heilongjiang Province. The data come from Heilongjiang Statistical Yearbook, Harbin Statistical Yearbook and statistical bulletins of national economic and social development published by regional statistical bureaus. Because of the serious data missing in Wudalianchi city, the research object of this paper includes the other ten resource-based cities in Heilongjiang province except Wudalianchi.

2.2.2 Construction of Index System

The establishment of the evaluation index system of green economic transformation in resource-based cities should follow the principles of systematicness, conciseness, scientificity, feasibility and objective. Considering the four aspects of economic development, social life, resource guarantee and ecological environment, an index system for evaluating the effect of economic green transformation of resource-based cities in Heilongjiang Province is constructed [17].

The evaluation of the transformation effect of economic dimension can be divided into two secondary indicators: urban economic level and industrial structure. Among them, the per capita GDP, GDP growth rate and the proportion of fiscal revenue to GDP are selected to measure the economic level of resource-based cities. The industrial structure level mainly examines the optimization degree of industrial structure of resource-based cities in the process of transformation, including three specific indicators: the proportion of primary industry to GDP, the proportion of tertiary industry to GDP and the proportion of employees in mining industry.

Social life dimension includes two secondary indicators: people's living standard and urban green development. People's living standard is expressed by disposable income of urban households, urban registered unemployment rate and urban gas penetration rate. Urban green development is represented by four indicators: urbanization rate, the total population at the end of the year, the number of public transport vehicles per 10,000 people and the green coverage rate of built-up areas.

The indicators of resource protection level include two secondary indicators: resource consumption and resource carrying. Resource consumption is expressed by the commonly used indicators of energy consumption, electricity consumption and water consumption of 10,000 yuan GDP in research. Regional resource carrying capacity is expressed by two indicators: per capita park green area and per capita local water resources.

The ecological evaluation indexes include two secondary indexes: environmental pollution and pollution improvement. Environmental pollution is measured by three indicators: industrial sulfur dioxide emissions, industrial wastewater emissions and industrial smoke emissions. Environmental improvement includes two indicators: the proportion of energy conservation and environmental protection expenditure to public finance expenditure and the amount of urban domestic garbage removal.

According to the above analysis, the evaluation index system of economic green transformation of resource-based cities in Heilongjiang Province is constructed, as shown in Table 1.

3 Evaluation of Green Transformation of Resource-Based Cities in Heilongjiang Province

In this paper, the evaluation criteria commonly used in previous studies are used for reference. According to each city's own development, the longitudinal evaluation is made with the development time course, and the comprehensive scores of the economic green transformation effect of each resource-based city in Heilongjiang Province and the scores of the four subsystems of economic development, social life, resource guarantee and ecological environment are shown in Table 2.

Table 1 Evaluation Index System of Economic Green Transformation of Resource-based Cities in Heilongjiang Province

Primary index	Secondary index	Three-level index	Index attribute
Economic development	Economic level	Per capita GDP A_1	Forward direction
		GDP growth rate A_2	Forward direction
		Proportion of fiscal revenue to GDP A_3	Forward direction
	Industrial structure	Proportion of primary industry output value to GDP A_4	Negative direction
		The output value of tertiary industry accounts for the proportion of GDP A_5	Forward direction
		Proportion of employees in mining industry A_6	Negative direction
Social life	The standard of living of the population	Per capita disposable income B_1	Forward direction
		Urban registered unemployment rate B_2	Negative direction
		Urban gas penetration rate B_3	Forward direction
	Urban green development	Urbanization rate B_4	Forward direction
		Year-end population B_5	Forward direction
		Every 10,000 people have public transport capacity B_6	Forward direction
		Green coverage rate of built-up area B_7	Forward direction
Resource guarantee	Resource consumption	Ten thousand yuan GDP energy consumption C_1	Negative direction
		Electricity consumption of 10,000 yuan GDP C_2	Negative direction
		Ten thousand yuan GDP water consumption C_3	Negative direction
	Carrying resources	Per capita park green area C_4	Forward direction
		Per capita water resources C_5	Forward direction

(continued)

Table 1 (continued)

Primary index	Secondary index	Three-level index	Index attribute
Ecological environment	Environmental pollution	Industrial sulfur dioxide emissions D_1	Negative direction
		Total industrial wastewater discharge D_2	Negative direction
		Industrial smoke (powder) dust emission D_3	Negative direction
	Improvement of environment	Proportion of environmental protection expenditure to public finance expenditure D_4	Forward direction
		Urban garbage removal D_5	Forward direction

3.1 Overall Evaluation

The comprehensive index of economic green transformation of resource-based cities in Heilongjiang Province (Fig. 1) showed a development trend of first decreasing and then increasing during the research period (2010–2019). From 2010 to 2016, the comprehensive index of economic green transformation of resource-based cities in Heilongjiang Province showed a downward trend, from 0.344 in 2010 to 0.308 in 2016. From 2017 to 2019, it began to show an upward trend. By 2019, the index of economic green transformation reached 0.362, which was 0.054 higher than that of 2016 and exceeded the development level of 2010. This trend may be due to the "Implementation Opinions on Supporting the Industrial Transformation and Upgrading of Old Industrial Cities and Resource-based Cities" issued by the state in 2016, which proposes to strengthen the transformation and development of old industrial cities and comprehensively promote the optimization of urban resource-based industries through supply-side structural reform. Under this background, all resource-based cities in Heilongjiang Province are actively working to develop new industries on the basis of their own leading industries. For example, Yichun City actively develops eco-tourism, healthy food, green mining and deep wood processing industries by using the abundant forest resources in the region; Shuangyashan City focused on developing green food industry while strengthening the transformation of regional coal to electrification; Hegang actively develops the pension industry; Qitaihe city vigorously promotes forestry economy and e-commerce; Jixi has implemented the development strategy of four industrial clusters of coal, graphite, food and medicine. The implementation of these measures has greatly promoted the development of emerging industries in various resource-based cities and promoted the green and healthy development of urban economy.

Table 2 Comprehensive score and ranking of economic green transformation of resource-based cities in Heilongjiang Province from 2010 to 2019

City	Economic development	Sort	Social life	Sort	Resource guarantee	Sort	Ecological environment	Sort	Comprehensive score	Sort
Jixi	0.077	6	0.122	4	0.043	9	0.073	2	0.316	6
Hegang	0.074	8	0.112	6	0.044	8	0.069	3	0.298	7
Shuangyashan	0.070	10	0.121	5	0.047	6	0.053	6	0.290	8
Daqing	0.167	1	0.180	1	0.044	7	0.052	7	0.443	1
Yichun	0.075	7	0.104	8	0.077	2	0.100	1	0.356	4
Qitaihe	0.094	3	0.103	9	0.035	10	0.054	5	0.286	9
Mudanjiang	0.109	2	0.157	2	0.056	4	0.049	8	0.372	2
Heihe	0.071	9	0.138	3	0.066	3	0.045	9	0.319	5
Da Hinggan Ling	0.078	5	0.112	7	0.118	1	0.055	4	0.363	3
Shangzhi	0.082	4	0.091	10	0.053	5	0.040	10	0.265	10

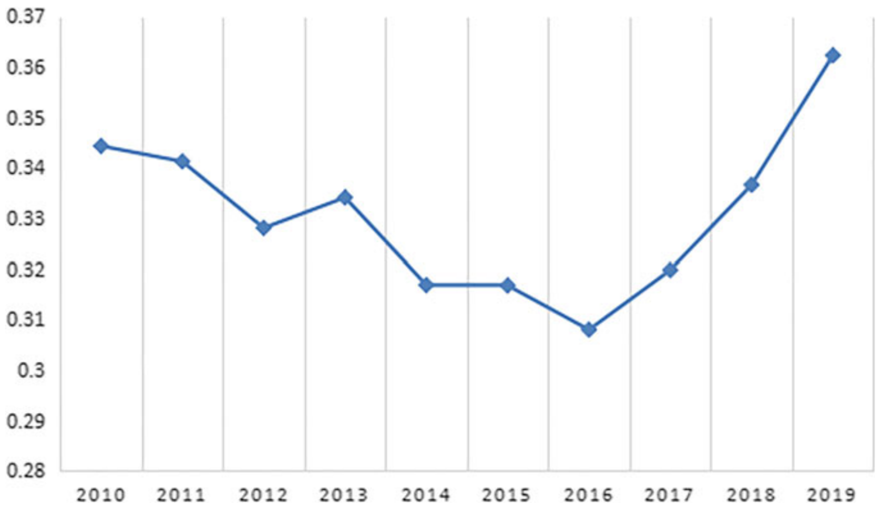

Fig. 1 Comprehensive score of economic green transformation of resource-based cities in Heilongjiang Province

According to the scores of economic green transformation of various resource-based cities in Heilongjiang Province (Fig. 2), the comprehensive scores of transformation in the past 10 years from high to low are Daqing City, Mudanjiang City, Da Hinggan Ling, Yichun City, Heihe City, Jixi City, Hegang City, Shuangyashan City, Qitaihe city City and Shangzhi city City. Daqing has the highest comprehensive score, rising from 0.42 in 2010 to 0.443 in 2019, an increase of 0.023. According to the average comprehensive score and ranking of resource-based cities in Fig. 2, Daqing ranks first in the past ten years, indicating that the region has a good level of economic green transformation. Daqing City, located in the west of Heilongjiang Province, is one of the most important petrochemical production bases in China, and Daqing Oilfield in its jurisdiction is the largest oilfield in China. There are many kinds of rich resources in the city. Apart from the huge oil resources, there are a lot of grassland, lakes, wetlands and other resources, which have laid a good foundation for the development of regional tourism. In recent years, Daqing City has implemented a series of measures to promote regional economic transformation and sustainable development: taking "turning the oil into the tail" as the main line, implementing industrial structure adjustment, and becoming an industrial transformation and upgrading demonstration area in 2020, which is the only industrial transformation demonstration area in Heilongjiang Province. At the same time, Daqing has also played an important role in the economic cooperation between China and the Far East, and has become an important node city of the "Longjiang Silk Road Belt" connecting the coordinated economic development among China, Mongolia and Russia. These measures have obviously accelerated the pace of economic transformation in Daqing. In addition, in recent years, Daqing City has vigorously carried out

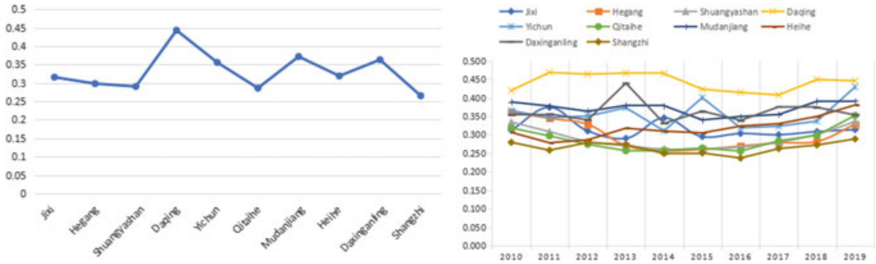

Fig. 2 Average comprehensive score of economic green transformation of various resource-based cities in Heilongjiang Province and comprehensive scores of each year

ecological environmental protection work, and promoted the extensive and unreasonable consumption-oriented production mode to the green production mode. In 2020, the green coverage rate of Daqing will be 43.68%, and the proportion of days with excellent air quality will reach 89.1% in a year, and the overall environmental quality of the whole city will remain at a good level.

3.2 Multidimensional Evaluation

3.2.1 Evaluation of Economic Development Subsystem

Figure 3 shows the radar change chart of comprehensive score and various scores of economic development subsystem of resource-based cities in Heilongjiang Province, and analyzes the development trend of economic development subsystem of resource-based cities in Heilongjiang Province.

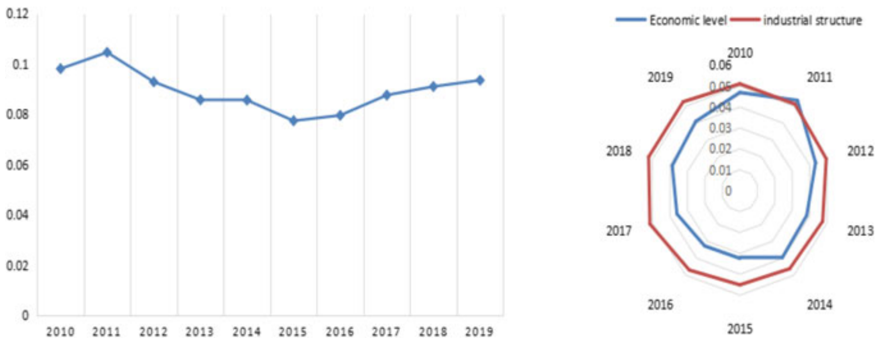

Fig. 3 Radar change chart of comprehensive score and various scores of economic development subsystem

As can be seen from Fig. 3, the comprehensive score of economic development subsystem of resource-based cities in Heilongjiang Province shows a trend of first decreasing and then increasing. From 2011 to 2015, the economic development subsystem showed a downward trend, and from 2015 to 2019, it rose steadily. Generally speaking, in recent years, the economic level of resource-based cities in Heilongjiang Province has been continuously improved, the industrial structure has been continuously optimized, the proportion of secondary industry has been continuously reduced, and the quality of economic development has been significantly improved. From the secondary indicators of green economy (Fig. 3), the comprehensive score of economic level from 2010 to 2016 increased from 0.047 to 0.033, and the comprehensive score of industrial structure decreased from 0.051 to 0.47; From 2016 to 2019, the comprehensive score of economic level rose from 0.033 to 0.041, and the industrial structure rose from 0.047 to 0.053. It can be seen that the lack of economic development level is the main constraint that leads to the economic development level transformation of resource-based cities in Heilongjiang Province.

Generally speaking, although the economic level of resource-based cities in Heilongjiang Province has gradually improved and the industrial structure has been continuously optimized in recent years, the economic development speed is very slow, and many indicators have not reached the target requirements of the Plan. For example, in 2020, the standard for the growth rate of regional GDP of resource-based cities in China is 8%, while that of Heilongjiang Province is 4.2%, which is far lower than the national standard, indicating that the economic development level of resource-based cities in Heilongjiang Province needs to be further improved. Through comprehensive analysis of the economic development of resource-based cities in Heilongjiang Province, it can be seen that in recent years, the proportion of secondary industry in resource-based cities in Heilongjiang Province has been shrinking, and the tertiary industry has been developing and expanding. In the subsequent process of transformation and development, Heilongjiang Province should continue to optimize its industrial structure, speed up the development of the tertiary industry, support strategic emerging industries, and strive for an early green economic transformation and regional sustainable development.

3.2.2 Evaluation of Social Life Subsystem

Figure 4 shows the radar change chart of comprehensive score and various scores of social life transformation subsystem of resource-based cities in Heilongjiang Province, and analyzes the development trend of social life subsystem of resource-based cities in Heilongjiang Province.

As can be seen from Fig. 4, the comprehensive score of social life subsystem of resource-based cities in Heilongjiang Province from 2010 to 2019 increased from 0.117 in 2010 to 0.139 in 2019, showing an overall upward trend. It shows that the concept of green development in Heilongjiang Province has gradually been deeply rooted in people's hearts during the research period, the living standard of urban residents has been continuously improved, and the vitality of urban development has

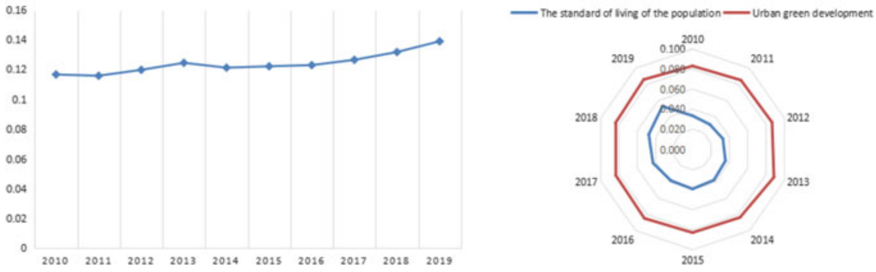

Fig. 4 Radar changes of comprehensive scores and scores of social life subsystem

been continuously improved. Figure 4 shows that from 2010 to 2019, the comprehensive score of green living standard rose from 0.033 to 0.053, and the urban green development was relatively stable, with the comprehensive score rising from 0.083 to 0.086. It can be seen that green living standard is an important driving force to promote the transformation of green society. From the specific indicators, the per capita disposable income of urban residents increased from 14,372 yuan to 29,141 yuan, the registered urban unemployment rate decreased from 3.58% to 3.28%, and the gas penetration rate increased from 75.64% in 2010 to 89.13% in 2019. It can be seen that the basic people's living standard is constantly improving, the degree of green life is constantly increasing, and their participation is constantly increasing. In addition, as can be seen from Fig. 4, the growth rate of the social life subsystem has been small. The reason is that the number of public transport vehicles per 10,000 people has increased from 17.14 standard buses/10,000 people in 2010 to 18.52 standard buses/10,000 people in 2019, with a small increase rate, which to some extent restricts the further improvement of residents' social living standards. In the future green development of cities, resource-based cities in Heilongjiang Province should pay attention to the popularization rate of public transportation, enhance residents' low-carbon awareness, reduce residents' travel costs, and promote the green transformation of regional economy.

3.2.3 Evaluation of Resource Guarantee Subsystem

Figure 5 is the radar change chart of comprehensive score and various scores of the resource guarantee subsystem of resource-based cities in Heilongjiang Province, based on which the development level of the resource guarantee subsystem of resource-based cities in Heilongjiang Province is analyzed.

As can be seen from Fig. 5, from 2010 to 2019, the comprehensive score of the resource guarantee subsystem of resource-based cities in Heilongjiang Province was on the rise, from 0.052 in 2010 to 0.068 in 2019, indicating that Heilongjiang Province has achieved certain results in resource utilization during the research period. Figure 5 The development trend of the secondary indicators of the resource support subsystem shows that the comprehensive score of resource consumption from 2010 to 2019 is

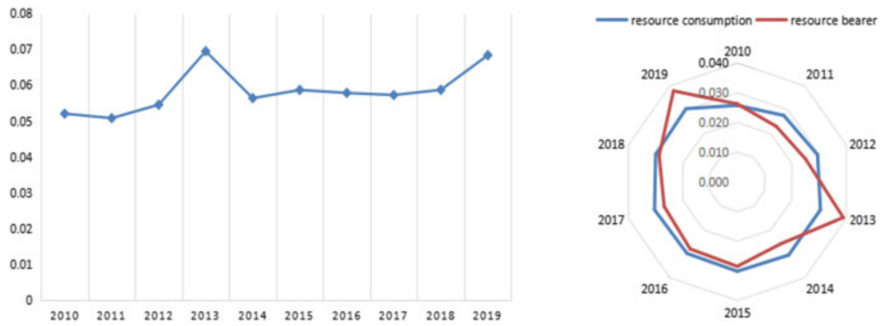

Fig. 5 Radar change chart of comprehensive score and various scores of resource support subsystem

relatively stable, rising from 0.026 to 0.030, with a small increase, and the comprehensive score of resource carrying increased from 0.026 to 0.038, which shows that resource carrying has a great influence on the transformation of green resources. From the specific indicators, the energy consumption, electricity consumption and water consumption per unit GDP of resource-based cities in Heilongjiang province decreased during the study period, while the per capita garden green area and the per capita local water resources ownership increased. It can be seen that the utilization rate of resources in Heilongjiang province has been increasing in recent years, and the carrying capacity of resources has been gradually strengthened. In order to further improve the utilization efficiency of urban resources, in the future green transformation and development, we should take accelerating the healthy growth and sustainable development of resource-based cities as the fundamental starting point, strengthen the exploration and exploration of resource-based cities in Heilongjiang Province, strengthen the effective reserve of regional resources, implement the rational development of superior resources, and support the green transformation of resource-based cities' economy with resource finishing and industry deepening.

3.2.4 Eco-Environmental Subsystem Evaluation

Figure 6 shows the radar changes of comprehensive scores and scores of eco-environmental subsystems of resource-based cities in Heilongjiang Province. Based on this, the development level of eco-environmental subsystems of resource-based cities in Heilongjiang Province is analyzed.

As can be seen from Fig. 6, 2010–2016. The comprehensive score of eco-environmental subsystem of resource-based cities in Heilongjiang Province showed a downward trend, and gradually increased after 2016. On the whole, the comprehensive score dropped from 0.078 in 2010 to 0.061 in 2019, which showed a downward trend, indicating that the environmental pollution in Heilongjiang Province was serious in the early stage of research, and the environmental protection was insufficient. In recent years, the situation began to improve. According to the scores

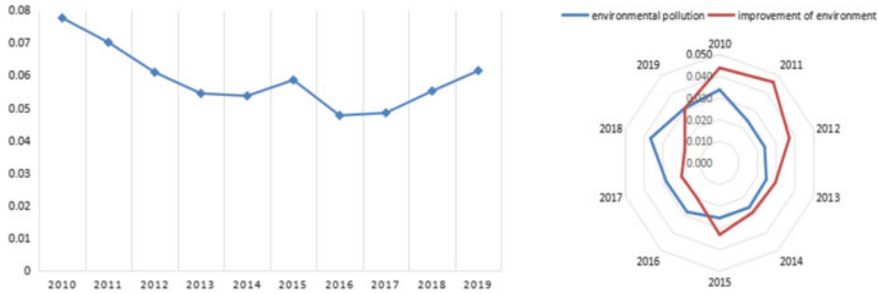

Fig. 6 Radar change chart of comprehensive score and various scores of ecological environment subsystem

of eco-environment subsystem (Fig. 6), the comprehensive score of environmental pollution decreased from 0.034 to 0.031 in 2010–2019, and the change of environmental improvement fluctuated greatly in the past ten years, and the comprehensive score decreased from 0.044 to 0.031, which shows that environmental improvement is the main factor affecting the development of eco-environment in resource-based cities. From the specific indicators, the overall wastewater discharge is increasing, and the industrial sulfur dioxide and industrial smoke (powder) dust discharge are gradually decreasing. The substantial changes of these two indicators will gradually improve the overall environmental quality of Heilongjiang Province after 2016. Therefore, although the environmental protection in Heilongjiang Province has been strengthened in recent years and the ecological environment has been improved, the heavy industry in resource-based cities still accounts for a large proportion in the economic development, and coupled with the environmental damage in the early stage, the ecological environment protection in resource-based cities in Heilongjiang Province still has a long way to go.

4 Conclusions and Suggestions

4.1 Research Conclusion

Based on the "double-carbon" goal, this paper first calculates the data of 24 indicators of 10 resource-based cities and 4 subsystems in Heilongjiang from 2010 to 2019, and obtains the comprehensive score of economic green transformation effect of each resource-based city in Heilongjiang Province and the scores of four subsystems: economic development, social life, resource guarantee and ecological environment. Based on this, it evaluates the economic green development situation of resource-based cities in Heilongjiang Province, and draws the following research conclusions:

From the overall evaluation results, the comprehensive index of economic green transformation of resource-based cities in Heilongjiang Province showed a development trend of first decreasing and then increasing during the research period (2010–2019). In the past 10 years, the comprehensive scores of transformation from high to low were Daqing, Mudanjiang, Da Hinggan Ling, Yichun, Heihe, Jixi, hegang, Shuangyashan, Qitaihe and Shangzhi city. Judging from the evaluation results of each subsystem, in recent years, the economic level of resource-based cities in Heilongjiang Province has gradually improved and the industrial structure has been continuously optimized, but the economic development speed is very slow, and many indicators have not met the requirements of the Plan. During the research period of 2010–2019, the concept of green development in Heilongjiang Province has gradually been deeply rooted in people's hearts, the living standard of urban residents has been continuously improved, and the vitality of urban development has been continuously improved, but the growth rate of social life subsystem has been small. At the same time, the utilization rate of resources in Heilongjiang Province is constantly increasing, and the carrying capacity of resources is gradually increasing. However, its environmental pollution is serious and environmental protection is insufficient. In recent years, the situation has begun to improve.

4.2 Countermeasures and Suggestions

In view of the inconsistent effects of economic green transformation among resource-based cities in Heilongjiang Province, and some cities have low effects, in order to better achieve the goal of "double carbon", this paper puts forward the following suggestions for economic green transformation in Heilongjiang Province:

(1) Increase government support. Local governments can increase the enthusiasm of enterprises to carry out green transformation in a short period of time by issuing transformation subsidies and other policy means to related enterprises [18]. At the same time, they can formulate medium-and long-term policies to promote the development of regional resource-based industries to green, reduce the transformation risks and costs of enterprises, and form a long-term mechanism for the transformation of green industries. Local governments should constantly improve the hardware and software infrastructure in their own areas and actively promote the development of local independent industries. Establish an assessment, supervision and incentive system for green transformation, incorporate environmental protection indicators into the assessment system, and encourage regions to give priority to improving ecological environment. At the same time, the provincial government should give some policy inclinations to the cities with poor economic green transformation effect in resource-based cities, such as the government allocating funds to improve the local education, medical care, railways, highways and other public infrastructure.

(2) Improve the degree of opening to the outside world. Actively carry out investment promotion from the aspects of existing enterprises, various superior resources of cities, social development and cultural brands, and expand investment promotion channels. All local governments should do a good job in the publicity and promotion of opening to the outside world, and create a good investment environment to ensure the smooth implementation of investment attraction. Heilongjiang province should make full use of all advantages, reasonably introduce foreign investment, explore a green transformation road suitable for itself, and promote the healthy economic development of regional resource-based cities. Speeding up the construction of cargo transportation roads connecting the key areas along the border with the central cities such as Heihe River can not only improve the cargo transportation speed from Harbin to Heihe River, but also greatly improve the traffic convenience of the surrounding areas, facilitate the surrounding areas to give full play to their resource advantages to open up the tourism market, and create a new pattern of Heilongjiang province's all-round opening to Northeast Asia.

(3) Optimize the environment for scientific and technological innovation. All local governments should give priority to the improvement of regional innovation environment to improve the level of regional green technology. For resource-based cities where talents are in short supply, it is even more important to increase the introduction of foreign talents and implement preferential policies in research funding, housing and social security. At the same time, local governments should speed up the integration of regional science and technology resources, build and upgrade enterprise technology research and development centers, and promote the research of new technologies. Encourage qualified enterprises to build enterprise technology R&D centers, so as to coordinate the technical personnel of enterprises, realize the rapid transformation of technological progress into productivity, promote product upgrading and improve the production capacity of enterprises [19].

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