Evaluation and Spatial-Temporal Differentiation of Supply Chain Resilience in China's High-Tech Industry

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Abstract. China's high-tech industry supply chain is confronted with multifaceted pressures from both internal and external environments in maintaining its security and stable development. This paper collects various operational data of Chinese high-tech enterprises spanning from 2012 to 2021, constructs a unique supply chain resilience index system tailored for the high-tech industry, and employs the entropy weight-TOPSIS method to conduct a comprehensive evaluation of supply chain resilience in China's high-tech industry. Furthermore, GIS techniques are utilized to analyze the spatiotemporal evolution characteristics of supply chain resilience. The research findings indicate that technology research and development capability and open innovation capability exert the greatest influence on the resilience of China's high-tech industry supply chain. Moreover, the resilience of the supply chain exhibits temporal instability with an overall downward trend and significant spatial disparities in its distribution pattern. Based on these findings, this paper proposes corresponding countermeasures, including strengthening core technology research and development capability, optimizing the regional development environment, and enhancing international cooperation, aiming to provide substantial theoretical and practical implications for enhancing the resilience of the high-tech industry supply chain.

Keywords: high-tech industry, supply chain, resilience

1 Introduction

In recent years, the global industrial and supply chains have confronted a series of challenges, including new internal and external shocks, structural shifts in industries, technological transformations, as well as the rise of trade protectionism and unilateralism, leading to a restructuring of the chain landscape. Under the current circumstances, both the internal and external circulations of China's high-tech industry supply chain are being impacted by factors such as disrupted component supply, decreased effective demand, obstructed knowledge circulation, and insufficient internal production capacity [1]. According to scholarly research, the resilience of China's high-tech industry supply chain is influenced by various aspects, including the policy environment [2, 3], talent

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quality [4], R&D capabilities [5], green innovation [6] and innovation levels [7]. Therefore, it is urgent to explore countermeasures to enhance supply chain resilience.

Supply chain resilience refers to the system's ability to rapidly adapt and resume normal operations when subjected to internal or external shocks and disruptions [8,9]. Previous scholars' research on supply chain resilience has primarily focused on visibility [10], security [11], robustness [12] and adaptability [13], which directly reflect the response capacity of supply chains when facing various internal and external shocks.

However, due to the technology-intensive nature of high-tech industries, in measuring the resilience of high-tech industry supply chains, it is crucial to pay closer attention to the influence of technological capabilities and innovation capabilities. Moreover, given the prominent imbalance in the regional development of China's high-tech industries and the scarcity of research focusing on the spatiotemporal evolution characteristics of China's high-tech industry supply chains, this paper centers on scientifically measuring the resilience of China's high-tech industry supply chains and further analyzing the spatiotemporal evolution characteristics of their resilience. This paper aims to draw policy suggestions for improving the supply chain resilience of China's high-tech industries through the analysis behind the industrial data.

2 The Construction of Indicator System

This paper adheres to the principles of comprehensiveness, practicality, clarity, stability, and dynamism. It integrates the specific technical requirements of the high-tech industry and takes into account all dimensions of previous scholars' assessments of supply chain resilience. The evaluation index system for supply chain resilience in China's high-tech industry is constructed based on four dimensions: risk resistance capability, technology research and development capability, adaptive resilience capability, and open innovation capability. This includes 4 primary indicators, 8 secondary indicators, and 16 tertiary indicators as presented in **Table 1.**

Table 1. Evaluation index system of high-tech industry supply chain resilience.

Dimension	Indicator	Indicator Description	Indicator Nature
Risk resistance capability B1	Enterprise size C1	Number of Enterprises (% of Industrial Enterprises above Designated Size) D1	Positive
		Average Number of Employees (% in Industrial Enterprises above Designated Size) D2	Positive
	Operating performance C2	Per Capita Main Operating Income (% in Industrial Enterprises above Designated Size) D3	Positive
		Total Profit (% in Industrial Enterprises above Designated Size) D4	Positive

Technology research and development capability B2	R&D input C3	Internal and External Expenditure of R&D Funds D5	Positive
		Expenditure of R&D Institutions D6	Positive
	R&D scale C4	Number of Enterprises in R&D Activities D7	Positive
		Number of R&D Personnel D8	Positive
		Percentage of Enterprises in R&D Institutions D9	Positive
Adaptive resilience Capability B3	Debt management C5	Total Liabilities D10	Negative
	Technology dependence C6	Expenditure on Introducing Overseas Technology D11	Positive
		Expenditure on Technological Transformation D12	Positive
Open innovation capability B4	Innovation input C7	Expenditure on New Product Development D13	Positive
		Number of New Product Development Projects D14	Positive
	Innovation output C8	Sales Revenue from New Products D15	Positive
		Number of In-force Invention Patents D16	Positive

3 Supply Chain Resilience Evaluation

3.1 Data Sources

This paper selects China's high-tech industry as the research object. Considering the availability and comparability of data, we use the relevant data of high-tech enterprises in each year from 2012 to 2021 (excluding 2017), covering the five industries of pharmaceutical manufacturing, electronic and communication equipment manufacturing, computer and office equipment manufacturing, medical equipment and instrument manufacturing, and information chemicals manufacturing. These data mainly come from China's High-tech Industry Statistical Yearbook, China Statistical Yearbook, Statistical Communique of National Economic and Social Development, and statistical yearbooks of various provinces and cities.

Data preprocessing is carried out on the statistical data, part of the missing data is filled in by linear interpolation, and data integration is carried out on the cleaned data. This paper chooses the Min-Max Normalization method. For the standardized numerical values, we need to perform a shift operation to facilitate the subsequent calculation of entropy values without the negative value influence. We take the shift parameter H=0.001.

3.2 Weight Calculation

Considering the characteristics of this study's data, we choose to employ the entropy weight method in this paper due to its suitability for multi-indicator evaluations, independence from outlier interference, greater objectivity compared to subjective evaluation methods and analytic hierarchy process, as well as its ability to reasonably quantify indicator weights.

The weight of the standardized data is calculated by entropy weight method, and the information entropy and weight of each three-level index are shown in **Table 2.**

Table 2. Information entropy, difference coefficient and weight of evaluation indexes.

Indicator	Entropy	Weight	Sorting
Number of Enterprises D1	0.9350	0.0303	11
Average Number of Employees D2	0.9462	0.0250	13
Per Capita Main Operating Income D3	0.9784	0.0101	15
Total Profit D4	0.9553	0.0208	14
Internal and External Expenditure of R&D Funds D5	0.8512	0.0692	8
Expenditure of R&D Institutions D6	0.7507	0.1160	2
Number of Enterprises in R&D Activities D7	0.8592	0.0656	10
Number of R&D Personnel D8	0.8579	0.0661	9
Percentage of Enterprises in R&D Institutions D9	0.9462	0.0250	12
Total Liabilities D10	0.9923	0.0036	16
Expenditure on Introducing Overseas Technology D11	0.6562	0.1601	1
Expenditure on Technological Transformation D12	0.8395	0.0747	6
Expenditure on New Product Development D13	0.8320	0.0782	4
Number of New Product Development Projects D14	0.8480	0.0707	7
Sales Revenue from New Products D15	0.8358	0.0764	5
Number of In-force Invention Patents D16	0.7678	0.1081	3

3.3 Evaluation Result

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a multi-criteria decision analysis technique that aims to help decision-makers determine the best choice among a set of alternatives. The method is based on the calculation of Euclidean distance and Manhattan distance and determines the best solution by comparing the similarity between each alternative and the Positive Ideal Solution and the Negative Ideal Solution.

The composite values of supply chain resilience evaluation of high-tech industries in various provinces obtained through the above calculations are shown in **Table 3.**

Table 3. Comprehensive values of supply chain resilience evaluation of high-tech industry.

Year / Province	2012	2013	2014	2015	2016	2018	2019	2020	2021
Beijing	0.2959	0.2707	0.2039	0.1575	0.1462	0.1499	0.1480	0.1521	0.1708
Hebei	0.0220	0.0302	0.0373	0.0249	0.0212	0.0124	0.0363	0.0337	0.0414
Liaoning	0.0340	0.0357	0.0865	0.0342	0.0701	0.0437	0.0299	0.0320	0.0239
Shanghai	0.2429	0.2021	0.1813	0.1188	0.1023	0.0977	0.0973	0.0872	0.0840
Jiangsu	0.6447	0.6421	0.6329	0.4519	0.4084	0.3042	0.2904	0.3019	0.3146
Zhejiang	0.2550	0.2682	0.2493	0.2368	0.2019	0.1754	0.1750	0.1886	0.2005
Anhui	0.0561	0.0622	0.0607	0.0643	0.0639	0.0777	0.0774	0.0846	0.0936
Henan	0.0389	0.0654	0.0606	0.0650	0.0546	0.0563	0.0466	0.0511	0.0572
Hubei	0.0654	0.0946	0.0779	0.0690	0.0523	0.0547	0.0579	0.0653	0.0738
Hunan	0.0573	0.0790	0.0869	0.0866	0.1033	0.0568	0.0510	0.0542	0.0801
Guangdong	0.7553	0.7151	0.7550	0.8420	0.8730	0.9644	0.9549	0.9556	0.9408
Chongqing	0.0493	0.0523	0.0571	0.0608	0.0656	0.0790	0.0753	0.0918	0.0797
Sichuan	0.3739	0.1249	0.1193	0.0746	0.0818	0.0862	0.0803	0.0850	0.0857
Shaanxi	0.0640	0.0637	0.0917	0.0694	0.0678	0.0513	0.0495	0.0523	0.0451

Based on the four dimensions covered by the supply chain resilience of the high-tech industry, the changing trend of the mean value of fractal dimension resilience of China's high-tech industry from 2012 to 2021 is shown in **Fig. 1.**

Compared with the overall resilience trend, the changes in technological R&D capacity and open innovation capacity are small and gentle, while the changes in adaptive resilience capacity are large and have a significant impact on the overall resilience level. Although there are fluctuations in risk resistance capacity, its trend remains basically unchanged and it accounts for a small weight in the overall resilience level.

(1) Among the components of the resilience of China's high-tech industry supply chain, the risk resistance capability declined slowly from 2012 to 2015, showed an "M" type fluctuation from 2015 to 2021, and showed a spiraling upward trend.

(2) The technology R&D capacity reached its highest value in 2013, then gradually declined from 2013 to 2018, and slowly recovered from 2018 to 2021.

(3) The adaptive resilience capacity continued to decline from 2012 to 2020, with a larger decline from 2014 to 2015, and began to recover after 2020.

(4) The open innovation capacity rose steadily from 2012 to 2015, declined from 2015 to 2019, and then began to rise.

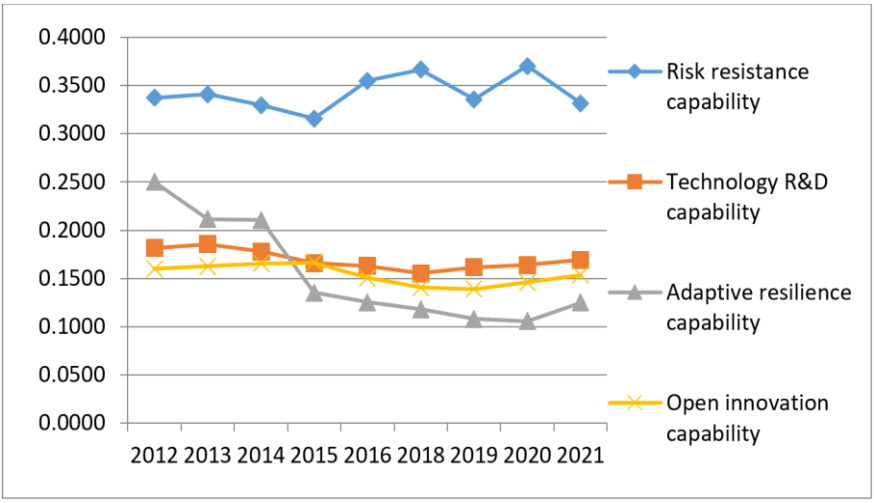

Fig. 1. The trend of mean value of fractal dimension toughness in each year.

4 Analysis and Countermeasures

4.1 Analysis of the Spatio-temporal Pattern of High-tech Industry Supply Chain Resilience

This section will further discuss the evolution characteristics of the high-tech industry supply chain resilience from a spatial perspective, and conduct spatial visualization analysis of the high-tech industry supply chain resilience in China in 2012, 2015, 2018, and 2021 through ArcGIS software. As a geographic information system (GIS), it can be used to analyze and visualize geospatial data. Analyzing the spatial layout evolution of the high-tech industry supply chain resilience in China through GIS can more intuitively show the differences in resilience development.

Due to the lack of a unified division of the resilience development level, the natural fracture method is adopted to divide the industrial chain resilience development level from high to low into five levels: high-value area, higher value area, median area, lower value area, and low-value area. The high-value area is >0.3, the higher-value area ranges from 0.1 to 0.3, the median area ranges from 0.05 to 0.1, the lower value area is 0.02 to 0.05 and the low-value area is <0.02. The spatial pattern evolution distribution of the high-tech industry supply chain resilience level in 2012, 2015, 2018, and 2021 is shown in **Fig. 2.**

According to the analysis of the change in the number of cities in each area, the number of provinces and cities in high-value areas was 3 in 2012 and then reduced to 2 in 2021. From 2012 to 2015, the number of provinces and cities in medium and high-value areas was stable at 3. However, after that, the number of provinces and cities in medium and high-value areas decreased to 2, with little overall change. The number of provinces and cities in medium and high resilience value areas and above showed a trend of "high decrease". On the contrary, from 4 in 2012 to 7 in 2015, 8 in 2018, and

then 7 in 2021, the number of provinces and cities in medium-value areas gradually increased, showing a trend of "overall flat". On the other hand, the number of provinces and cities in low-value areas gradually decreased from 4 in 2012 to 2 in 2015, and 1 in 2018, and rose again to 3 in 2021. Despite the decline in the number of provinces and cities in medium and low resilience value areas and below, there are signs of a rebound in the past two years.

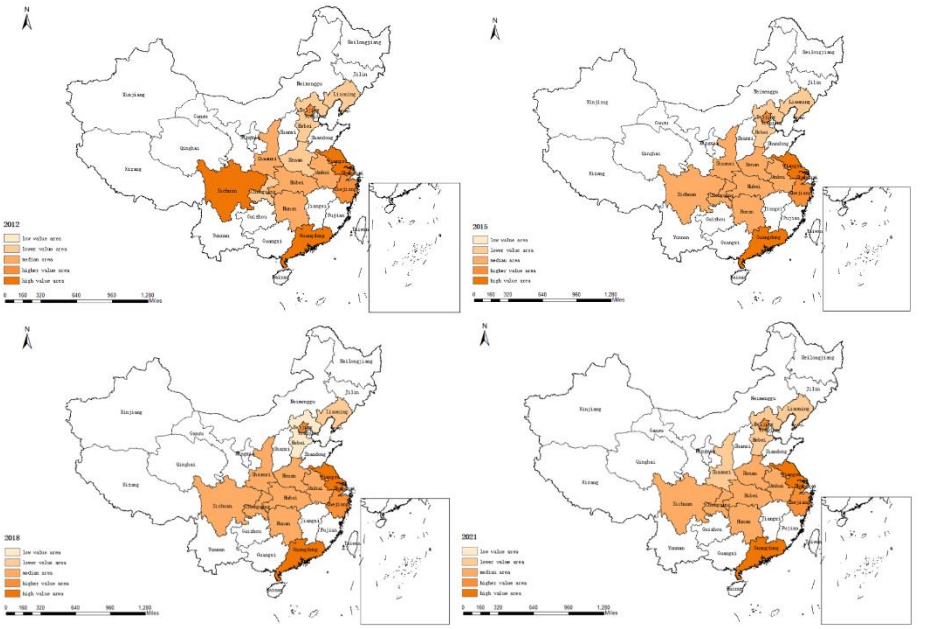

Fig. 2. Evolution of spatial pattern of high-tech industry supply chain resilience level.

4.2 Countermeasure

(1) At the macro level: **strengthen policy guidance and support, and strengthen international cooperation and exchanges.** According to the weight calculation results, technology dependence and R&D investment are the secondary indicators with the highest weight, and the key factor affecting the resilience of the high-tech industry supply chain is its adaptive recovery ability. The current international political and economic environment is unstable and uncertain, such as trade protectionism, geopolitical risks, and other changes in the external environment make the need for technology dependence from abroad to domestically, strengthening independent research and development ability, strengthening international exchanges and cooperation to improve their own technology research and development ability and adaptive recovery ability is a key move to break the situation.

(2) At the medium level: **establish a supply chain risk management system and strengthen the coordinated development of the regional supply chain.** According to the results of spatial pattern distribution, it can be seen that the development of

China's high-tech industry is uneven among regions, and its supply chain resilience is easily disturbed by external factors, which is directly related to the degree of regional economic development, and the development imbalance between regions in China will continue to worsen in the future. To improve the resilience level of the high-tech industry supply chain, it is still necessary to improve the risk resistance ability of the supply chain, which not only depends on the economic scale and business performance of the enterprise itself but also depends on whether a complete supply chain risk management system is built.

(3) At the Micro level: **promote digital and intelligent transformation, and strengthen talent training and introduction.** According to the empirical measurement results, the open innovation ability, which is the factor with a high weight in the factors affecting the resilience of the high-tech industry supply chain, has continued to decline in four of the past six years, and the overall level is still not ideal. Under the current situation, the key to strengthening the competitiveness of the industry lies in the implementation of the innovation-driven development strategy, through the optimization of the innovative ecological environment, the strengthening of intellectual property protection, and the promotion of scientific and technological achievements to stimulate the creativity of enterprises and enhance their open innovation growth ability.

5 Conclusions

(1) Based on the literature review, this paper starting from the technical and innovative characteristics of the high-tech industry constructs the evaluation index system of China's high-tech industry supply chain resilience from four dimensions: risk resistance ability, technology research, and development ability, adaptive recovery ability and open innovation ability. And the entropy method is used to weight the evaluation indexes and determine the specific impact weight of the evaluation index system. The results show that the technology research and development capacity of the high-tech industry has the largest weight, followed by the open innovation capacity, the adaptive and resilient capacity, and the risk resistance capacity.

(2) Through literature research, this paper collects and collates the data of high-tech enterprises in 14 provinces and cities in China from 2012 to 2021, and uses the TOPSIS model to evaluate the resilience, to comprehensively measure the resilience level of China's high-tech industry supply chain. The results show that the average values of high-tech industry supply chain resilience in China are ranked from large to small as follows: Guangdong, Jiangsu, Zhejiang, Beijing, Shanghai, Sichuan, Anhui, Hunan, Hubei, Chongqing, Shaanxi, Henan, Liaoning, Hebei.

(3) This paper analyzes the spatio-temporal characteristics of the resilience of the high-tech industry supply chain by using GIS, revealing the current situation of regional development imbalance, and the future development imbalance between China's regions will still show a growing trend. Finally, based on empirical findings, this paper proposes specific measures and recommendations to enhance the resilience level of high-tech industry supply chains.

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