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Evaluation and Dynamic Evolution of Supply Chain Resilience in the Yangtze River Basin

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Abstract

This study aims to explore the regional differences in the supply chain resilience of enterprises in 12 Chinese city clusters and their dynamic evolution characteristics. By employing the non-parametric Kernel density estimation method and Theil index, this paper analyzes the spatial imbalanced distribution of supply chain resilience among enterprises in the 12 city clusters of the Yangtze River Basin and its dynamic changes over time. The findings reveal significant differences in supply chain resilience levels among city clusters, with these differences widening over time. The Dianchi city cluster exhibits the highest average supply chain resilience, demonstrating strong resilience and stability, while the Chang-Zhu-Tan city cluster has the lowest average supply chain resilience, indicating a relatively lower level of resilience. Additionally, the study finds that intra-regional differences are the main cause of overall regional disparities, with less developed city clusters showing greater intra-regional differences in supply chain resilience. The results of this study are of significant importance for understanding the regional characteristics of supply chain resilience, formulating targeted policy measures, and promoting coordinated regional economic development.

Keywords

Supply Chain Resilience; Dynamic Evolution; Kernel Density Estimation; Theil Index.

1. Introduction

Supply chain resilience refers to the ability of a supply chain to optimize resource allocation, adjust industrial structures, withstand shocks, maintain its structural and functional integrity when facing unexpected risks, and quickly resolve the risk impact to return to normal operations after supply chain disruptions [1, 2]. With the deepening development of economic globalization and the complex and variable international and domestic situation, the importance of supply chain resilience is becoming increasingly prominent. Strengthening supply chain resilience can effectively mitigate the negative effects of external turbulence, promote supply chain enterprises to adapt to market changes, and gain competitive advantages.

As a vital engine of China's economic growth, the supply chain of the Yangtze River Basin covers numerous industries and fields, and its stable state directly relates to the robust operation of China's economy and society. The Yangtze River Basin connects China's eastern coastal and central-western inland regions, and cities within the region exhibit significant spatial heterogeneity in terms of resource endowments, production factors, and industrial structures [3], with notable differences in their capabilities to withstand risk shocks, exacerbating urban development disparities. Therefore, scientifically assessing the supply chain resilience of the Yangtze River Basin and exploring dynamic evolution trends can help ensure the economic synergy and stable growth of city clusters in the basin, leading to coordinated, stable, and sustainable regional economic growth for the country.

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Currently, domestic and international research on supply chain resilience mainly focuses on two levels. On one hand, different scholars have varying definitions of supply chain resilience. Some scholars consider supply chain resilience to be the ability of a company's supply chain to return to normal operations after disruptions [4-6] define supply chain resilience from a physical and economic perspective and use supply chain breakage resilience, shock resilience, and collaborative resilience to construct a comprehensive evaluation system for grain supply chain resilience. Wieland and Wallenburg divide supply chain resilience into three aspects: preventive power, resistance, and recovery[7]. On the other hand, there are studies on the influencing factors of supply chain resilience. Based on dynamic capability theory and multiple mediation models, Zhao et al. point out that supply chain digitization can enhance supply chain resilience by improving cost-effectiveness and information communication efficiency[2]. Wu et al. discuss the positive effects of inter-organizational governance such as contract governance and relational governance on supply chain resilience[8]. Ma Xiaoyu et al. expand the application range of structural equation models and innovatively use fuzzy-set qualitative comparative analysis methods, finding that flexibility, agility, adaptability, visibility, and supply chain collaboration can all enhance supply chain resilience[9]. Compared to existing literature, this paper focuses on the Yangtze River Basin, conducts targeted supply chain resilience assessments, proposes scientific insights, studies the dynamic evolution of supply chain resilience, and reveals the dynamic changes of supply chain resilience over time, providing literature support for the formulation of long-term policy measures and new development directions for supply chain enterprises in the Yangtze River Basin.

2. Methods and Data

2.1. Kernel Density Estimation Non-parametric Method

This paper will employ the Kernel density estimation non-parametric method to investigate the spatial imbalanced distribution dynamics of supply chain resilience among enterprises in the 12 city clusters of the Yangtze River Basin (including the Basin itself). Kernel density estimation is a commonly used method for studying spatial imbalance by comparing the differences in sample distributions at different time points. It assumes that the density function of the random variable x is f(x), and the probability density at point x is represented by Equation (1):

$$f(x)=\frac{1}{N_h}\sum_{i=1}^{N}K(\frac{X_i-x}{h}) \tag{1}$$

where $\boldsymbol{N}$ is the number of observations, $\boldsymbol{h}$ is the bandwidth, K(·) is the Kernel function, and $\boldsymbol{X_i}$ are the observed values. The Kernel density function has various expressions such as uniform kernel, quadratic kernel, and Gaussian kernel, among which Gaussian kernel is most commonly used. Therefore, this paper also adopts a Gaussian kernel to estimate the dynamic evolution process of the distribution of supply chain resilience of high enterprises in 12 urban agglomerations in the Yangtze River Basin (including the Yangtze River Basin). The expression of Gaussian kernel function is shown in equation (2).

$$f(x)=\frac{1}{\sqrt{2\pi}}\exp(-\frac{x^2}{2}) \tag{2}$$

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2.2. Theil Index

Let $\boldsymbol{Y_i}$ represent the supply chain resilience (SCR) of enterprise i in city cluster j, and $\overline{\boldsymbol{Y}}$ represent the average SCR of all city clusters. The Theil index (TH) of intra-regional differences in supply chain resilience can be calculated using the following formula:

$$TH = \frac{1}{n}\sum_{i-1}^{n}\frac{Y_i-\bar{Y}}{Y}\ln(\frac{Y_i-\bar{Y}}{Y}) \quad (3)$$

where denotes the number of city clusters, $\boldsymbol{Y_i}$ denotes the mean value of corporate supply chain toughness of the ith city cluster, and $\overline{\boldsymbol{Y}}$ denotes the total average value of corporate supply chain toughness of all city clusters. The formula measures the degree of imbalance within a city cluster by calculating the difference between the enterprise supply chain toughness of each city cluster and the total average and summing the logarithms of these differences. The larger the value of Theil's index, the greater the internal variation; the closer the value is to 0, the smaller the internal variation.

2.3. Objects and Data Sources

The 14th Five-Year Plan and Long-Range Objectives (2021-2035) for National Economic and Social Development of the People's Republic of China takes the enterprises in the 12 city clusters of the Yangtze River Basin (including the Basin itself) such as Chengdu-Chongqing, Dianchi, Chang-Zhu-Tan, Central Guizhou, Yangtze River Delta, Upper Yangtze River, Middle Yangtze River, Lower Yangtze River, Jianghuai, Poyang Lake, and Wuhan "8+1" as research objects. Following Xu Xingmei, this paper uses the supply chain concentration to measure the enterprise supply chain resilience (SCR), specifically calculated as the average of the proportion of purchases from the top five suppliers and the proportion of sales to the top five customers[10]. The data for this paper comes from the CSMAR database of basic information on listed companies in China's A-shares from 2018 to 2022.

3. Regional Differences in Enterprise Supply Chain Resilience among City Clusters in the Yangtze River Basin

3.1. Overall Enterprise Supply Chain Resilience Performance of the 12 City Clusters in the Yangtze River Basin

Table 1. Overall corporate supply chain resilience levels of 12 city clusters in the Yangtze River Basin

City cluster	2018	2019	2020	2021	2022	average value	sorted
Changjiang or Yangtze River basin	33.379	34.036	35.407	35.706	35.607	34.827	4
Chengdu and Chongqing	35.185	33.850	33.886	34.569	34.230	34.344	7
South Yunnan	37.732	37.736	35.564	37.275	37.213	37.104	1
Surrounding Poyang Lake	33.030	33.889	35.563	35.562	35.510	34.711	5
SurroundingChangZhuTan	29.600	30.133	32.221	32.454	33.318	31.545	11
Surrounding the Jianghuai River	30.177	30.451	31.400	31.192	31.201	30.884	12
Yangtze River Delta	32.900	33.596	35.362	35.468	35.329	34.530	6
Upper reaches of the Yangtze	36.396	35.494	35.569	36.080	36.026	35.913	2
Middle reaches of the Yangtze River	31.474	32.970	34.634	34.813	34.835	33.745	8
Lower reaches of the Yangtze River	31.889	32.664	33.625	33.987	33.997	33.232	10
Qianzhong	31.726	33.602	33.552	32.729	35.587	33.439	9
Wuhan "8+1"	36.084	36.305	35.462	35.877	35.113	35.768	3

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Table 1 presents the overall supply chain resilience levels of the 12 city clusters in the Yangtze River Basin, represented by the average values of enterprise supply chain resilience.

(1) *Trends in Supply Chain Resilience Levels Among City Clusters*

The Dianchi city cluster has the highest average supply chain resilience at 37.104, and it remains relatively stable over the five years, indicating that the supply chain in this city cluster has a high level of resilience and stability. The Central Guizhou city cluster ranks second with an average supply chain resilience of 34.311, showing good resilience levels. The Wuhan "8+1" city cluster has an average supply chain resilience of 35.768, ranking third, and demonstrates strong resilience.

(2) *Comparison of Supply Chain Resilience Levels Among City Clusters*

The Upper Yangtze River city cluster has an average supply chain resilience of 35.913, ranking fourth, showing strong resilience. The Yangtze River Basin and the Yangtze River Delta city clusters have average supply chain resilience levels of 34.827 and 34.530, respectively, ranking fifth and seventh, indicating that the supply chain resilience levels in these two regions are quite close. The Middle and Lower Yangtze River city clusters have average supply chain resilience levels of 33.745 and 33.232, respectively, ranking ninth and tenth, suggesting that the supply chain resilience levels in these two regions are relatively low.

(3) *Annual Changes in Supply Chain Resilience Levels Among City Clusters*

The Chengdu-Chongqing city cluster had the highest average supply chain resilience in 2018, which then declined but rebounded in 2022, showing some volatility. The supply chain resilience of the Poyang Lake City cluster fluctuated little from 2018 to 2022, remaining relatively stable overall. The Chang-Zhu-Tan city cluster's supply chain resilience increased significantly from 29.600 in 2018 to 33.318 in 2022.

(4) *Ranking Changes in Supply Chain Resilience Among City Clusters*

Over the five years, the Dianchi city cluster consistently ranked first, demonstrating its leading position in supply chain resilience. The Wuhan "8+1" city cluster's ranking rose from third in 2018 to fourth in 2022, indicating an enhancement in its supply chain resilience. The Upper Yangtze River city cluster's ranking fluctuated between third and fourth, showing its competitive level of supply chain resilience.

3.2. Intra-regional Differences in Enterprise Supply Chain Resilience among the 12 City Clusters in the Yangtze River Basin

Table 2. Results of intra-regional differences in the Theil index of corporate supply chain

City cluster	2018	2019	2020	2021	2022	average value	sorted
Changjiang or Yangtze River basin	0.13840	0.16293	0.13188	0.12627	0.12386	0.13666	8
Chengdu and Chongqing	0.13358	0.15604	0.13070	0.12304	0.11836	0.13234	9
South Yunnan	0.16573	0.15598	0.11729	0.11633	0.13835	0.13873	6
Surrounding Poyang Lake	0.13892	0.16505	0.13323	0.12821	0.12577	0.13823	7
Surrounding ChangZhuTan	0.16296	0.17848	0.15770	0.14459	0.16826	0.16239	1
Surrounding the Jianghuai River	0.14877	0.17740	0.13130	0.12189	0.12406	0.14068	5
Yangtze River Delta	0.12451	0.15077	0.12230	0.11921	0.11569	0.12649	11
Upper reaches of the Yangtze	0.13475	0.14834	0.12562	0.12130	0.12195	0.13039	10
Middle reaches of the Yangtze River	0.14800	0.19271	0.14146	0.13518	0.12812	0.14909	4
Lower reaches of the Yangtze River	0.16793	0.18749	0.15788	0.14401	0.14707	0.16087	2
Qianzhong	0.08651	0.13394	0.09338	0.10176	0.10368	0.10385	12
Wuhan "8+1"	0.15243	0.18965	0.15187	0.13532	0.13546	0.15294	3

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This paper calculates the Theil index of supply chain resilience for the 12 city clusters in the Yangtze River Basin to analyze the intra-regional differences and ranks the city clusters based on their average intra-regional differences, with the results shown in Table 2.

The analysis reveals a significant correlation between the level of regional development and the regional differences in supply chain resilience. Specifically, less developed city clusters exhibit larger intra-regional differences in supply chain resilience. For instance, the Chang-Zhu-Tan city cluster has an average Theil index of 0.16239, ranking first among all city clusters, reflecting a significant imbalance in supply chain resilience. The Lower Yangtze River city cluster and the Jianghuai city cluster, with average Theil indices of 0.16087 and 0.14068, rank second and fifth, respectively, also showing that less developed city clusters have relatively large regional differences in supply chain resilience.

In contrast, more economically developed city clusters such as the Yangtze River Delta, Chengdu-Chongqing, and Upper Yangtze River city clusters have relatively lower average Theil indices of 0.12649, 0.13234, and 0.13475, respectively, demonstrating better regional equity in supply chain resilience. Notably, the Central Guizhou city cluster has the lowest average among all city clusters, indicating that it has achieved a high level of balanced development in supply chain resilience. These differences may stem from various factors such as economic development levels, industrial structures, infrastructure construction, and policy environments of different city clusters. Developed city clusters, with their more complete industrial chains, efficient logistics systems, and stronger policy support, can better withstand uncertainties and risks in the supply chain, thus maintaining the stability and resilience of the supply chain. In contrast, less developed city clusters may suffer from inadequate infrastructure, incomplete industrial chains, and insufficient policy support, leading to larger regional differences in supply chain resilience.

3.3. Temporal Evolution Characteristics of Enterprise Supply Chain Resilience among City Clusters in the Yangtze River Basin

To further reveal the time evolution characteristics of the distribution of enterprise supply chain toughness in 12 city clusters in the Yangtze River Basin, this paper used the Kernel kernel density estimation nonparametric method to map the density distribution of enterprise supply chain toughness in 12 city clusters in the Yangtze River Basin from 2018 to 2022, respectively (Figure 1 to Figure 12).

Firstly, the Kernel density estimation plots of the 12 city clusters display the probability distribution characteristics of supply chain resilience among enterprises. The central tendency of these distribution curves shows a rightward shift over time, indicating that, overall, the supply chain resilience of enterprises in various city clusters is strengthening, i.e., the supply chain's risk resistance and adaptability are improving. This rightward shift reflects those enterprises, in the face of market fluctuations and potential disruptions, have enhanced the overall resilience of the supply chain by adopting effective risk management measures and optimizing supply chain structures.

Secondly, the width changes of the distribution curves reveal the regional differences in supply chain resilience among city clusters. Over time, the distribution curves for the Chang-Zhu-Tan, Lower Yangtze River, and Dianchi city clusters have increased in width, indicating that the differences in supply chain resilience within these city clusters are expanding. This may imply that there are significant disparities in supply chain management levels and technological innovation capabilities among different enterprises, leading to an unbalanced development of supply chain resilience.

Thirdly, upon further analysis, some city clusters' distribution curves exhibit distinct unimodal or bimodal characteristics, which may indicate a phenomenon of polarization in supply chain resilience. For example, the distribution curve changes for the Lower Yangtze River city cluster

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suggest a clear unimodal characteristic, with a prominent main peak and inconspicuous side peaks, which may imply that the regional differences in supply chain resilience are narrowing, and the overall supply chain resilience level is trending towards equilibrium. The distribution curve for the Middle Yangtze River city cluster shows a transition from bimodal to unimodal, with a high main peak value, indicating that the phenomenon of polarization in supply chain resilience growth has been effectively controlled, and the overall level of supply chain resilience shows a consistent upward trend. The Central Guizhou city cluster's distribution curve shows a clear transition from multimodal to unimodal, indicating that the differences in supply chain resilience within the city cluster are decreasing, the overall level of supply chain resilience is becoming more consistent, and the phenomenon of polarization has been effectively curbed. These changes suggest that the city clusters in the Yangtze River Basin are gradually moving from polarization to unipolarization in terms of supply chain resilience, and the optimization of supply chain management and the application of technological innovations may play a key role in this process.

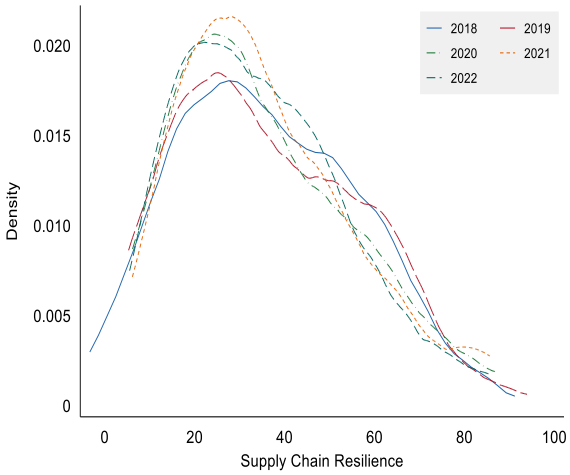

Figure 1. Yangtze River Basin

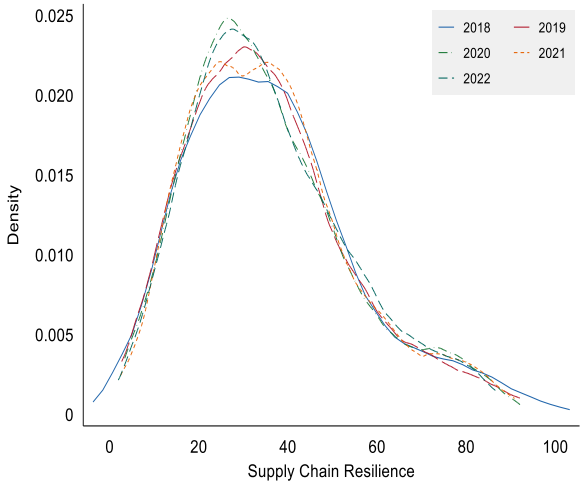

Figure 2. Chengdu-Chongqing city cluster

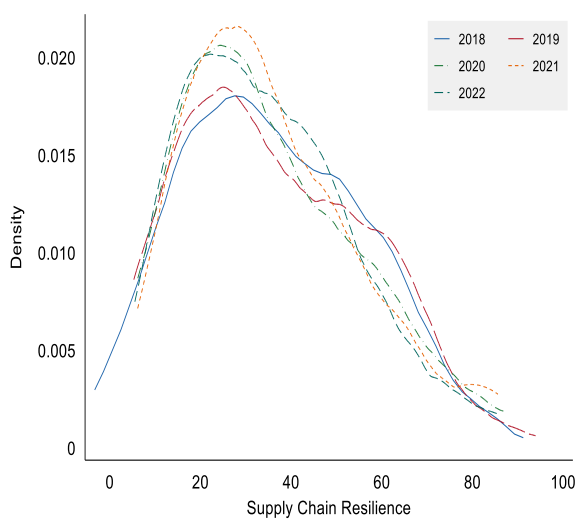

Figure 3. Surrounding Poyang Lake

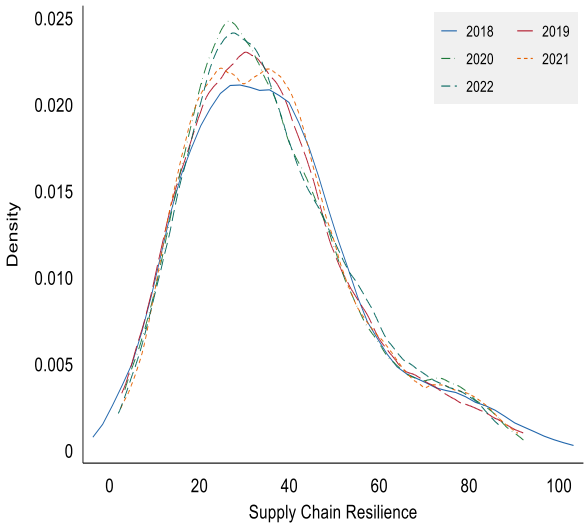

Figure 4. Surrounding ChangZhuTan

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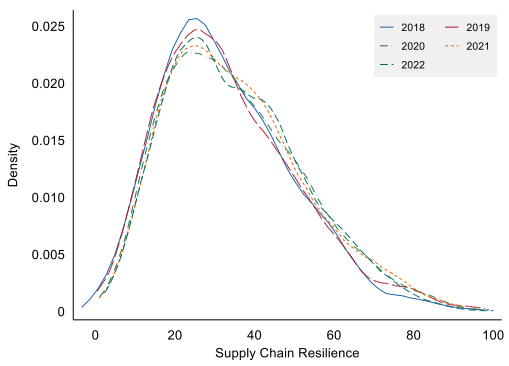


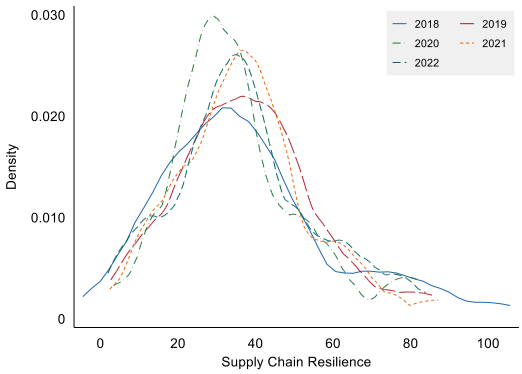
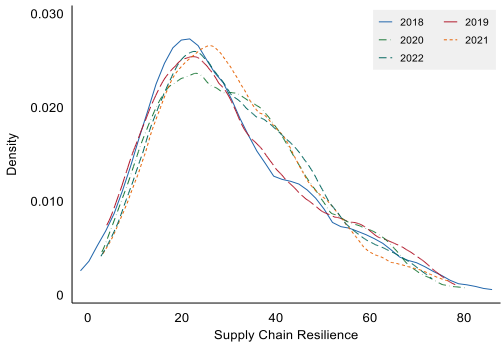


Figure 5. Surrounding the Jianghuai River **Figure 6.** Qianzhong



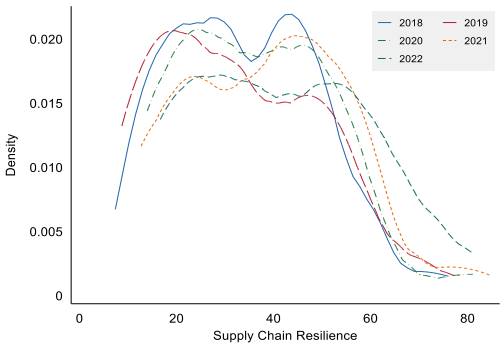
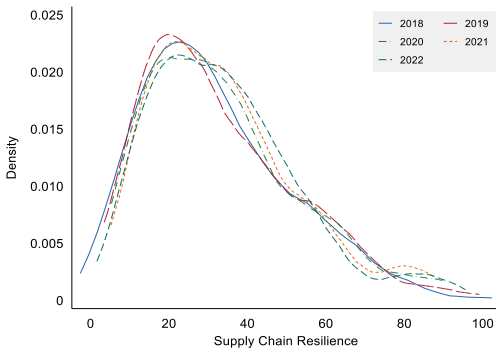


Figure 7. Wuhan "8+1" **Figure 8.** Upper reaches of the Yangtze



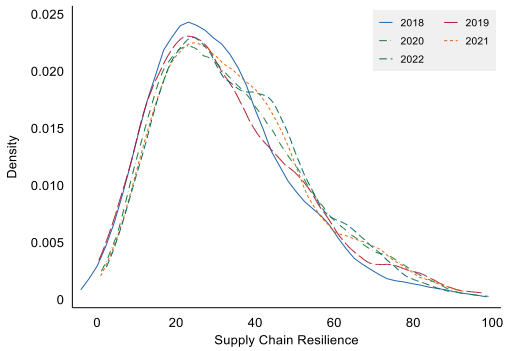
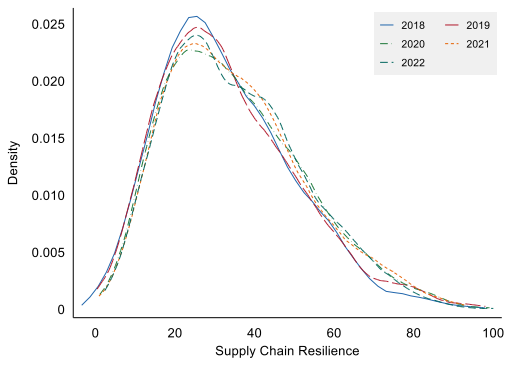


Figure 9. Middle reaches of the Yangtze **Figure 10.** Lower reaches of the Yangtze



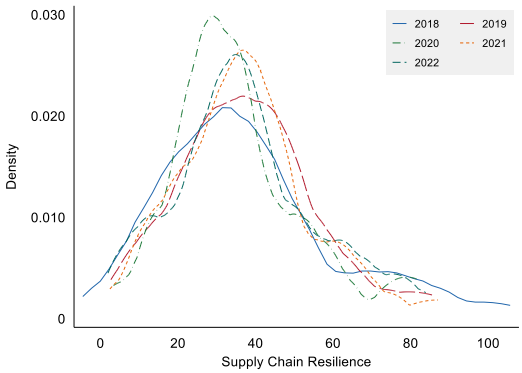


Figure 11. Yangtze River Delta **Figure 12.** South Yunnan

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4. Conclusion and Implications

This paper provides an in-depth analysis of the regional differences and dynamic evolution of enterprise supply chain resilience among 12 city clusters in the Yangtze River Basin from 2018 to 2022. The main conclusions are as follows:

(1) There are significant differences in supply chain resilience levels among city clusters, and these differences have shown an increasing trend over time. The Dianchi city cluster demonstrates the highest supply chain resilience, while the Chang-Zhu-Tan city cluster has a relatively lower supply chain resilience.

(2) Intra-regional differences are the primary cause of overall regional disparities. Less developed city clusters exhibit larger intra-regional differences in supply chain resilience, which may be related to various factors such as infrastructure, industrial structure, and policy support.

(3) The dynamic evolution characteristics of supply chain resilience indicate that the supply chain resilience of enterprises in various city clusters generally shows an upward trend, but there are differences in the speed and level of development among different city clusters.

Based on the above conclusions, this study offers the following implications:

(1) Policymakers should pay attention to the differences in supply chain resilience within city clusters and formulate corresponding support policies for less developed city clusters to promote balanced regional economic development.

(2) Strengthen infrastructure construction and improve the policy environment, especially in less developed city clusters, to enhance the overall resilience and efficiency of the supply chain.

(3) Encourage enterprises to adopt innovative measures, such as digitalization and intelligentization, to enhance the flexibility and adaptability of the supply chain and reduce the impact of external risks.

(4) Promote cooperation and exchange between regions to improve the overall supply chain management level of city clusters through resource sharing and information exchange.

(5) Emphasize long-term planning and dynamic management of supply chain resilience to ensure that city clusters can respond quickly and maintain stable economic growth in the face of future uncertainties.

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