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Research article

Spatio-temporal analysis of the new quality productive forces of China's logistics industry

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Abstract: With the sustained economic expansion of China, the logistics sector functions as a vital conduit linking production and consumption, holding significant importance. Moreover, the emergence of the new quality productive forces (NQPF) concept positions the logistics industry's own NQPF as a pivotal driver accelerating sectoral advancement. Leveraging panel data on the development level of logistics NQPF across 30 Chinese provinces (excluding Tibet, Hong Kong, Macao, and Taiwan due to data constraints) from 2015 to 2022, this study employed a suite of methodologies—including the entropy weight method, kernel density estimation, the Dagum Gini coefficient, Moran's I, and the spatial Durbin model—to conduct statistical measurement, spatial characterization, and factor analysis. The findings reveal pronounced regional imbalances in development, with the east region markedly outperforming others and exhibiting substantial gradient disparities relative to the middle, west, and northeast regions. Nevertheless, significant spatial autocorrelation exists among provinces, predominantly manifesting in the first and third quadrants, indicating clusters of high-high agglomeration (H-H) and low-low agglomeration (L-L). Furthermore, factor analysis identified the key determinants influencing the evolution of NQPF within China's logistics industry.

Keywords: new quality productive forces of logistics industry; entropy weight method; kernel density estimation; Dagum Gini coefficient; Moran's I; Spatial Durbin model

JEL Codes: C23, R11, O33

1. Introduction

New quality productive forces (NQPF) refer to the advanced productivity form with new technology, new structure, new function, new business type, and new mode formed by integrating the latest science, technology and management results into the productivity elements and their optimal combination under the background of the new era (Bai et al., 2024). The improvement of NQPF has significantly contributed to the upgrading and transformation of traditional industries and the steady progress of the economy toward the goal of high-quality growth. Furthermore, as the new driving force of the new era, NQPF can effectively reduce the logistics cost of the whole society (Wang and Duan, 2024). The logistics industry is the basic, strategic, and leading industry of the national economy. Thus, how to effectively reduce the logistics cost and promote the development of the logistics industry has become the focus of attention. The NQPF can reduce the logistics cost by optimizing the logistics structure, improving the business environment, and accelerating the construction of the international logistics system (Editorial Department of this journal, 2024), so as to promote the development of the logistics industry. Therefore, introducing the NQPF into the logistics industry and vigorously developing the NQPF are of great significance to promote the vigorous development of the logistics industry.

The logistics industry's iteration of NQPF constitutes a field-specific instantiation of the concept, retaining its essential characteristics. NQPF is a new type of productivity centered on technological innovation, which drives the economy and society towards a path of green and high-quality development, with the fundamental aim of meeting the people's needs for a better life (Wang, 2025). Its essence lies in achieving qualitative transformation and enhancement of productivity through technological breakthroughs, upgrading of production factors, and industrial integration. The NQPF of the logistics industry is a specific manifestation of the NQPF in the logistics field. It is a new type of productivity that integrates multiple elements such as technological innovation, factor innovation, industrial upgrading, and industrial integration, and can significantly improve the production efficiency and service quality of the logistics industry (Liu and Lan, 2024). Driven by the NQPF, the logistics industry is gradually transforming toward smart logistics, green logistics, supply chain logistics, and other directions, accelerating the deep integration of new-generation information technologies such as the Internet of things, cloud computing, and big data with the logistics industry, demonstrating the huge potential for developing the NQPF of the logistics industry. From the literature, research on NQPF analyze several aspects such as connotation characteristics (Zhuang, 2024; Guo et al., 2024; Pan and Tao, 2024), practical paths (Tian and Wang, 2024; Han and Zhang, 2024), theoretical logic (Li and Feng, 2024; Liu et al., 2024), research on influencing factors (Cheng and Feng, 2024; Fu, 2024; Dong and Wang, 2024), statistical measurement (Zhang et al., 2024; Yang and Hong, 2024) , and spatiotemporal evolution (Miao et al., 2024; Hu and Xu, 2024), and mainly concentrate on major fields such as agriculture (Wang et al., 2025), finance(Meng and Lu, 2025), and strategic emerging industries (Huang et al., 2025), while the relevant research on the logistics industry is relatively scarce. However, as a foundational and strategic pillar of the national economy, the logistics sector is indispensable for safeguarding the seamless flow of economic activities and driving regional prosperity. Consequently, dedicated research efforts focusing on the NQPF within logistics, informed by their core properties, serve a dual purpose: they address critical research gaps while simultaneously offering robust theoretical frameworks and actionable strategies essential for navigating the industry's high-quality development journey. At present, research on the NQPF of the logistics industry mainly focuses on theoretical research, sorts out the key obstacles from the aspects of technology application, infrastructure, institutional supervision, and talent supply and demand, and proposes practical paths for empowering the high-quality growth of the logistics industry with NQPF (Tang, 2024); exploring the use of NQPF to drive the reduction of logistics costs in the whole society from three aspects: Digital reconstruction power, collaborative evolution power, and innovation strategy power (Wang and Duan, 2024); exploring the bidirectional interaction logic between logistics and NQPF from the perspective of digital logistics (Song and Xu, 2024); and, in order to accelerate the promotion of green and low-carbon development, from the perspective of green logistics, exploring the inherent value of empowering green logistics with NQPF (Liu, 2024). Existing research on the NQPF in logistics predominantly engages in theoretical exploration of its three core dimensions: technology, digitalization, and greenness, examining their influence on the sector's NQPF development. Specifically: Technological studies often employ static analyses, diagnosing current application levels and challenges to propose practical solutions; digitalization research investigates how digital technologies propel logistics NQPF and the interplay between them; green initiatives, motivated by national supportive policies, probe the value of green logistics for NQPF advancement. A key limitation, however, is the difficulty in capturing the dynamic evolution and long-term trajectories of each element's impact. This indicates a prevalent reliance on static perspectives within current logistics NQPF research, lacking sufficient dynamic analysis. Given that logistics NQPF is a continuously evolving process shaped by multiple factors, static approaches frequently fall short of accurately depicting its true state and developmental trends. Consequently, adopting a spatio-temporal methodology that incorporates dynamic and regional perspectives offers a more holistic view. This approach compensates for the shortcomings of traditional static analysis, enables the tracking of dynamic element changes, reveals regional disparities and their temporal evolution, analyzes the co-evolutionary processes of elements, and comprehensively evaluates policy dynamics and spatial effects. Thereby, it furnishes more robust theoretical support and actionable guidance for logistics NQPF development, effectively bridging critical research voids.

Therefore, in this article, we focus on the development level of NQPF of the logistics industry, explore the regional spatial differences and spatial correlations of the development level of NQPF of the logistics industry from the perspective of spatiotemporal evolution (Zhang et al., 2025), and further analyze the key factors that affect its spatial characteristics. First, we establish an evaluation index system for the NQPF of the logistics industry and use the entropy weight method to measure the level of NQPF of the logistics industry in 30 provinces in China from 2015 to 2022. Second, we use the kernel density estimation method, Dagum Gini coefficient and its decomposition method, and Moran's I method to analyze the spatial differences and correlations of the NQPF level of the logistics industry. Finally, the spatial Durbin model is selected to analyze the factors that affect the development level of NQPF of the logistics industry.

2. Research design

2.1. Constructing the indicator system

The NQPF of the logistics industry is an effective means to enhance the resilience of the supply chain, an effective path to drive the industrial chain towards the mid to high end, an effective support for high-quality economic development, and an effective guarantee for smooth dual circulation. For the construction of measurement indicators for NQPF, different scholars have different dimensions for dividing indicators. Scholars have constructed a comprehensive evaluation index system for NQPF from three dimensions: Technological innovation, industrial innovation, and factor innovation, and based on the connotation and characteristics of NQPF (Li et al., 2024), to highlight the important role of innovation in the development of NQPF, scholars have constructed an indicator system from five aspects: Human resources, innovation platforms, research and development capabilities, innovation environment, and innovation achievements (Gui et al., 2024)[0]. Moreover, due to the new momentum and vitality released by the NQPF from a new perspective, some scholars have built a new quality productive force system from three aspects: Workers, labor objects, and labor materials (Wang, 2024).

In order to promote the development of NQPF of the logistics industry, the research experience of the above scholars is used for reference. Furthermore, according to the connotation characteristics of the NQPF of the logistics industry, a three-level index system with statistical significance is constructed to measure the dynamic level of the evolution of the NQPF of the logistics industry in China to analyze the spatio-temporal evolution characteristics of the NQPF of the logistics industry in China. Therefore, in order to conform to the development trend of the logistics industry, align with the connotation of NQPF, and meet the demands of high-quality industry development, in combination with the “Report on the Development of Logistics Technology”, “White Paper on the Development of Green Logistics”, and “Report on the Development of Digital Logistics”, and referring to the research ideas of Song et al.(2024), a new productivity measurement index system for the logistics industry is constructed from the three dimensions of scientific and technological productivity, green productivity, and digital productivity. This system will cover the three core elements of technology, environment, and digitalization of the NQPF of the logistics industry from three dimensions, comprehensively reflecting the overall level of the development of the NQPF of the logistics industry. The specific index system is shown in Table 1.

Table 1. NQPF index evaluation system of China’s logistics industry.

Primary Index	Secondary Index	Three-level Index	Attribute
Technology Productivity	Educational Investment	Number of students in general higher education of logistics related majors	+
	Technology R&D	Number of R&D researchers in logistics industry	+
		Internal expenditure of logistics R&D funds	+
	Industrial Development	Foreign direct investment in logistics industry	+
Green Productivity	Environment Protecting	Forest coverage	+
		Proportion of railway freight volume	+
	Energy Consumption Status	Proportion of total social electricity consumption of logistics industry	+
Digital Productivity	Digital Industry	E-commerce sales	+
		Software business income	+
	Digital Scale	Number of logistics business outlets	+
		Number of fixed Internet broadband access users	+
	Digitization Level	Mobile phone penetration	+
		Optical cable line length	+

2.2. Data sources

In this paper, we take the NQPF level of logistics industry in 30 provinces in China from 2015 to 2022 (for the sake of data availability, Tibet and Hong Kong, Macao and Taiwan are not included) as the measurement object, and the data used are mainly mostly the China Statistical Yearbook, China Logistics Yearbook, EPS database, and statistical yearbook for each province. The mean value method of nearby points is used to fill in the missing values, which ensures the integrity of the data. Of course, this method may have some limitations. When the data is locally stable, it may not be able to capture the dynamic changes of the data or handle outliers. However, since the number of missing values in the text is relatively small, in the case of a limited number of missing values, the impact of these limitations on the overall analysis results is relatively controllable.

3. Research methods

3.1. Entropy weight method

In order to avoid the deviation of subjective weight and make the evaluation results more objective and scientific, we use the entropy weight method to calculate the entropy weight of each index by using the information entropy and then modify the weight of each index by using the entropy weight to obtain a more objective index weight to measure the NQPF level of the logistics industry.

(1) In order to eliminate the impact of the magnitude difference between data on the comprehensive evaluation, the range method is used to standardize the original data.

Positive indicators:

$$X_{\text{ij}} = \frac{x_{ij} - min(x_j)}{max(x_j) - min(x_j)} \tag{1}$$

Negative indicators:

$$X_{ij} = \frac{max(x_j) - x_{ij}}{max(x_j) - min(x_j)} \tag{2}$$

In the formula, i represents the number of samples, referring to the i -th sample; and j represents the number of indicators, referring to the j -th indicator.

(2) Calculate the information entropy of each index.

Proportion of indicators:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

Information entropy:

$$e_j = -\frac{1}{ln\, m} \times \sum_{i=1}^{m} P_{ij} \times ln\, P_{ij} \tag{4}$$

Among these, m is the year of evaluation.

(3) Calculate information entropy redundancy and index weight.

Information entropy redundancy:

$$d_j = 1 - e_j \tag{5}$$

Index weight:

$$\lambda_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{6}$$

(4) Calculate the NQPF level of logistics industry in each region.
New quality productive forces level:

$$S_i = \sum_{j=1}^{m} \lambda_j \times x_{ij} \tag{7}$$

3.2. Kernel density estimation

After the entropy weight method is used to calculate the NQPF development index of the logistics industry in 30 provinces in China, to explore the dynamic distribution and development mode of the NQPF of the logistics industry in China, we use the kernel density estimation method (Peng et al., 2022) to analyze the dynamic evolution trend of the NQPF of the logistics industry in the sample period. The calculation formula is as follows:

$$f_h(x) = \frac{1}{nh} \sum_{i=1}^{n} K(\frac{x_i - \overline{x}}{h}) \tag{8}$$

$$K(x) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{x^2}{2}\right) \tag{9}$$

In the formula, n represents the number of observations, h is the smoothing parameter, $\overline{x}$ is the sample mean, x_i is the sample observation value, and $K(\bullet)$ is a Gaussian kernel function.

3.3. Dagum gini coefficient

The Dagum Gini coefficient and its decomposition method (Dagum, 1997; Yao, 1999) are used to decompose it into three parts: Intra group difference contribution, inter group difference contribution, and super variable density contribution to further analyze the regional differences and their sources. The calculation formula is as follows:

1. Overall Gini coefficient

$$G = \frac{\sum_{j=1}^{k} \sum_{h=1}^{k} \sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{2n^2 \overline{y}} \tag{10}$$

$$G_{jj} = \frac{\frac{1}{2\overline{y}} \sum_{i=1}^{n} \sum_{r=1}^{n} |y_{ji} - y_{jr}|}{n_j^2} \tag{11}$$

$$G_{\mathrm{jh}} = \frac{\sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{n_j n_h (\overline{y}_j + \overline{y}_h)} \tag{12}$$

2. Gini coefficient decomposition:

$$G_w = \sum_{j=1}^{k} G_{jj} q_j l_j \tag{13}$$

$$G_b = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh} (q_j l_h + q_h l_j) D_{jh} \tag{14}$$

$$G_t = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh} (q_j l_h + q_h l_j)(1 - D_{jh}) \tag{15}$$

$$D_{jh} = \frac{m_{jh} - q_{jh}}{m_{jh} + q_{jh}} \tag{16}$$

$$m_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y - x) dF_h(x) \tag{17}$$

$$q_{jh} = \int_0^\infty dF_h(y) \int_0^y (y-x) dF_j(x) \quad (18)$$

In the formula, G is the overall Gini coefficient, G_{jj} is Gini coefficient of j region, G_{jh} is the Gini coefficient between region j and region$h$, G_w indicates the intra-area difference, G_b indicates the difference between regions, G_t means hypervariable density, D_{jh} represents the relative impact of the NQPF level of logistics industry between j region and $h$region, m_{jh} represents the difference in the level of NQPF of the logistics industry between regions, and q_{jh} stands for the first moment of hyper transformation.

3.4. Moran's I

In order to further analyze its spatial correlation, Moran's I method (Zhao et al., 2025) is used to reveal the spatial agglomeration mode and evolution trend of the NQPF of China's logistics industry. First, select the global Moran's I (Maddison, 2006; Wu et al., 2025) to study whether the data has global spatial correlation. The calculation formula is as follows:

$$\text{Global Moran's I} = \frac{\sum_i^n \sum_{j \neq i}^n w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{s^2 \sum_i^n \sum_{j \neq i}^n w_{ij}} \quad (19)$$

Furthermore, the local Moran's I (Anselin, 1995)[0] is used to study the local spatial correlation. The calculation formula is as follows:

$$Local\ Moran's\ I = \frac{(x_i - \overline{x})}{s^2} \sum_{j=1}^n w_{ij}(x_j - \overline{x}) \quad (20)$$

In the formula, x_i and x_j represent the development level of NQPF of the logistics industry in different provinces, $\overline{x}$ is the average level of development of NQPF of the logistics industry, s^2 is the sample variance, and $w_{ij}$is an element of the spatial weight matrix.

3.5. Spatial econometrics

To explore the factors affecting the spatial characteristics of NQPF in China's logistics industry, a spatial econometric model (Zhang et al., 2023; Wu, 2024; Yang et al., 2025) is selected for analysis, and a suitable spatial econometric model is determined through the LM, Hausman test, LR, and Wald test. The three common spatial econometric models are as follows:

(1) The spatial autoregressive model (SAR), which considers that there is a strong spatial dependence among the explained variables, incorporates the spatial lag term of the explained variables into the model:

$$Y = \rho WY + X\beta + \varepsilon \quad (21)$$

In the formula, Y is the dependent variable, which represents the level of development of NQPF in the logistics industry, X is each independent variable, β is the regression coefficient of the independent variable, ρ is the spatial autocorrelation coefficient, W is the spatial weight matrix, and ε is the error term.

(2) The Spatial Error Model (SEM), due to the presence of other factors that have an impact on the development level of NQPF in the logistics industry that have not been considered, adds a spatial lag term of u spatial error term in the model:

$$Y = X\beta + u \tag{22}$$

In the formula $u = \lambda Wu + \varepsilon$, λ is the spatial autocorrelation coefficient, and β is the regression coefficient of the independent variable.

(3) The Spatial Durbin Model (SDM) incorporates both the spatial lag term of the dependent variable and the spatial lag term and spatial error term of the explanatory variable:

$$Y = \rho WY + X\beta + WX\theta + \lambda_t + \varepsilon \tag{23}$$

In the formula, Y is the dependent variable, X is the independent variable, W is the spatial weight matrix, β is the regression coefficient of the independent variable, ρ and θ are spatial correlation coefficients, λ_t is the time fixed effect, and ε is the error term.

4. Analysis of the spatiotemporal characteristics of the development level of NQPF of China's logistics industry

4.1. Analysis of measurement results

Due to significant differences in resource distribution and industrial structure among regions, the eastern region has a more developed economy, higher logistics demand, and a higher level of logistics industry development; however, the middle and west regions are relatively lagging behind, with a lower level of development in the logistics industry; in recent years, the northeast region has been facing the challenge of transformation and upgrading. Therefore, in order to better understand and analyze the development status of NQPF in the logistics industry in various regions, formulate targeted regional development strategies, promote coordinated development between regions, and achieve rational allocation and optimized utilization of resources, China is divided into four major regions for analysis: East, middle, west, and northeast.

(1) Based on national and four regional perspectives

From the point of view of the whole country (as shown in Table 2), the development level of the NQPF of the logistics industry in China shows a trend of rising steadily. In terms of growth rate, it increased from 1.4874 in 2015 to 1.5371 in 2022, with an average annual growth rate of 0.79%. Among them, the average annual growth rate in the middle and west regions exceeds the national average level, especially the west region with a faster average annual growth rate of 0.99%. Furthermore, the lowest average annual growth rate in the east region is 0.62%, indicating that the development level of NQPF in the national logistics industry shows a decreasing trend in the west region, middle region, northeast region, and east region. It can be seen that there is a significant "catch-up effect" in the west, middle, and northeast regions. From the average perspective, the average NQPF of the logistics industry in China from 2015 to 2022 was 1.5371, with 1.5918 in the east region, 1.5733 in the middle region, 1.4633 in the west region, and 1.5528 in the northeast region. It can be concluded that the average productivity of the east region is 1.01 times that of the middle region, 1.09 times that of the west region, and 1.03 times that of the northeast region, indicating that the overall development level of NQPF in the logistics industry in the east region is higher than that of the other three regions, with a significant gap compared to the west region.

Table 2. Measurement results of the development level of NQPF in China's logistics industry from 2015 to 2022.

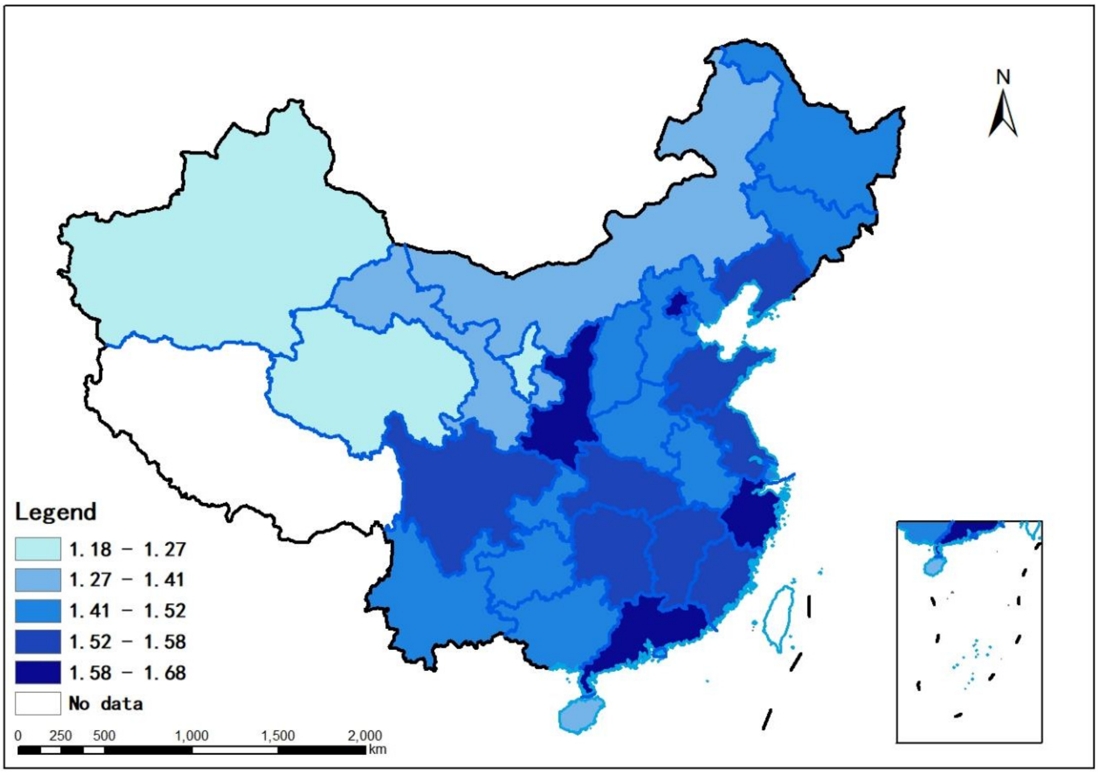
Region	Province	2015	2016	2017	2018	2019	2020	2021	2022	Mean	Growth Rate
East	Beijing	1.6627	1.6655	1.6669	1.6711	1.6777	1.6809	1.6867	1.6881	1.6749	0.22%
	Tianjin	1.4583	1.4797	1.4953	1.5143	1.5306	1.5474	1.5541	1.5580	1.5172	0.95%
	Heibei	1.5100	1.5302	1.5476	1.5631	1.5765	1.5799	1.5847	1.5970	1.5611	0.80%
	Shanghai	1.5163	1.5264	1.5523	1.5461	1.5609	1.5653	1.5710	1.5756	1.5517	0.55%
	Jiangsu	1.5476	1.5608	1.5721	1.5882	1.5991	1.6046	1.6134	1.6189	1.5881	0.65%
	Zhejiang	1.6402	1.6463	1.6644	1.6781	1.6868	1.6860	1.6929	1.7036	1.6748	0.54%
	Fujian	1.5846	1.6003	1.6121	1.6322	1.6407	1.6340	1.6454	1.6604	1.6262	0.67%
	Shandong	1.5295	1.5451	1.5655	1.5696	1.5817	1.5925	1.6015	1.6130	1.5748	0.76%
	Guangdong	1.6777	1.6879	1.7039	1.7200	1.7297	1.7242	1.7376	1.7422	1.7154	0.54%
	Hainan	1.3906	1.4080	1.4243	1.4417	1.4560	1.4454	1.4532	1.4509	1.4338	0.61%
	Regional Mean	1.5518	1.5650	1.5805	1.5924	1.6040	1.6060	1.6141	1.6208	1.5918	0.62%
Middle	Shanxi	1.5145	1.5329	1.5471	1.5696	1.5809	1.6048	1.6044	1.6181	1.5715	0.95%
	Anhui	1.4691	1.4885	1.5159	1.5275	1.5376	1.5476	1.5658	1.5646	1.5271	0.90%
	Jiangxi	1.5440	1.5618	1.5938	1.5959	1.6016	1.6111	1.6155	1.6137	1.5922	0.63%
	Henan	1.5079	1.5251	1.5356	1.5538	1.5633	1.5626	1.5786	1.5826	1.5512	0.69%
	Hubei	1.5455	1.5596	1.5810	1.5871	1.6020	1.5999	1.6103	1.6182	1.5880	0.66%
	Hunan	1.5574	1.5778	1.6030	1.6085	1.6238	1.6254	1.6371	1.6477	1.6101	0.81%
	Regional Mean	1.5231	1.5409	1.5627	1.5737	1.5849	1.5919	1.6020	1.6075	1.5733	0.77%
West	Inner Mongolia	1.4122	1.4320	1.4591	1.4678	1.5074	1.5170	1.5417	1.5270	1.4830	1.12%
	Guangxi	1.4774	1.4930	1.5273	1.5452	1.5635	1.5773	1.5857	1.5979	1.5459	1.13%
	Chongqing	1.5067	1.5311	1.5476	1.5667	1.5792	1.5796	1.5936	1.5988	1.5629	0.85%
	Sichuan	1.5588	1.5746	1.5944	1.6190	1.6269	1.6309	1.6436	1.6454	1.6117	0.77%
	Guizhou	1.4419	1.4549	1.4773	1.4897	1.5010	1.5065	1.5199	1.5360	1.4909	0.91%
	Yunnan	1.4582	1.4781	1.5033	1.5179	1.5337	1.5430	1.5480	1.5560	1.5173	0.93%
	Shaanxi	1.6149	1.6344	1.6465	1.6656	1.6743	1.6945	1.6779	1.6901	1.6623	0.65%
	Gansu	1.3511	1.3634	1.3856	1.3975	1.4046	1.4182	1.4388	1.4369	1.3995	0.88%
	Qinghai	1.1807	1.1972	1.2061	1.2263	1.2336	1.2617	1.2723	1.2702	1.2310	1.05%
	Ningxia	1.1828	1.2063	1.2609	1.2731	1.2813	1.2952	1.3139	1.3198	1.2667	1.58%
	Xinjiang	1.2716	1.2597	1.3011	1.3320	1.3234	1.3757	1.3600	1.3813	1.3256	1.19%
	Regional Mean	1.4051	1.4204	1.4463	1.4637	1.4753	1.4909	1.4996	1.5054	1.4633	0.99%
North east	Liaoning	1.5654	1.5792	1.5961	1.6008	1.6167	1.6230	1.6281	1.6331	1.6053	0.61%
	Jilin	1.4700	1.4966	1.5069	1.5286	1.5391	1.5429	1.5381	1.5245	1.5183	0.52%
	Heilongjiang	1.4752	1.4986	1.5220	1.5267	1.5500	1.5645	1.5607	1.5793	1.5346	0.98%
	Regional Mean	1.5036	1.5248	1.5417	1.5520	1.5686	1.5768	1.5756	1.5790	1.5528	0.70%
National	Mean	1.4874	1.5032	1.5238	1.5375	1.5495	1.5581	1.5658	1.5716	1.5371	0.79%

(2) From the perspective of various provinces across the country

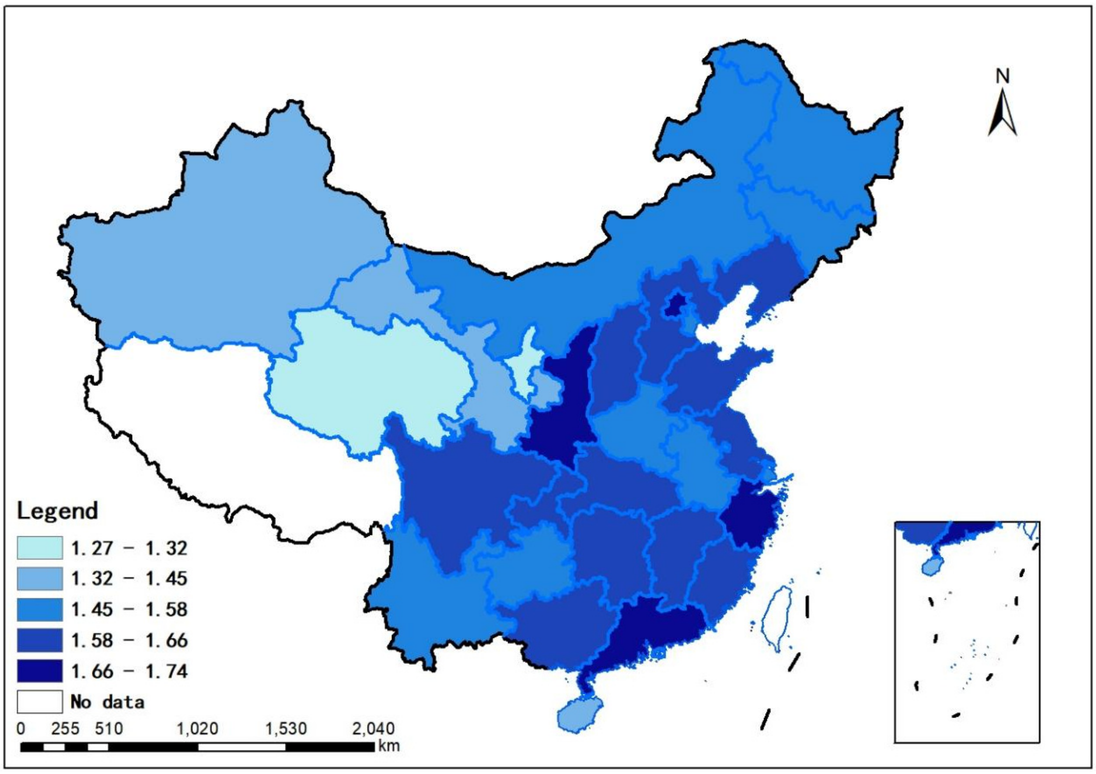
In terms of growth rate (as shown in Table 2), the growth rates of Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region, Qinghai Province, Inner Mongolia, and Guangxi Province are relatively high, above 1%. The growth rates of Beijing, Jilin Province, Guangdong Province, Shanghai, and Zhejiang Province are relatively low, below 0.6%. On average, the annual average development level of NQPF in the logistics industry in Beijing, Zhejiang Province, and Guangdong Province has reached over 1.67. Among them, Guangdong Province has the highest level, while Qinghai Province, Ningxia Hui Autonomous Region, and Xinjiang Uygur Autonomous Region have the lowest annual average development level. Among them, Qinghai Province's development level of NQPF in the logistics industry is only 1.2310. From the above analysis, it can be seen that provinces with relatively high development levels of NQPF in the logistics industry have a slow upward trend in annual growth rate, while provinces with relatively weak development levels have a rapid upward trend in annual growth rate. This indicates that provinces with relatively high development levels may be in a bottleneck period of development, and provinces with relatively weak development levels have greater development space. Generally speaking, there are some differences in the development level of NQPF of logistics industry in various provinces.

Furthermore, in order to more intuitively reflect the spatiotemporal distribution characteristics of the development level of NQPF in China's logistics industry, we use ArcGIS software to draw the spatial distribution maps of the comprehensive index of NQPF in China's logistics industry for 2015 and 2022 based on the data in the above table and combined with the natural discontinuity grading method. As shown in Figure 1, the development level of NQPF in the logistics industry of 30 provinces in China (excluding provinces with missing data) is divided into 5 levels. The darker the color, the higher the development level of NQPF of the logistics industry in the region, and the lower vice versa.

According to Figure 1A, in 2015, the high level development of NQPF in China's logistics industry included Beijing, Zhejiang Province, Guangdong Province, and Shaanxi Province; regions with relatively higher levels of development in NQPF in the logistics industry include Shandong Province, Jiangsu Province, Fujian Province, Liaoning Province, Jiangxi Province, Hunan Province, Hubei Province, and Sichuan Province; regions with a medium level of development in NQPF in the logistics industry include Heilongjiang Province, Jilin Province, Hebei Province, Tianjin, Shanghai, Shanxi Province, Henan Province, Anhui Province, Chongqing, Guizhou Province, Yunnan Province, and Guangxi Zhuang Autonomous Region; regions with relatively lower levels of development in NQPF in the logistics industry include Gansu Province, Hainan Province, and Inner Mongolia Autonomous Region; and regions with low levels of NQPF development in the logistics industry include Xinjiang Uygur Autonomous Region, Qinghai Province, and Ningxia Hui Autonomous Region. It can be seen that in 2015, there were 12 regions with high and relatively higher levels of NQPF development in China's logistics industry, and 6 regions with low and relatively lower levels of development. The overall trend showed a decreasing trend from the east to the middle and west regions. According to Figure B, by 2020, Hebei Province, Shanghai, Shanxi Province, Chongqing, and the Guangxi Zhuang Autonomous Region will develop from a medium level to a relatively higher level, while Hainan Province and the Inner Mongolia Autonomous Region will develop from a relatively lower level to a medium level; the Xinjiang Uygur Autonomous Region has developed from a low level to a relatively lower level. It can be seen that the overall development level of NQPF in China's logistics industry is showing an upward trend, and the development level of NQPF in the logistics industry in the middle and west regions is steadily improving.



2015 (A)



2022 (B)

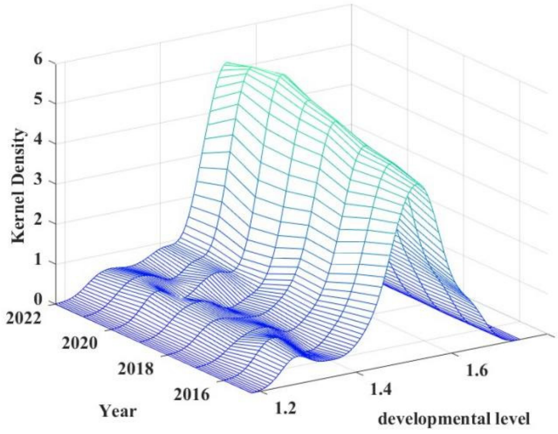
Figure 1. Spatial distribution of development level of NQPF in the logistics industry in China.

4.2. Sequential dynamic evolution

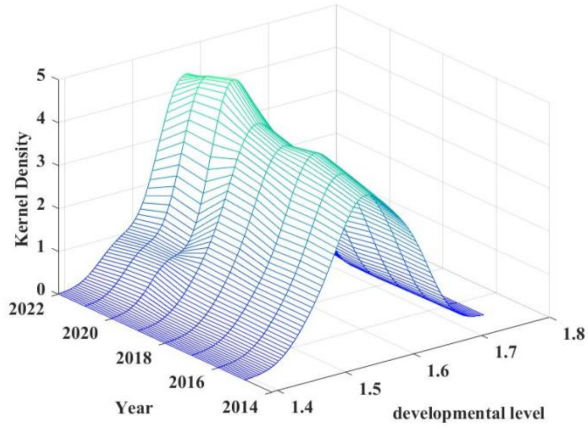
To gain deeper insights into the temporal evolution of NQPF advancement within China's logistics sector, we present kernel density estimates depicting the distribution of logistics NQPF nationally and across the east, middle, west, and northeast regions from 2015 to 2022. As illustrated in Figure 2, analysis of the distribution's position and shape reveals that the estimated kernel density curves for both the national aggregate and the four major regions exhibit varying degrees of rightward displacement over the study period. This pattern signifies a consistent upward trajectory in the overall NQPF development level across China's logistics industry. Examining regional disparities, a pronounced divergence is observed between the middle, west regions and their east counterpart. This marked gap suggests robust growth momentum in logistics NQPF development within the middle and west areas, while progress in the east appears comparatively stable. The minimal shift observed in the northeast region's curve points to a relatively lower baseline level of logistics NQPF development there, highlighting an area requiring focused enhancement and further advancement.

From the peak shape, the fluctuation degree of the national and regional kernel density curve is observed. The national wave crest shows a trend of change from low to high, indicating that the regional differences among provinces experiences a process of narrowing and then expanding. From the regional perspective, the crest of the east region tends to be narrow, which reflects that the regional difference in the development level of the NQPF of the logistics industry in the east region is gradually narrowing, and the development trend is more balanced. The peak of the estimated nuclear density curve in the middle region increased significantly in 2020, indicating that the middle region may have undergone technological innovation and industrial adjustment during this period. The change of wave crest in west region is relatively stable. Moreover, there are multiple peaks in the northeast region, indicating significant regional differences.

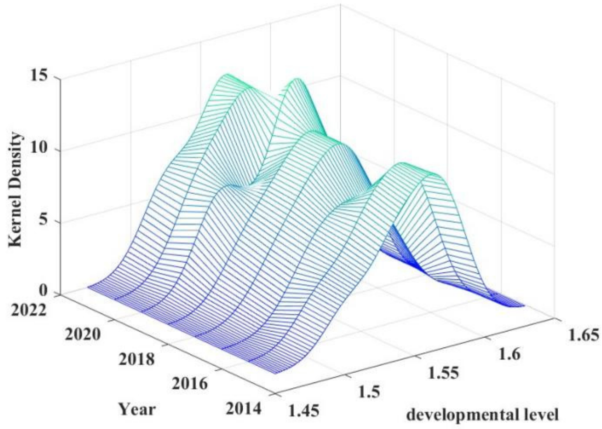
From the perspective of polarization state, there is no multi peak phenomenon in the east and west regions, while there is a distribution state of dual peaks coexisting in the middle and northeast parts of the country. From a regional perspective, there is no obvious multipolar differentiation in the east and west regions, while there is polarization in the national, middle, and northeast regions. The polarization phenomenon is more pronounced in the northeast region, indicating that the development of various provinces in the region is relatively uneven, with some provinces having a higher level of development in the NQPF of the logistics industry, leading to a two-tier differentiation phenomenon. However, over time, the polarization phenomenon across the country, as well as in the middle and northeast regions, is gradually disappearing and weakening.



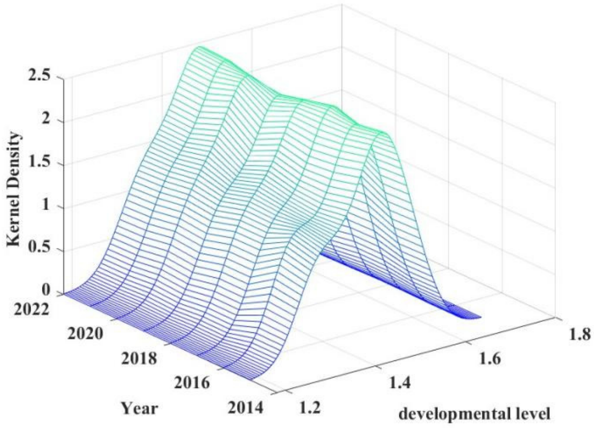
(a) National.



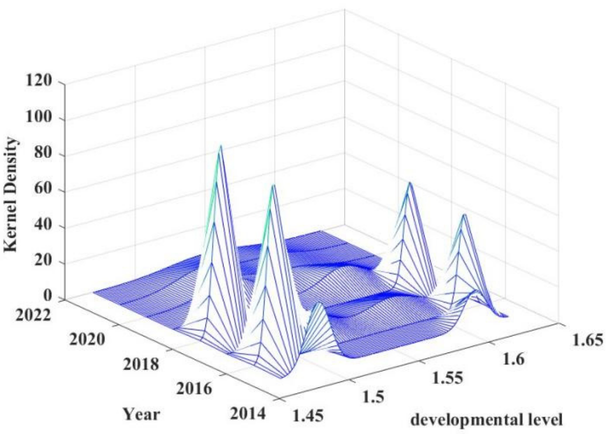
(b) East.



(c) Middle.



(d) West.



(e) Northeast.

Figure 2. Kernel density map of the NQPF development level in the logistics industry.

4.3. Spatial heterogeneity analysis

To delve deeper into the spatial heterogeneity of logistics NQPF development across China, this study employs the Dagum Gini coefficient decomposition method, focusing on the distinct spatial configurations of the east, middle, west, and northeast regions. Results (Tables 3 and 4) reveal divergent temporal patterns: the regional Gini coefficients for logistics NQPF in the east, middle, and west demonstrated a consistent decline between 2015 and 2022, whereas the northeast region experienced an oscillatory increase. Examining intra-regional disparities (Gini within groups): east and west regions exhibited notably higher coefficients, particularly the west, registering a mean annual figure of 0.0519; the middle region displayed significantly lower internal inequality, with a mean annual Gini of 0.0099. Despite the downward trajectory in the east and west, pronounced developmental asymmetries persist internally, reflecting substantial inter-provincial variations in logistics NQPF levels. Notwithstanding northeast upward trend, intra-regional development in the northeast remains comparatively more balanced than in the east and west. While the middle region maintains relative stability, its future trajectory warrants closer monitoring. Analysis of inter-regional disparities (Gini between groups) highlights: The development gap between the east and west regions stands out as particularly pronounced. Significant differences also characterize the disparities between the middle-west and west-northeast pairings. In essence, the evidence points towards persistent regional asymmetries in the advancement of logistics NQPF across China.

Table 3. Decomposition results of the Gini coefficient difference within the group.

Year	Intra-group Gini Coefficient			
	Northeast	East	Middle	West
2015	0.0140	0.0320	0.0110	0.0550
2016	0.0120	0.0300	0.0110	0.0560
2017	0.0130	0.0280	0.0110	0.0530
2018	0.0110	0.0280	0.0100	0.0520
2019	0.0110	0.0270	0.0100	0.0530
2020	0.0110	0.0260	0.0090	0.0500
2021	0.0130	0.0270	0.0080	0.0480
2022	0.0150	0.0270	0.0090	0.0480
Mean	0.0125	0.0281	0.0099	0.0519

Table 4. Decomposition results of the Gini coefficient differences between groups.

Year	Inter-group Gini Coefficient					
	East & Northeast	East & Middle	East & West	Middle & Northeast	Middle & West	West & Northeast
2015	0.0300	0.0250	0.0590	0.0160	0.0490	0.0460
2016	0.0270	0.0240	0.0580	0.0140	0.0490	0.0470
2017	0.0260	0.0230	0.0540	0.0140	0.0460	0.0430
2018	0.0250	0.0220	0.0530	0.0130	0.0450	0.0420
2019	0.0240	0.0210	0.0520	0.0130	0.0440	0.0430
2020	0.0230	0.0210	0.0490	0.0120	0.0420	0.0400
2021	0.0240	0.0200	0.0480	0.0140	0.0410	0.0380
2022	0.0260	0.0210	0.0480	0.0150	0.0410	0.0390
Mean	0.0256	0.0221	0.0526	0.0139	0.0446	0.0423

Based on the Gini coefficient decomposition method and contribution rate, we analyze the sources of regional differences in the development level of the NQPF in China's logistics industry. As shown in Table 5, in terms of contribution rate, the contribution rate of intra- regional differences increases from 26.64% to 27.80%, with an average contribution rate of 27.37%; the contribution rate of inter-regional differences decreases from 54.42% to 48.64%, with an average contribution rate of 51.26%; and the contribution rate of super variable density increased from 18.94% in 2015 to 23.56% in 2022, with an average contribution rate of 21.37%. From this, it can be seen that, as shown in Figure 3, although the contribution rate of inter-regional differences shows a downward trend, compared with the contribution rate of intra-regional differences, the regional differences in the level of NQPF in the logistics industry are mainly caused by inter-regional differences.

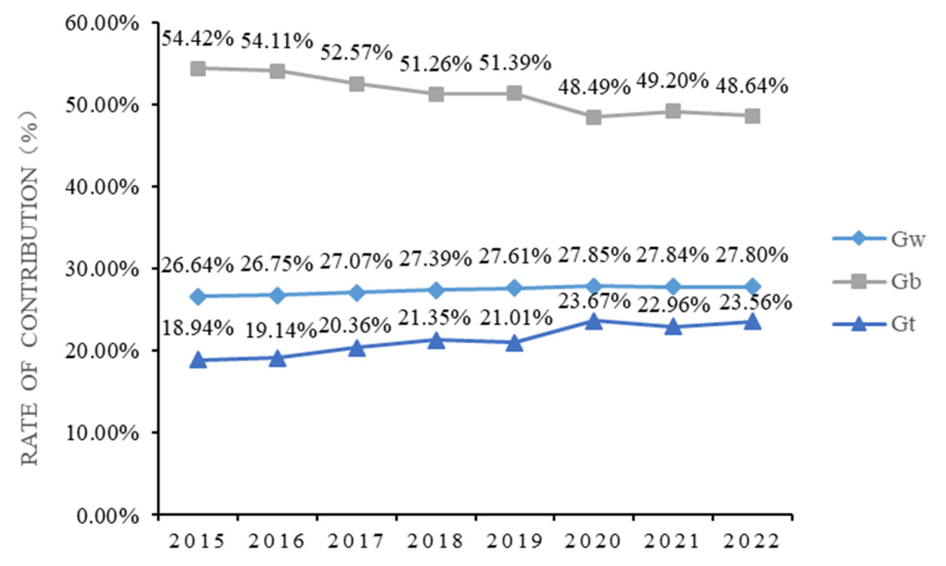


Figure 3. Gini coefficient contribution rate.

Table 5. Dagum Gini coefficient and contribution rate results.

Year	Gini Coefficient				Rate of Contribution (%)		
	Total	Intra-group Gini Coefficient Gw	Inter-group Gini Coefficient Gb	Super Variable Density Gini Coefficient Gt	Intra-group Contribution Rate Gw	Inter-group Contribution Rate Gb	Super Variable Density Contribution Rate Gt
2015	0.0420	0.0110	0.0230	0.0080	26.64%	54.42%	18.94%
2016	0.0410	0.0110	0.0220	0.0080	26.75%	54.11%	19.14%
2017	0.0390	0.0110	0.0210	0.0080	27.07%	52.57%	20.36%
2018	0.0380	0.0100	0.0200	0.0080	27.39%	51.26%	21.35%
2019	0.0380	0.0100	0.0190	0.0080	27.61%	51.39%	21.01%
2020	0.0360	0.0100	0.0170	0.0080	27.85%	48.49%	23.67%
2021	0.0350	0.0100	0.0170	0.0080	27.84%	49.20%	22.96%
2022	0.0350	0.0100	0.0170	0.0080	27.80%	48.64%	23.56%
Mean	0.0380	0.0104	0.0195	0.0080	27.37%	51.26%	21.37%

4.4. Spatial ccorrelation analysis

(1) Global Moran’s I

When conducting spatial correlation analysis, we define the spatial weight matrix as W, where adjacent regions in a geographical location are defined as 1, otherwise they are 0, and construct a 0–1 spatial adjacency matrix. Moran’s I is used to test the spatial correlation of the development level of

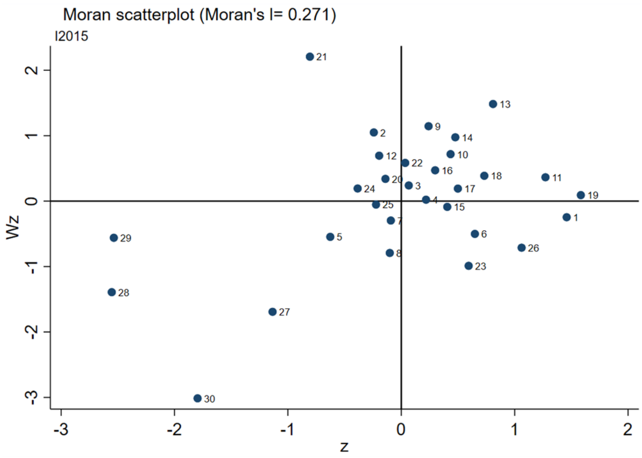
NQPF in the logistics industry among provinces, as well as to determine whether there is a spatial aggregation feature. As shown in Table 6, the Moran's I from 2015 to 2022 were all greater than 0 and the P values were all less than 0.05, through significance testing, indicating that there is a significant spatial correlation in the development level of NQPF in China's logistics industry, and the phenomenon of spatial agglomeration is obvious, that is, regions with similar development levels tend to cluster spatially. Moreover, Moran's I decreased from 0.271 in 2015 to 0.266 in 2022, indicating that with the continuous strengthening of economic circulation in the logistics industry in various regions of China, the differences in the development level of NQPF in the logistics industry between regions are gradually narrowing.

Table 6. Global development level of NQPF in China's logistics industry from 2015 to 2022 using Moran's I.

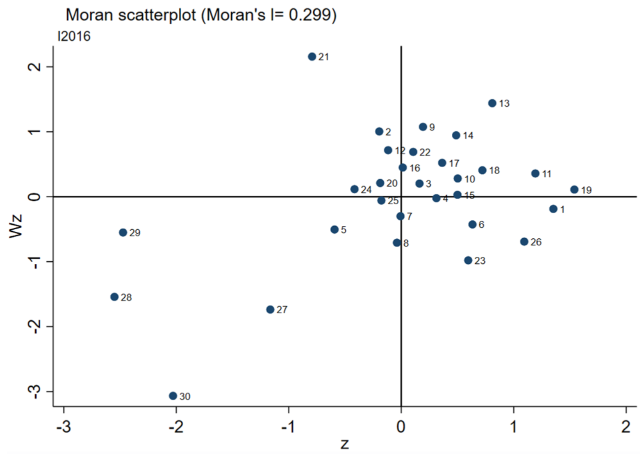
Year	Moran's I	E(I)	sd(I)	Z-Value	P- Value
2015	0.271	−0.034	0.120	2.548	0.005
2016	0.299	−0.034	0.120	2.786	0.003
2017	0.307	−0.034	0.119	2.860	0.002
2018	0.290	−0.034	0.119	2.715	0.003
2019	0.307	−0.034	0.119	2.870	0.002
2020	0.251	−0.034	0.119	2.391	0.008
2021	0.271	−0.034	0.119	2.559	0.005
2022	0.266	−0.034	0.119	2.515	0.006

(2) Local Moran's I

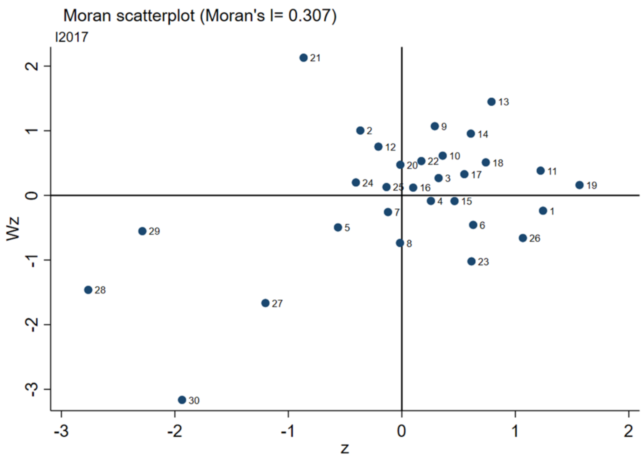
To illustrate the local agglomeration characteristics exhibited in the development process of NQPF in China's logistics industry, the Moran's I scatter plot from 2015 to 2022 is calculated (as shown in Figure 4) to divide the agglomeration areas of the logistics industry's NQPF development levels in each province. The 30 provinces in China are distributed in four quadrants representing four spatial autocorrelation patterns. The provinces in the first quadrant and adjacent provinces have a higher level of development, which is a high-high agglomeration type (H-H); the provinces in the second quadrant have a lower level of development, but neighboring provinces have a higher level of development, forming a low-high agglomeration type (L-H); the provinces in the third quadrant have a lower level of development compared to neighboring provinces, indicating a low-low agglomeration pattern (L-L); and the provinces within the fourth quadrant have a higher level of development, but neighboring provinces have a lower level of development, forming a high-low agglomeration (H-L) pattern (note: In Figure 4, 1–30 respectively represent:1-Beijing; 2-Tianjin; 3-Heibei; 4-Shanxi; 5-Inner Mongolia; 6-Liaoning; 7-Jilin; 8-Heilongjiang; 9-Shanghai; 10-Jiangsu; 11-Zhejiang; 12-Anhui; 13-Fujian; 14-Jiangxi; 15-Shandong; 16-Henan; 17-Hubei; 18-Hunan; 19-Guangdong; 20-Guangxi; 21-Hainan; 22-Chongqing; 23-Sichuan; 24-Guizhou; 25-Yunnan; 26-Shaanxi; 27-Gansu; 28-Qinghai; 29-Ningxia; 30-Xinjiang).



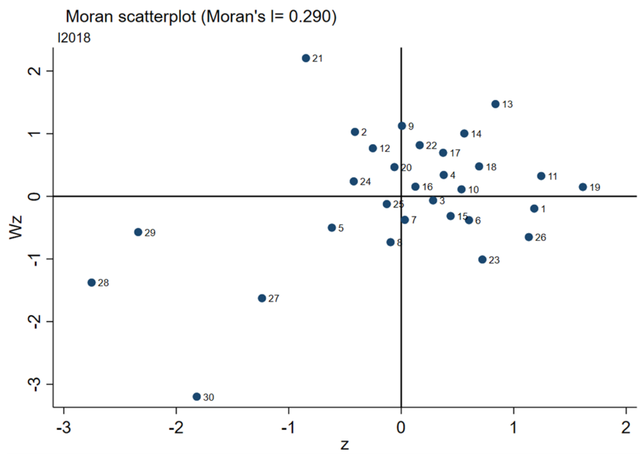
(a) Local Moran's I scatter plot in 2015.



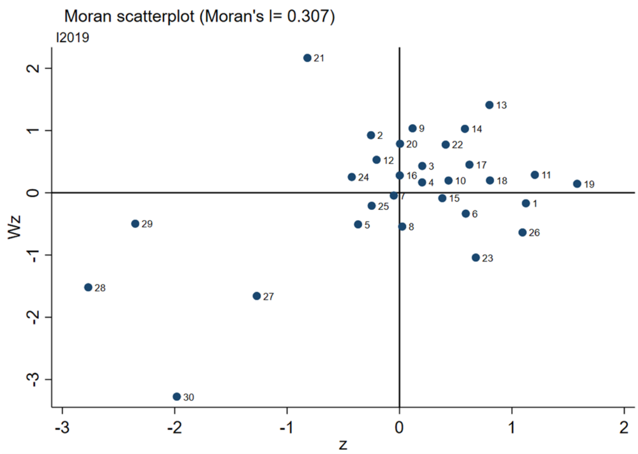
(b) Local Moran's I scatter plot in 2016.



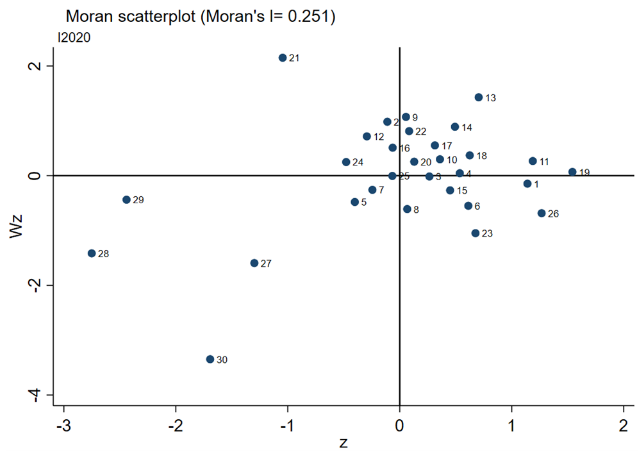
(c) Local Moran's I scatter plot in 2017.



(d) Local Moran's I scatter plot in 2018.



(e) Local Moran's I scatter plot in 2019.



(f) Local Moran's I scatter plot in 2020.

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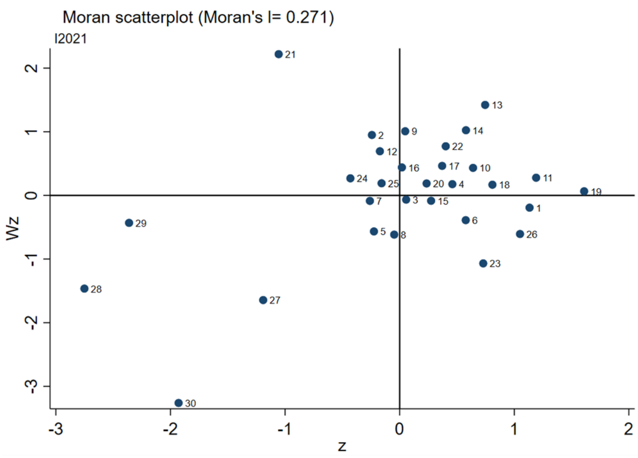
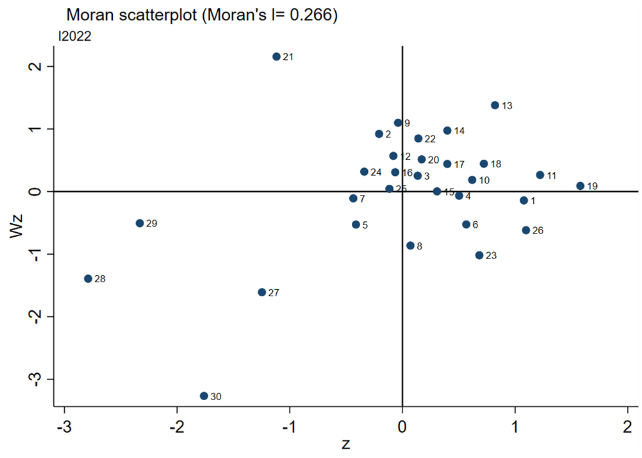


(g) Local Moran's I scatter plot in 2021.



(h) Local Moran's I scatter plot in 2022.

Figure 4. Local Moran's I scatter plot.

Table 7. Distribution of Local Moran's I region from 2015 to 2022.

Year	H-H	L-H	L-L	H-L
2015	Shanghai,Chongqing, Fujian,Jiangxi,Jiangsu, Hunan, Hubei, Shanxi, Hebei, Henan, Zhejiang, Guangdong	Guizhou, Guangxi, Anhui, Tianjin, Hainan	Ningxia, Qinghai, Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Jilin, Yunnan	Sichuan, Liaoning, Shaanxi, Beijing, Shandong
2016	Shanghai, Chongqing, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shandong, Hebei, Henan, Zhejiang, Guangdong	Guizhou, Guangxi, Anhui, Tianjin, Hainan	Ningxia, Qinghai, Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Jilin, Yunnan	Sichuan, Liaoning, Shaanxi, Beijing, Shanxi
2017	Chongqing, Shanghai, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Hebei, Henan, Zhejiang, Guangdong	Guizhou, Anhu, Tianjin, Hainan, Guangxi, Yunnan	Ningxia, Qinghai, Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Jilin	Shandong, Shanxi, Sichuan, Liaoning, Shaanxi, Beijing
2018	Chongqing, Shanghai, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shanxi, Henan, Zhejiang, Guangdong	Guizhou, Guangxi, Anhui, Tianjin, Hainan	Qinghai, Ningxia, Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Yunnan	Jilin, Hebei, Shandong, Sichuan, Liaoning, Shaanxi, Beijing
2019	Chongqing, Shanghai, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shanxi, Hebei, Henan, Zhejiang, Guangdong, Guangxi	Guizhou, Anhui, Tianjin, Hainan	Qinghai, Ningxia, Xinjiang, Gansu, Inner Mongolia, Jilin, Yunnan	Sichuan, Liaoning, Shaanxi, Beijing, Heilongjiang, Shandong
2020	Chongqing, Shanghai, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shanxi, Hebei, Zhejiang, Guangdong, Guangxi	Guizhou, Yunnan, Anhui, Tianjin, Hainan, Henan	Qinghai, Ningxia, Xinjiang, Gansu, Inner Mongolia, Jilin	Sichuan, Liaoning, Shaanxi, Beijing, Heilongjiang, Shandong
2021	Chongqing, Shanghai, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shanxi, Henan, Zhejiang, Guangdong, Guangxi	Guizhou, Yunnan, Tianjin, Hainan, Anhui	Qinghai, Ningxia, Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Jilin	Sichuan, Liaoning, Shaanxi, Beijing, Shandong, Hebei
2022	Chongqing, Fujian, Jiangxi, Jiangsu, Hunan, Hubei, Shandong, Hebei, Zhejiang, Guangdong, Guangxi	Guizhou, Yunnan, Anhui, Tianjin, Hainan, Shanghai, Henan	Qinghai, Ningxia, Xinjiang, Gansu, Inner Mongolia, Jilin	Sichuan, Liaoning, Shaanxi, Beijing, Heilongjiang, Shanxi

As shown in Table 7, spatial agglomeration and heterogeneity are in the development level of NQPF in China's logistics industry, mainly manifested in the high- high agglomeration type (H-H) in the east and middle regions, and the agglomeration distribution is unbalanced; the west and northeast regions are mainly concentrated in the low-low agglomeration type (L-L), the pattern differentiation is more significant, and there is an obvious positive correlation.

Furthermore, this spatial agglomeration trend is constantly adjusting over time. In 2017, Yunnan province evolved from a low-low agglomeration type (L-L) to a low-high agglomeration type (L-H) and subsequently experienced minor fluctuations, reverting temporarily to the low-low agglomeration type (L-L), before stabilizing in the low-high agglomeration type (L-H) by 2020; in 2019, Heilongjiang province evolved from low-low agglomeration type (L-L) to high-low agglomeration type (H-L); and Guangxi province evolved from a low-high agglomeration type (L-H) to a high -high agglomeration type (H-H). Guangxi and Yunnan provinces have relatively lower levels of development but are surrounded by high level neighboring regions, showing negative spatial spillover effects. With the development of the west region's economy, the development level of themselves and their neighboring regions has improved, showing a positive spatial agglomeration effect and a trend of development improvement. Therefore, influenced positively by regions with higher levels of development, it has evolved into regions with relatively higher levels of agglomeration. Heilongjiang province, on the other hand, may begin to experience some form of growth or development, but this growth has not driven the development of surrounding areas, showing an uneven development pattern. From this, it can be seen that the east and middle regions have higher spatial stability, with only a few provinces experiencing minor fluctuations; the west region shows a positive spatial agglomeration effect; and the northeast region faces the problem of uneven development. In short, the spatial pattern of the development level of NQPF in China's logistics industry is relatively stable, with only a few provinces experiencing regional changes. However, in order to further promote the development of NQPF in China's logistics industry, it is necessary to further explore the key factors that affect the development of NQPF in China's logistics industry.

5. Analysis of factors influencing spatial relationships

5.1. Select influencing factors

The preceding analysis reveals that logistics NQPF development manifests distinctive spatial variations and interdependencies. In light of this spatial patterning, our approach integrates spatial effects across regions, leading us to conduct spatiotemporal analyses examining the factors influencing China's logistics NQPF development levels.

By reviewing relevant literature and combining with the current development status of the logistics industry (Tian and Zhang, 2019), we select indicators from the following five aspects as influencing factors to explore their impact on the development level of NQPF of the logistics industry. These factors include:

(1) Logistics Infrastructure. The physical foundations of the logistics sector are paramount. These backbone facilities serve as crucial conduits for balancing goods supply and demand. Leveraging them for intermodal transport solutions fosters cooperation across transportation modes and strengthens inter-departmental collaboration, while also enabling coordinated regional infrastructure utilization and enhanced logistics quality. Total railway mileage stands as a pivotal indicator of a nation's logistics

infrastructure maturity. It captures not only the logistics network's scale and reach, but also embodies critical dimensions like transport efficiency, regional economic advancement, multimodal connectivity, and green, low-carbon development. Consequently, we employ total railway mileage (denoted as INF) as the proxy variable for logistics infrastructure.

(2) Level of Economic Development. Robust economic expansion propels households toward lifestyle enhancement, thereby unlocking latent demand for tangible goods. This amplified material consumption demand, in turn, acts as a catalyst for logistics sector advancement. To accurately gauge regional economic health, prevailing scholarly practice employs provincial GDP as a proxy. Nevertheless, GDP as a standalone metric fails to account for demographic variations. Consequently, we adopt per capita GDP (denoted as PGDP) as the explanatory variable characterizing regional economic growth.

(3) Information Technology Level. Regional disparities in fixed broadband subscriptions serve as a proxy for varying levels of IT advancement, contributing to the facilitation of coordinated regional growth. In the context of the digital economy's meteoric rise, the expansion of broadband user bases closely tracks the scale and sophistication of digital economic activities, constituting a key driver for socio-economic progress. Accordingly, we adopt the number of Internet broadband access users (denoted as TEC) as the indicator for information technology level.

(4) Human Resource Level. Effective human resource management can improve service quality, support technological innovation, promote strategic implementation, and address talent shortages. Optimal deployment of talent is instrumental in propelling logistics sector growth, with employment figures in transportation, warehousing, and postal services serving as a critical barometer of human resource capacity within these industries. Accordingly, the workforce count across transportation, warehousing, and postal sectors is selected as the proxy variable for human resource level, denoted as HRL.

(5) Government Support Intensity. The government's support has a certain impact on the development of the logistics industry. It has a profound impact on the development of the logistics industry through measures such as policy guidance, capital investment, cost reduction and efficiency improvement, industrial linkage, and international cooperation. The fixed assets investment in transportation infrastructure is chosen to represent the government's support, because it not only reflects the government's emphasis on the logistics field, but also is an important tool for the government to achieve macroeconomic regulation, promote regional coordinated development, and respond to economic fluctuations. Therefore, the amount of fixed assets investment in transportation infrastructure is selected and expressed in GOV.

5.2. Selection of spatial econometric models

The model selection process commenced by employing the Lagrange Multiplier (LM) test to diagnose potential spatial error effect and spatial lag effect. Subsequently, the Hausman test determined the suitability of fixed versus random effects specification. Building upon an initial Spatial Durbin Model (SDM) assumption, Likelihood Ratio (LR) and Wald tests were conducted to assess potential model degeneration into simpler Spatial Error (SEM) or Spatial Lag (SLM) specifications. The definitive model was then identified by synthesizing these test outcomes. As presented in Table 8, statistically significant LM test p-values confirmed the presence of both spatial error and spatial lag effects. Mixed panel regression is rejected and the spatial Durbin model is initially selected. The p-value of Hausman's test is 0.022, which is less than 0.05; therefore, a fixed effects model is used. The p-values of the LR test and Wald test are both less than 0.05, indicating that the spatial Durbin model will not degrade. Consequently, the fixed effects Spatial Durbin model was selected as the most appropriate specification for the ensuing analysis.

Table 8. Model validation results.

Test Method	Statistical Value	P- Value
(Spatial error) Lagrange multiplier	271.314	0.000
Robust Lagrange multiplier	102.715	0.000
(Spatial lag) Lagrange multiplier	174.222	0.000
Robust Lagrange multiplier	5.623	0.018
LR Lag	12.550	0.028
LR Err	16.660	0.005
Wald Lag	11.200	0.048
Wald Err	18.050	0.003
Hausman	14.800	0.022

5.3. Analysis of regression results of spatial econometric models

After the selection of the spatial econometric model, the 0-1 adjacency matrix is constructed, the spatial Durbin model with time fixed effect is used for spatial econometric regression, and SAR and SEM models are selected for comparison.

Moreover, to ensure the robustness of the results, we conduct robustness tests using a geographic distance matrix and economic distance matrix (Wang and Guo, 2023). The regression results presented in Table 9 show that the findings from the SAR and SEM models are largely consistent with those of the SDM model. This consistency further supports the robustness of the findings in this study.

According to Table 9, the coefficient of logistics infrastructure is negative, but its impact on the development level of NQPF of China's logistics industry has passed the test at a significance level of 1%. The reason for this phenomenon might be that during the infrastructure construction period, problems such as traffic congestion and construction interference may occur, thereby temporarily reducing the logistics efficiency and briefly affecting the development of NQPF of the logistics industry. Moreover, there may be differences in the construction progress and operational efficiency of logistics infrastructure in different regions. Such regional differences may lead to the development of the overall outcome, resulting in a negative impact on the NQPF of the logistics industry. The influences of the level of economic development and the level of human resources pass the test at the significance level of 1%, but the coefficients of the spatial lag terms are not significant. This indicates that regions with a higher level of economic development are often the frontiers of technological innovation, new technologies, and new models, which can be applied and promoted more quickly in these regions. This technological diffusion effect can drive the overall upgrading of the logistics industry. Furthermore, this approach can enhance the cultivation of high-caliber logistics talent, accelerating the advancement of NQPF within the sector, the resulting lag may be due to the fact that neighboring regions need time to adjust and adapt to the new economic environment and development opportunities. Notably, the coefficient for IT level is the most significant and exerts a statistically robust positive influence (significant at the 1% level) on the NQPF development of China's logistics industry. This prominence likely reflects the heightened demands of the digital era for sophisticated IT application. Leveraging IT enables rapid logistics information exchange, efficient data processing and storage, thereby boosting operational efficiency and precision. Consequently, it drives the industry's shift from traditional practices towards modernization and high-quality development, aligning intrinsically with the core tenets of NQPF. Enhancing IT capabilities is therefore pivotal for effectively fostering NQPF growth in logistics.

Table 9. Spatial econometric regression and robustness test results.

Main	Adjacent 0-1 Matrix			Geographic Distance Matrix			Economic Distance Matrix		
	SAR	SEM	SDM	SAR	SEM	SDM	SAR	SEM	SDM
lnINF	−0.013**	−0.020***	−0.018***	−0.025***	−0.020***	0.001	−0.030***	−0.027***	−0.021***
	(−1.99)	(−3.47)	(−2.58)	(−3.54)	(−2.90)	(0.13)	(−3.90)	(−3.75)	(−2.82)
lnPGDP	0.042***	0.041***	0.039***	0.034***	0.048***	0.070***	0.039***	0.039***	0.033***
	(4.83)	(5.11)	(3.94)	(3.48)	(4.6)	(5.79)	(3.75)	(3.87)	(2.80)
lnTEC	0.053***	0.062***	0.057***	0.063***	0.063***	0.048***	0.072***	0.073***	0.076***
	(11.12)	(12.17)	(10.11)	(10.49)	(11.11)	(6.87)	(13.70)	(14.22)	(13.79)
lnHRL	0.041***	0.0287***	0.040***	0.033***	0.036***	0.029***	0.034***	0.031***	0.022***
	(8.66)	(6.80)	(7.5)	(6.34)	(6.61)	(4.85)	(5.81)	(5.67)	(3.71)
lnGOV	0.001	−0.002	0.002	−0.004	−0.009*	−0.012**	−0.006	−0.007	−0.006
	(0.29)	(−0.38)	(0.53)	(−0.93)	(−1.83)	(−2.23)	(−1.39)	(−1.48)	(−1.48)
lnINF*W	-	-	−0.012	-	-	1.236***	-	-	−0.373**
	-	-	(−0.82)	-	-	(3.80)	-	-	(−2.25)
lnPGDP*W	-	-	0.003	-	-	1.266***	-	-	−0.500**
	-	-	(0.14)	-	-	(4.80)	-	-	(−2.03)
lnTEC*W	-	-	−0.022**	-	-	−0.328***	-	-	0.055
	-	-	(−2.45)	-	-	(−2.71)	-	-	(0.93)
lnHRL*W	-	-	0.014	-	-	−0.745***	-	-	0.193
	-	-	(1.18)	-	-	(−4.36)	-	-	(1.50)
lnGOV*W	-	-	−0.002	-	-	−0.095*	-	-	0.016
	-	-	(−0.25)	-	-	(−1.83)	-	-	(0.60)
R2	0.875	0.866	0.849	0.751	0.825	0.818	0.842	0.850	0.795
Log-likelihood	461.926	459.872	468.2	431.379	438.915	448.729	424.501	426.7174	389.6426
Sample Size	240	240	240	240	240	240	240	240	240

Note：***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

5.4. Spatial effect decomposition

To further identify key influencing factors and improve estimation accuracy, we analyze the mutual influence between provinces, decompose spatial effects, and divide spatial global effects into direct effects and indirect effects, as shown in Table 10.

Table 10. Decomposition results of spatial effects.

Variable	Direct Effect	Indirect Effect	Global Effect
lnINF	−0.022**	−0.048	−0.070
	(−2.46)	(−1.32)	(−1.62)
lnPGDP	0.044***	0.061	0.105*
	(3.77)	(1.22)	(1.81)
lnTEC	0.060***	0.026	0.086***
	(9.71)	(1.42)	(3.91)
lnHRL	0.047***	0.085***	0.132***
	(6.86)	(2.67)	(3.55)
lnGOV	0.002	−0.001	0.001
	(0.45)	(−0.03)	(0.08)

Note：***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

In the direct effect, the impact of economic development level, information technology level, and human resource level on the development level of NQPF of China's logistics industry is tested at a significance level of 1%, and the coefficient is positive, indicating that the local economic development level, information technology level, and human resource level will significantly promote the development of NQPF of the local logistics industry. For the indirect effect, the impact of human resource level on the development level of NQPF of China's logistics industry pass the test at a significance level of 1%, and the coefficient is positive, showing a positive spillover effect, indicating that the human resource level in adjacent regions will also drive the development of NQPF of the local logistics industry. Among them, the impact coefficients of logistics infrastructure and government support are negative, indicating a negative spillover effect. Moreover, this reflects that the higher the level of logistics infrastructure in adjacent areas, the greater the government support, which will have a siphon effect on the logistics resources in the region and a negative impact on the development of NQPF of the logistics industry. The reason for this phenomenon lies in, with the development of the current era, the intensification of resource competition, which has led to the situation that if the logistics infrastructure in adjacent regions is more complete and the government's support is greater, more logistics enterprises, funds, and projects will be attracted. This may result in the diversion of logistics resources in this region, thereby causing greater pressure on the development of the logistics industry in this region. Moreover, the advanced regions' logistics infrastructure and policy advantages may enable them to dominate the regional logistics market, making it difficult for local logistics enterprises to obtain sufficient market share, leading to more severe market segmentation and resulting in the loss of talents in this region and the flow of outstanding talents to adjacent regions with greater innovation capabilities and development potential. Therefore, this phenomenon has an adverse impact on the development of the NQPF of the logistics industry of this region and is not conducive to the development of the NQPF of the logistics industry of this region.

5.5. Regional heterogeneity analysis

From the above spatial feature analysis, there is a regional difference pattern in the development level of NQPF of the logistics industry in the four major regions of China. Therefore, a regional sample regression is conducted to explore the regional differences in the impact of the variables studied in this article on the development level of NQPF of China's logistics industry.

According to Table 11, there are certain differences in the influencing factors of the development of NQPF of the logistics industry in the four major regions of east, middle, west, and northeast China. The logistics infrastructure and economic development level in the east region pass the test at the 1% significance level, and the coefficient is positive, indicating that the economic development level in the east region is relatively high, and the logistics infrastructure is relatively complete. Moreover, the efficient and convenient transportation conditions can significantly reduce transportation costs and improve transportation efficiency; therefore, it is conducive to the development of NQPF of the logistics industry in the east region and is a key factor for the development of the east region. The logistics infrastructure, economic development level, and human resource level in the middle region are very significant and have positive coefficients. This indicates that in recent years, with the economic development of the middle region, a large number of outstanding talents have flowed in, significant progress has been made in the construction of transportation infrastructure, and the improvement of infrastructure has directly enhanced the transportation efficiency of logistics and reduced transportation costs. This has effectively promoted the development of NQPF of the logistics industry in the middle region and is an important factor for the development of the middle region. However, the information technology levels in the east region and the middle region pass the test at the 5% and 1% significance levels, respectively, but the coefficients are negative. This might be because the east and middle regions have established relatively mature technology application models, and further improvement in information technology levels may require a longer adaptation period. In the short term, this could lead to a decline in efficiency, thus resulting in a negative impact on the outcome.

Table 11. Regional heterogeneity regression results.

Variable	East	Middle	West	Northeast
lnINF	0.054***	0.067**	−0.032**	−0.073*
	(5.59)	(2.13)	(−2.51)	(−1.65)
lnPGDP	0.095***	0.076***	0.100***	0.134***
	(8.32)	(3.31)	(10.19)	(7.15)
lnTEC	−0.020**	−0.092***	0.067***	0.042***
	(−2.09)	(−7.92)	(12.69)	(3.63)
lnHRL	−0.007	0.032***	0.099***	0.094***
	(−1.43)	(4.6)	(8.86)	(5.16)
lnGOV	0.005	0.001	0.001	0.005***
	(1.11)	(0.13)	(0.24)	(2.75)
lnINF*W	0.002	0.027	0.055	−0.126***
	(0.08)	(0.38)	(1.6)	(−2.65)
lnPGDP*W	0.027	0.103**	0.105***	0.061*
	(0.88)	(2.22)	(4.3)	(1.68)
lnTEC*W	−0.018	−0.092**	0.084***	−0.157***
	(−1.19)	(−2.43)	(9.55)	(−3.82)
lnHRL*W	−0.048	−0.007	−0.077***	0.211***
	(−5.68)	(−0.37)	(−2.98)	(6.38)
lnGOV*W	−0.007	0.009	−0.005	−0.016***
	(−0.72)	(0.69)	(−1.17)	(−3.39)
R2	0.410	0.842	0.909	0.358
Log-likelihood	207.7194	193.3092	271.3956	123.037
Sample Size	80	48	88	24

Note：***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

The economic development level, information technology level, and human resource level in the west region pass the tests, and the coefficients are positive. This indicates that the west region may benefit from the Western Development Strategy and has made remarkable progress in economic development and informatization, which is conducive to promoting the development of NQPF of the logistics industry in the west region. The economic development level, information technology level, human resource level, and government support in the northeast region have a significant positive impact on the development of NQPF of the logistics industry. This indicates that the country has invested a large amount of policy support and resources in infrastructure construction and industrial support for the northeast region through the Northeast Revitalization Strategy. Therefore, these factors have effectively promoted the development of NQPF of the logistics industry in the northeast region. However, the level of logistics infrastructure in the west and northeast regions has a significant negative impact on the development of NQPF of the logistics industry, indicating that it might be due to the limitations of geographical environment and natural conditions, which result in high construction costs and greater construction difficulties. As a consequence, the construction of the logistics infrastructure lags behind, and the utilization efficiency is low, causing a negative outcome.

6. Conclusions and suggestion

6.1. Research conclusions

This study employs a multi-method analytical framework—integrating entropy weighting, kernel density estimation, Dagum Gini coefficient, and Moran's I—to quantitatively assess the developmental trajectory of NQPF within China's logistics sector from 2015 to 2022. Our i nvestigation focuses on spatial heterogeneity and correlation patterns. And a spatial Durbin m odel identifies determinants influencing the spatial distribution of logistics NQPF across Chin ese regions. Key findings reveal:

(1) From an overall perspective, the development level of NQPF in China's logistics industry showed an increasing trend from 2015 to 2022, and the growth rates of the four major regions showed a decreasing trend in the west, middle, northeast, and east regions, respectively; however, the overall development level of NQPF in the logistics industry in the east region is higher than that in the other three regions, with a significant gap compared to the west region. From the perspective of various provinces, provinces with relatively higher development levels of NQPF in the logistics industry show a slow upward trend in annual growth rate, while provinces with relatively weaker development levels show a rapid upward trend in annual growth rate. Thus, there are differences in the development level of NQPF in the logistics industry among provinces.

(2) Analysis of spatial disparities in China's logistics NQPF reveals a nationwide ascending developmental gradient. However, substantial differentials exist between east provinces and other regions, while middle and northeast areas exhibit clustered multipolar development patterns. During the 2015 to 2022 observation window, China's aggregate Gini coefficient declined from 0.042 to 0.035, signaling progressive convergence in logistics NQPF development across provinces. Notwithstanding downward trajectories in intra-regional inequality within both east and west zones, their persistently elevated Gini values reflect significant internal developmental imbalances. Notably, the highest inter-regional disparity occurs between east and west China, confirming a pronounced developmental schism.

(3) Regarding the spatial patterns of NQPF advancement within China's logistics sector, significant geographical interdependence is evident. Provincial development clusters predominantly within the high-high (H-H) and low-low (L-L) agglomeration categories, corresponding to the first and third quadrants, with the other two categories exhibiting less prominence. A distinct east-west divide emerges: east provinces overwhelmingly fall into the first quadrant, while their west counterparts are largely concentrated in the third quadrant. This clear bifurcation underscores the pronounced regional disparity. The analysis further suggests transitions occurring in some west and northeast provinces, pointing to the existence of spatial spillover effects.

(4) Analysis of the driving factors reveals that overall NQPF growth in the logistics industry receives a significant boost from economic development, information technology (IT), and human resources. Notably, IT exerts the strongest favorable influence, possessing the largest impact coefficient. Economic development also contributes positively to NQPF progress, although its spatial spillover effect remains limited. Regionally, the impacts vary: in the east, logistics infrastructure and economic development are the most influential regional drivers; middle provinces see significant enhancement of their logistics NQPF stemming from logistics infrastructure, economic development, and human resources; for the west provinces, economic development, IT, and human resources each

provide a measurable developmental impetus; northeast development is shaped by economic conditions, IT capabilities, human resources, and government support.

6.2. Countermeasure and suggestion

6.2.1. Optimize regional layout and promote balanced development

The advancement of NQPF within China's logistics sector exhibits pronounced regional disparities, yet concurrently demonstrates significant spatial interdependence across provinces. Consequently, fostering robust logistics collaboration among the east, middle, west, and northeast regions is imperative. Leveraging policy frameworks and strategic resource allocation is key to driving cross-regional logistics integration. A primary objective is to mitigate regional imbalances. Given the notably higher NQPF development level in the east region compared to others, particularly the substantial gap with the west, implementing a regional coordination strategy is essential. This entails augmenting policy backing and resource commitments towards the middle, west, and northeast areas. Facilitating industrial relocation and establishing targeted assistance programs can channel advanced technologies and managerial expertise from the east to these regions. Such initiatives will accelerate the interconnectivity of regional logistics infrastructure and effectively bridge the development divide. Second, strengthen spatial synergy. There is spatial correlation among the NQPF of the logistics industry among provinces, and the agglomeration effect should be fully utilized. The east region can rely on its technological and resource advantages and carry out in-depth cooperation with the middle and west regions and the northeast region. Through establishing regional logistics alliances and sharing logistics information platforms, the optimization of logistics resources and efficient utilization can be achieved. Furthermore, cooperation and exchanges among regional logistics enterprises should be encouraged, and the spatial spillover effect should be fully utilized to drive the development of NQPF of the logistics industry in surrounding regions, especially for the leapfrog development that has occurred in some provinces in the west and northeast regions. Moreover, further exploration of successful experiences should be carried out, promoted, and applied in other regions.

6.2.2. Promote the application of information technology and enhance the training of logistics professionals

The evolution of NQPF in the logistics sector is profoundly shaped by three core drivers, regional economic development, IT level, and human resources level. Building upon a foundation of economic growth, IT capabilities elevate operational efficiency through digitalization, while skilled human resources furnish essential intellectual capital for industry innovation. The synergistic interplay of these elements catalyzes the holistic enhancement of logistics NQPF. Prioritizing IT development is critical. Given its demonstrably strong positive effect on logistics NQPF, strategic emphasis should be placed on augmenting investments in logistics IT R&D and deployment. This entails accelerating the sector's digital transformation and facilitating the diffusion of technological expertise from east and middle regions to their west and northeast counterparts, thereby enabling industrial upgrading. Moreover, given that economic development exerts a significant influence on logistics NQPF advancement, and regions with stronger economies exhibit heightened demand for sophisticated IT applications, these more developed areas should assume leadership through fiscal incentives and policy frameworks. This will accelerate the integration of information technologies within logistics operations, fostering collective progress across neighboring regions. Secondly, enhancing human capital development is imperative. The quality of human resources substantially impacts logistics NQPF growth. Underpinned by economic strength, the higher education and vocational training systems must prioritize cultivating specialized professionals aligned with modern logistics needs. Concurrently, governments should implement talent incentive schemes to attract skilled individuals to middle, west, and northeast areas. Such measures will facilitate balanced inter-regional talent distribution, solidifying the human resource foundation essential for logistics NQPF evolution.

Author contributions

Zichun Wang: Data collection, data processing, research methods, result analysis and original draft writing and editing. Song Han: Framework ideas and content modifications guidance.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflicts of interest.

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