Evolution Characteristics and Influencing Factors of the Spatial Pattern of Logistics Enterprises in China at the Prefecture-Level City Scale (Postprint)

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Date: 2026-01-19T13:54:41+00:00

Abstract

Logistics enterprises play a critical role in regional economies, and their spatial distribution directly affects the allocation of regional resources and market competitiveness. Investigating the evolutionary characteristics and influencing factors of the spatial pattern of logistics enterprises at the prefecture-level city scale is conducive to revealing the formation mechanisms of logistics enterprise agglomeration. Based on the geographic location data of logistics enterprises in Chinese prefecture-level cities from 2006 to 2023, this study employs spatial analysis methods such as kernel density analysis, standard deviational ellipse, average nearest neighbor, and spatial autocorrelation to obtain the spatiotemporal pattern and evolutionary characteristics of logistics enterprises at the prefecture-level city scale. A multi-scale geographically weighted regression model is then used to analyze the factors influencing the spatial pattern of logistics enterprises and their spatial heterogeneity. The results show that: (1) The spatial distribution of logistics enterprises in China has consistently exhibited agglomeration characteristics. Its spatial pattern has undergone an evolutionary process from "single core driving, multi-point agglomeration" to "multi-core," and then gradually to "dual-core," with both corridor diffusion and neighborhood diffusion effects. (2) The development of logistics enterprises has a significant positive spillover effect, whereby rapidly developing cities can drive the development of surrounding cities. Underdeveloped cities, affected by the "siphon effect" of developed cities, are located in the low-lying areas of the "siphon tide" and exhibit a significant negative spillover effect. (3) The number of employees in the tertiary industry and the total volume of imports and exports are the main factors influencing the spatial pattern of logistics enterprises. Among them, the total volume of imports and exports and the number of foreign-funded enterprises are global influencing factors, whereas the number of employees in the

tertiary industry and per capita GDP are local influencing factors.

Full Text

Preamble

ARID LAND GEOGRAPHY Vol. 49 No. 1 Jan. 2026

Spatial Pattern Evolution Characteristics and Influencing Factors of Logistics Enterprises in China at Prefecture-level City Scale

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Abstract

Logistics enterprises play a crucial role in regional economies, and their spatial distribution directly affects resource allocation and market competitiveness. Investigating the evolution characteristics and influencing factors of logistics enterprise spatial patterns at the prefecture-level city scale can help reveal the formation mechanisms of logistics enterprise agglomeration. Based on geographic location data of logistics enterprises in Chinese prefecture-level cities from 2006 to 2023, this study employs spatial analysis methods including kernel density analysis, standard deviation ellipse, average nearest neighbor, and spatial autocorrelation to characterize the spatiotemporal patterns and evolution of logistics enterprises. Multi-scale geographically weighted regression (MGWR) models are used to analyze the factors influencing logistics enterprise spatial patterns and their spatial differentiation. The results indicate that: (1) The spatial distribution of logistics enterprises in China has consistently exhibited agglomeration characteristics, evolving from a pattern of "one-core-driven, multi-point agglomeration" to "multiple cores," and gradually transitioning to a "dual-core" structure, with evident corridor diffusion and neighborhood diffusion effects. (2) Logistics enterprise development demonstrates significant positive spillover effects, where rapidly developing cities can drive growth in surrounding cities. Underdeveloped cities affected by the "siphon effect" from developed cities, located in the low-lying areas of this "siphon tide," exhibit significant negative spillover effects. (3) The number of tertiary industry employees and total import-export volume are the primary factors influencing logistics enterprise spatial patterns. Among these, total import-export volume and number of foreign-funded enterprises are global influencing factors, while tertiary industry employment and per capita GDP are local influencing factors.

Keywords: logistics enterprises; spatial evolution; influencing factors; multi-scale geographically weighted regression; prefecture-level city; industrial agglomeration

1. Introduction

The "14th Five-Year Plan for Modern Distribution System Construction" issued in 2021 emphasized "optimizing the spatial layout of commerce, logistics, and transportation facilities," fully recognizing the critical role of logistics spatial patterns in modern distribution system development. Logistics enterprises serve as the economic entities of the logistics industry, undertaking multiple functions including transportation, warehousing, distribution, and information flow. In recent years, the dramatic increase in logistics enterprise numbers has led to increasing misalignment between their spatial distribution and industrial demand, severely constraining efficient logistics resource allocation and coordinated development with regional economies. Therefore, revealing the evolution characteristics and influencing factors of logistics enterprise spatial patterns can provide scientific guidance for logistics industry planning and theoretical basis and practical reference for enterprise site selection.

Recent research by domestic and international scholars on logistics enterprise spatial patterns and influencing factors has focused on three main aspects: spatial pattern evolution characteristics, influencing factors, and location selection, with spatial pattern evolution and influencing factors being particularly hot topics. Research objects have primarily concentrated on national scales (China, USA), provincial scales (Zhejiang), municipal scales (Atlanta, Xi'an, Zhengzhou, Wuhan, Shanghai), and urban agglomerations (Guanzhong Plain, Yangtze River Delta, Beijing-Tianjin-Hebei), while studies at the prefecture-level city scale remain relatively scarce. Since different cities exhibit significant variations in economy, policy, and transportation infrastructure, using prefecture-level cities as the analytical unit helps reveal the spatial differentiation mechanisms of urban logistics enterprises.

Regarding research methodology for influencing factors, foreign studies primarily employ logical induction, while domestic research utilizes Poisson regression models, geographic detectors, geographically weighted regression (GWR), and negative binomial regression models. Existing studies indicate that influencing factors of logistics enterprise spatial patterns exhibit significant spatial heterogeneity. The multi-scale geographically weighted regression (MGWR) model, as an improved version of the GWR model, effectively overcomes the limitations of GWR in analyzing multi-scale spatial heterogeneity. In terms of factor selection, domestic and international scholars have generally consistent choices, focusing on transportation infrastructure, market foundation, and economic development level. For transportation factors, studies typically select road freight volume or freight turnover volume as indicators, with few selecting road network density, which would help deepen understanding of how road networks influence logistics enterprise spatial distribution mechanisms.

In summary, based on geographic location data of logistics enterprises in Chinese prefecture-level cities from 2006 to 2023, this study takes logistics enterprises as the research object. Using spatial analysis methods such as kernel density analysis and standard deviation ellipse, we investigate the spatial pattern evolution characteristics of logistics enterprises at the prefecture-level city scale. MGWR models are employed to analyze the spatial differentiation characteristics of factors influencing logistics enterprise spatial patterns, aiming to provide references for logistics industry layout and guide coordinated development between logistics facility layout and urban space.

1.1 Research Scope

This study uses prefecture-level cities as the basic spatial analysis unit, focusing on logistics enterprises in 296 prefecture-level cities (Lhasa, Chamdo, Nyingchi, Nagqu, Shigatse, Shannan, and Sansha are excluded due to severe data missing). The time span covers 2006–2023. The "Eleventh Five-Year Plan for National Economic and Social Development of the People' s Republic of China" issued in 2006 explicitly proposed vigorously developing modern logistics, marking the establishment of modern logistics industry' s strategic position. Subsequently, a series of policy documents targeting the logistics industry were released, promoting its rapid development. Studying the spatial pattern evolution during this period can comprehensively analyze the industry' s development dynamics. Therefore, this study selects four time nodes (2006, 2010, 2015, and 2023) to investigate the spatial pattern evolution characteristics and influencing factors of logistics enterprises at the prefecture-level city scale.

1.2 Data Sources and Processing

Logistics enterprise information was obtained from the "Tianyancha" website. By restricting enterprise type and industry classification based on enterprise registration information from 2006, 2010, 2015, and 2023, we acquired research data for prefecture-level city logistics enterprises. Enterprise registration address information was converted to geographic coordinates using the Gaode Open Platform, treating logistics enterprises as "point" elements for geographic spatial matching. The 2006–2023 administrative boundary data were sourced from the Resource and Environmental Science Data Registration and Publication System (http://www.resdc.cn/). Socioeconomic data used in influencing factor analysis were obtained from provincial and municipal statistical yearbooks (2006–2023) and *China City Statistical Yearbook* (2006–2023). Missing data for individual indicators were supplemented using linear interpolation.

1.3 Research Methods

This study uses kernel density to characterize the spatial patterns of prefecture-level city logistics enterprises, standard deviation ellipse to quantify their spatial directional characteristics, average nearest neighbor to measure their spatial agglomeration features, and spatial autocorrelation to reveal overall and local correlation characteristics of logistics enterprise distribution. MGWR models are employed to analyze the spatial differentiation characteristics of factors influencing logistics enterprise spatial patterns.

Since influencing factors of logistics enterprise spatial patterns exhibit spatial heterogeneity, bandwidth is a key indicator for analyzing this heterogeneity. Although the GWR model can assign bandwidths to all dependent variables, its bandwidth is the average of each variable' s bandwidth, failing to reflect local differences among influencing factors. The MGWR model can set different bandwidths for different variables, comprehensively considering the impact of spatial heterogeneity. The MGWR model formula is as follows:

$$y_i = \sum_{j=1}^{k} \beta_{bwj}(u_i, v_i)x_{ij} + \varepsilon_i$$

where y_i is the dependent variable value at location i; β_{bwj} is the local regression coefficient for the jth explanatory variable using geographic bandwidth bw_j; (u_i, v_i) are the coordinates at location i; x_{ij} is the value of the jth explanatory variable at location i; and ε_i is the error term.

2. Results and Analysis

2.1 Spatial Pattern Evolution Characteristics

2.1.1 Spatial Evolution Features Using ArcGIS 10.8 software, we conducted kernel density analysis on prefecture-level city logistics enterprises for 2006, 2010, 2015, and 2023 [Figure 1: see original paper]. The study reveals that the spatial distribution of logistics enterprises has undergone evolution from "one-core-driven, multi-point agglomeration" to "multiple cores," and gradually to a "dual-core" pattern.

In 2006, the logistics industry was in its infancy with few and small-scale enterprises, showing a "single-core" agglomeration pattern centered in the Pearl River Delta region. Agglomeration points mainly emerged in coastal cities such as the Yangtze River Delta region, Qingdao, and Xiamen, as well as inland cities with rapid economic development like Chengdu, Wuhan, and Xi' an.

As urban logistics demand continued to grow and related industries developed rapidly, the kernel density range of logistics enterprises further expanded. Particularly in the Yangtze River Delta region, accelerated regional economic integration created a distinct logistics enterprise agglomeration area. Provincial capitals such as Kunming, Jinan, and Changsha also saw agglomeration points emerge. In 2015, driven by provincial capitals, logistics enterprises in surrounding cities developed, with agglomeration ranges expanding outward and agglomeration points forming in Xi' an, Chengdu, Wuhan, and Zhengzhou.

By 2020, the agglomeration effect of logistics enterprises gradually strengthened, with the Yangtze River Delta region and cities such as Xi' an, Chengdu, Zhengzhou, Wuhan, and Qingdao forming agglomeration cores. Agglomeration areas showed a "patchy" distribution, with significantly stronger agglomeration in eastern regions than in central and western regions. Following the promulgation of the *National Logistics Hub Layout and Construction Plan* and other policies, the integrated development of transportation and logistics achieved remarkable results. In 2023, the agglomeration range of logistics enterprises further expanded with increased agglomeration cores appearing in all provincial capitals, while other prefecture-level cities also saw logistics enterprise agglomeration areas emerge.

2.1.2 Spatial Diffusion Characteristics Corridor Diffusion. Corridor diffusion refers to the phenomenon where logistics activities are distributed and expanded along transportation corridors. Expressways serve as critical transportation corridors connecting prefecture-level cities, bearing the core function of freight transport. By matching the 2020 kernel density analysis of prefecture-level city logistics enterprises with the expressway network [Figure 2: see original paper], the study finds that logistics enterprise agglomeration shows significant corridor diffusion characteristics, specifically manifesting as belt-shaped extension along expressways and the formation of agglomeration points at expressway intersections.

Neighborhood Diffusion. Neighborhood diffusion refers to the phenomenon where cities or regions geographically close to core areas develop under the influence of core area radiation effects. [Figure 1: see original paper] shows that prefecture-level city logistics enterprise layout exhibits certain spatial neighborhood effects, with cities closer to agglomeration cores showing higher kernel density values. For instance, the diffusion of logistics enterprises from the Yangtze River Delta region to surrounding areas demonstrates that prefecture-level cities nearer to the Yangtze River Delta have higher kernel density values. Specifically, as one of China' s most economically developed regions, the Yangtze River Delta possesses a complete transportation network, dense market demand, and strong industrial cluster effects. These advantages promote the agglomeration and rapid development of logistics enterprises within the region, forming a significant agglomeration core that positively drives logistics enterprise development in surrounding cities.

2.1.3 Spatial Directional Characteristics Using ArcGIS 10.8 software, we conducted standard deviation ellipse analysis on prefecture-level city logistics enterprises for 2006, 2010, 2015, and 2023 . Overall, the spatial distribution pattern of prefecture-level city logistics enterprises roughly presents a "Northeast-Southwest" pattern. The long axis centerline lies along the "Jinan–Changsha" line, while the short axis centerline lies along the "Nanjing–Wuhan" line, with the ellipse interior primarily comprising prefecture-level cities in eastern and central regions. The ellipse center shows an overall trend of moving eastward and northward, indicating that influenced by terrain and urban economic development, the center of gravity of logistics enterprises gradually shifts toward the northeast. Specifically, in 2006, the ellipse had the largest flattening rate of 0.3497°, with the greatest difference between long and short axes, indicating the most pronounced directional trend and centripetal force. From 2010 to 2023, the difference between long and short axes gradually narrowed, and the ellipse flattening rate gradually decreased, suggesting that since 2010, the rapid nationwide growth in logistics enterprise numbers has gradually weakened the directional trend and centripetal force.

2.1.4 Spatial Agglomeration Characteristics Using ArcGIS 10.8 software, we conducted average nearest neighbor analysis on logistics enterprises for 2006, 2010, 2015, and 2023 . The results show that the nearest neighbor ratios for all four years are less than 1 and pass significance tests, indicating significant agglomeration of logistics enterprises. The average observed distance gradually decreased from 2006 to 2015, with the nearest neighbor ratio continuously declining, suggesting increasingly stronger agglomeration. Meanwhile, the Z-value continuously decreased, indicating a strong agglomeration distribution characteristic. However, in 2023, the average observed distance increased, with the nearest neighbor ratio rising from 0.3247 to 0.4106 and the Z-value increasing. Although the spatial distribution remained agglomerated, the spatial pattern experienced some diffusion before 2023, indicating that accelerated logistics resource integration has gradually led to outward expansion in logistics enterprise site selection and layout.

2.1.5 Spatial Correlation Characteristics To investigate the overall correlation characteristics of prefecture-level city logistics enterprises, we calculated the global Moran' s I for 2006, 2010, 2015, and 2023 using ArcGIS 10.8 . Overall, the global Moran' s I values are significantly positive at the 1% confidence level, indicating strong spatial agglomeration and dependency. Analyzing the dynamic trend of global Moran' s I reveals a fluctuating pattern of initial increase, subsequent decrease, another increase, and final decrease. Specifically, spatial agglomeration gradually strengthened from 2006 to 2010, weakened from 2010 to 2015, significantly strengthened again by 2020, but decreased in 2023.

To more accurately identify local correlation characteristics of logistics enterprise spatial patterns at each time node, we generated LISA cluster maps for 2006, 2010, 2015, and 2023 using ArcGIS 10.8 [Figure 4: see original paper]. Overall, the spatial distribution of prefecture-level city logistics enterprises shows high-high clustering patterns, with high-high clusters mainly distributed in China' s eastern coastal regions. In 2006, high-high clusters were concentrated in the southeastern coastal region, expanding to East China by 2010 and increasing to 42 cities by 2015, remaining stable through 2023. High-high cluster areas exhibit positive spillover effects, while low-low cluster areas are primarily found in economically underdeveloped regions of Northeast and West China. High-low clusters appear in provincial capitals within these underdeveloped regions. Due to the "siphon effect" from high-high clusters, low-low cluster areas located in the "low-lying areas" of this siphon tide experience slower logistics enterprise development.

2.2 Influencing Factor Analysis

2.2.1 Factor Selection Given that longer time spans have minimal impact on logistics enterprise spatial patterns, this study selects the number of logistics enterprises in prefecture-level cities for 2023 as the dependent variable. Based on existing research, we selected eight indicators from economic, social, market, and openness dimensions .

2.2.2 MGWR Model-Based Influencing Factor Analysis We employed Ordinary Least Squares (OLS) and MGWR models to analyze influencing factors of logistics enterprise spatial patterns. First, we used OLS to examine relationships between the spatial pattern and each variable. The results showed that except for GDP and total local fiscal revenue, all explanatory variables had variance inflation factor (VIF) values below 7.5. After removing GDP and total local fiscal revenue, we conducted MGWR analysis on the remaining factors.

Model comparison results show that the MGWR model has the lowest corrected Akaike Information Criterion (AICc) value and the highest goodness-of-fit (R^2) and adjusted R^2 (0.858 and 0.842, respectively), indicating that the MGWR model fits the actual situation better than OLS and GWR models. Subsequent analysis therefore focuses on MGWR results.

In MGWR models, bandwidth is crucial for analyzing spatial heterogeneity of influencing factors. Although the GWR model can assign bandwidths to all dependent variables, its bandwidth represents the average of each variable' s bandwidth, failing to reflect local differences. The MGWR model can set different bandwidths for different variables, comprehensively considering spatial heterogeneity impacts. The MGWR model formula is as follows:

$$y_i = \sum_{j=1}^{k} \beta_{bwj}(u_i, v_i)x_{ij} + \varepsilon_i$$

where y_i is the dependent variable value at location i; β_{bwj} is the local regression coefficient for the jth explanatory variable using geographic bandwidth bw_j; (u_i, v_i) are coordinates at location i; x_{ij} is the value of the jth explanatory variable at location i; and ε_i is the error term.

The MGWR model shows large bandwidth differences among influencing factors, reflecting spatial sensitivity. Based on bandwidth proportion in the global sample, factors with bandwidth proportion >25.8% are defined as global factors, while those <25.8% are local factors.

Analysis of Global Influencing Factors. Total import-export volume and number of foreign-funded enterprises are global influencing factors without spatial heterogeneity, showing small coefficient variation across space. The mean regression coefficient for total import-export volume is 0.412, indicating strong positive impact on logistics enterprise spatial layout. The mean coefficient for foreign-funded enterprises is -0.307, indicating strong negative impact. Currently, China' s high openness level has led to saturated foreign-funded enterprises that tend to locate in economically developed regions with strong market demand, complete infrastructure, and high market potential. Logistics enterprises preferentially locate in foreign-funded enterprise agglomeration areas, resulting in sparse distribution elsewhere.

Analysis of Local Influencing Factors. Tertiary industry employment and per capita GDP are local influencing factors with spatial heterogeneity, showing large coefficient variation across space. Tertiary industry employment positively impacts logistics enterprise spatial distribution, with minimal effects in eastern, northeastern, and western regions but strongest impact in central regions. For eastern, northeastern, and western regions with relatively high labor levels, increased labor has limited impact on logistics enterprise spatial distribution. However, in central regions with relatively low labor levels, labor cost reductions can significantly reshape regional logistics enterprise spatial patterns.

Per capita GDP shows small impacts on logistics enterprise spatial patterns in central and western regions, even negative impacts in Shanxi, Shaanxi, and Guangxi, but strong positive impacts in eastern coastal and northern regions. Compared with eastern coastal and northern cities, central and western regions have lower consumption capacity, longer transport distances, and higher logistics costs, making it difficult for logistics enterprises to achieve economies of scale and inhibiting their development. Therefore, residents' consumption capacity has less obvious agglomeration effects on logistics enterprises in these regions.

3. Discussion

Studying the evolution characteristics and influencing factors of logistics enterprise spatial patterns provides theoretical support for logistics industry development strategies and policy formulation, promoting coordinated development between logistics and regional economies. Due to difficulties in obtaining nationwide logistics enterprise data for mainland China, previous research has mostly focused on single scales such as provincial [10,12], municipal [14,16], or urban agglomeration [13,15] levels. This study attempts to include all logistics enterprises in mainland China within the research scope from a national perspective, greatly enriching the research perspective on logistics enterprises. Moreover, when exploring factors influencing logistics enterprise distribution characteristics, existing studies have paid limited attention to the spatial heterogeneity of influencing factors [10,16]. This study employs MGWR models to analyze whether each factor exhibits spatial heterogeneity, providing references for cities to adjust logistics layouts according to local conditions.

Finally, the study finds that tertiary industry employment and total import-export volume are the main factors influencing the national logistics enterprise spatial pattern. However, research on the Guanzhong Plain urban agglomeration [15] and Beijing-Tianjin-Hebei urban agglomeration [13] shows that enterprise agglomeration effects are the main influencing factors. This indicates differences across scales: at the national scale, logistics enterprise spatial patterns are influenced by labor levels and external trade, while at smaller scales, enterprise agglomeration effects become more significant, leading to different results.

4. Conclusions and Recommendations

4.1 Conclusions

From 2006 to 2023, logistics enterprise agglomeration evolved from "one-core-driven, multi-point agglomeration" to "multiple cores," and gradually to a "dual-core" pattern, with significant corridor diffusion and neighborhood diffusion effects in spatial distribution. Logistics enterprise development exhibits significant positive spillover effects, where rapidly developing cities can drive development in surrounding areas. Underdeveloped cities affected by the "siphon effect" from developed cities, located in low-lying areas of this "siphon tide," show significant negative spillover effects. In terms of influencing factors, tertiary industry employment and total import-export volume are the primary factors. Total import-export volume and number of foreign-funded enterprises are global influencing factors, while tertiary industry employment is a local influencing factor that promotes logistics enterprise agglomeration. Per capita GDP shows positive effects in most regions, but negative effects in underdeveloped central and western regions constrained by low consumption capacity, long transport distances, and high logistics costs.

4.2 Recommendations

Optimize Logistics Enterprise Layout. Attention should be paid to logistics enterprise layout along transportation networks, especially vigorously promoting logistics hub construction at transportation hub nodes [27]. Through policy support and planning guidance, promote agglomeration development of logistics enterprises along transportation lines to enhance logistics industry cluster effects.

Implement Coordinated Regional Development Policies. The analysis reveals significant negative spillover effects in underdeveloped regions such as Yunnan, Gansu, and Qinghai provinces. For optimizing logistics enterprise spatial layout in these areas, resource integration and industrial agglomeration should be encouraged, and negative spillover effects should be reduced through policy guidance to promote balanced logistics development.

Establish Logistics Industry Demonstration Zones. Establish demonstration zones in the Yangtze River Delta and Pearl River Delta regions with increased policy support and infrastructure construction to attract high-quality logistics enterprises and enhance regional logistics development levels. Leveraging the leading role of demonstration zones can promote logistics industry cluster effects, drive coordinated regional economic development, and provide replicable successful experiences for underdeveloped regions.

Accelerate Integration of Logistics with Other Industries and Promote Coordinated Development of International Trade and Logistics Enterprises. Establish "logistics-industry"collaborative development pilot platforms in free trade pilot zones and cross-border e-commerce comprehensive pilot zones to promote strategic alliances between logistics enterprises and advanced manufacturing, modern agriculture, and other industries. Simultaneously, focus on promoting digital transformation of node facilities such as smart ports, comprehensive bonded zones, and cross-border e-commerce industrial parks.

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Note: Figure translations are in progress. See original paper for figures.