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Article

The impact of land transportation integration on service agglomeration in Yangtze River Delta urban agglomeration

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Abstract: This study selected the Yangtze River Delta urban agglomeration as the research area, combining it with the current situation of the transportation development of the Yangtze River Delta urban agglomeration to construct the urban agglomeration land transportation integration index system and evaluate the development status of the Yangtze River Delta urban agglomeration transportation integration. The study examined the influence mechanism of transportation infrastructure on service industry agglomeration. The results are as follows: (1) From 2011 to2020, the Yangtze River Delta urban agglomeration land transportation integration index showed a clear upward trend. (2)The development of the integration level of local transportation has a certain inhibitory effect on the agglomeration of local service industry. The transportation integration of the Yangtze River Delta urban agglomeration plays an important role in promoting the agglomeration of local wholesale and retail industry, transportation, storage and postal services. Labor force and market size also have a significant impact on service agglomeration. (3) The integration of land transport in urban agglomeration affects the agglomeration of service industry through the knowledge spillover effect caused by the improvement of accessibility, and the impact is heterogeneous. The Yangtze River Delta urban agglomeration needs to accelerate the construction of trans-provincial and trans-municipal transportation infrastructure, and further improve the connectivity level of the urban agglomeration, so as to promote the integrated development of high-quality transportation in the Yangtze River Delta urban agglomeration.

Keywords: transportation integration; service industry agglomeration; Yangtze River Delta urban agglomeration; urban agglomeration transportation integration index system; knowledge spillover effect.

1. Introduction

With the continuous optimization and upgrading of China's industrial structure, the service-oriented tertiary industry has become the industry with the highest output value and the most employees in China, adding new impetus to the high-quality economic development. For the service industry, under the background of increasing economic globalization and deepening regional division of labor, spatial agglomeration is an important mode and path for its continuous development and expansion. As the most active spatial form leading China's economic development, urban agglomeration is a key platform to promote the agglomeration and development of service industry, especially producer service industry. The Yangtze River Delta urban agglomeration, with Shanghai as the center and Nanjing, Hangzhou and Hefei as the sub-centers, is one of the regions with the most dynamic economy, the highest degree of openness, the strongest innovation capacity, the largest number of migrants and the densest high-speed rail network in China [1,2]. It plays a pivotal strategic role in the construction of the overall and all-round opening pattern.

The Yangtze River Delta urban agglomeration has a relatively complete service industry system, especially producer service industry system. In 2020, the proportion of service industry in the Yangtze River Delta urban agglomerations accounted for far more than that of other industries in GDP, and the proportion of the added value of producer services in the total service industry increased steadily. The agglomeration development of producer services in urban agglomerations is conducive to promoting resource integration and cultivating advantageous industries in cities, so as to enhance the competitiveness of urban agglomerations and promote the high-quality development of regional economy [3,4].

The comprehensive three-dimensional transportation network of urban agglomeration is closely related to regional development [5]. The planning and layout of comprehensive transportation network determines the morphological change of urban agglomeration and the development path of urban agglomeration to a certain extent [6]. In the past decade, the construction of high-speed railway network in the Yangtze River Delta with spatio-temporal compression effect and network effect has developed rapidly, making great achievements that attract the attention of the world. The comprehensive three-dimensional transportation network of the Yangtze River Delta urban agglomeration, with high-speed railways and expressways as the main framework, has taken initial shape, and public transit operations have been implemented on the inter-city high-speed railways between the core cities of Shanghai-Nanjing, Shanghai-Hangzhou and Hangzhou-Ningbo. With the prominent economic agglomeration effect and the network connectivity of transportation infrastructure in the Yangtze River Delta urban agglomeration, the accessibility between cities in the urban agglomeration is gradually improved [7]and the scale of travel is increasing. The re-layout and division of labor of production factors and productive forces within the urban agglomeration, and the adjustment of industrial structure and spatial layout have triggered large-scale cross-city commuting, business travel, private travel and other normalized travel demands. The development of division of labor and cooperative operation of passenger transport hubs in urban agglomerations also derives the external travel demand of inter-city hub transfer in urban agglomerations. The development of transportation integration in the Yangtze River Delta urban agglomeration has had a profound impact on the high-quality development of the integrated Yangtze River Delta, China's regional economic development pattern and industrial spatial layout.

Then, whether the development of transportation integration in urban agglomeration can promote the agglomeration of service industry in urban agglomeration? Further, what is the mechanism of action? The answers to the above questions have a great theoretical significance for effectively giving play to the supporting, guiding and promoting roles of the comprehensive three-dimensional transportation network of urban agglomeration, promoting the agglomeration of service industries in urban agglomeration, and thus promoting the high-quality development of urban agglomeration. Under the background of the new development pattern, focusing on the evaluation of the integrated development of transportation in the Yangtze River Delta urban agglomeration and empirically exploring the supporting role of the high-speed transportation network in the Yangtze River Delta to the industry is conducive to deepening the cognition of the transportation network in the urban agglomeration, integrating the core urban resources, and optimizing the regional spatial order. It has a great practical significance to accomplish the pilot task of building a powerful transportation country and to advance the goal of higher quality integrated development of transportation in the Yangtze River Delta urban agglomeration.

In this paper, the Yangtze River Delta urban agglomeration was taken as the research area, and the land transportation infrastructure, mainly railways and highways, was taken as the research object. This paper examined the impact of transport infrastructure on service agglomeration from the perspective of land transport integration in urban agglomeration. The influence mechanism of urban agglomeration land transportation inte-

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gration on service industry agglomeration was also studied. The rest of this paper is organized as follows. In section 2, we re-view relevant literature and propose relevant research hypotheses. Section 3 introduces the relevant background, including the rapid development of land transportation infrastructure and the trend of service industry agglomeration in the Yangtze River Delta urban agglomeration. Section 4 describes how we prepared the data and our methodology for empirical research. Section 5 investigates the impact of urban agglomeration land transportation integration on service industry agglomeration in the Yangtze River Delta, examines the impact mechanism of urban agglomeration land transportation integration on service industry agglomeration, and reports our analysis results. Section 6 discusses the model estimation results based on section 5. Section 7 summarizes the main findings of the study and provides a conclusion. In the final section, we also discuss the contributions, impacts, limitations, and opportunities for future work in the study topic.

2. Literature review and research hypothesis

Industrial agglomeration refers to the phenomenon that some industries are concentrated in a specific area. The externality theory proposed by Marshall lays a theoretical foundation for the study of the causes of industrial agglomeration. His view is that the driving force of industrial agglomeration mainly comes from three aspects: skilled labor market, input of intermediate products and knowledge spillover [8]. With the rise of new economic geography, the theoretical research on industrial agglomeration has made a breakthrough. Krugman incorporated spatial factors such as "iceberg" transportation costs and increasing returns to scale into the framework of general equilibrium analysis and established the "center-periphery" model [9], which further explained the formation motivation of industrial agglomeration. The industrial agglomeration theory developed on the basis of urban economics theory [10] holds that the expansion of city scale, on the one hand, is conducive to accelerating the transfer of labor force among industries; on the other hand, along with the increase of urbanization rate, is conducive to the adjustment of industrial structure within the city and the realization of optimization and upgrading. These classical industrial agglomeration theories mainly take industry or manufacturing as the research object [11]. However, service industry and manufacturing industry have different industrial characteristics and are engaged in different production activities, so these classical theories cannot be directly used to study the agglomeration of service industry, especially the agglomeration of producer services.

In recent years, scholars have linked the agglomeration of service industry with high-speed transportation network, especially high-speed railway network. From the perspective of the economic effect of high-speed railway network, they have analyzed the factors leading to the agglomeration of service industry and their effects[12,13]. At present, a large number of studies have confirmed that the high-speed transportation network, especially the "eight vertical and eight horizontal" high-speed railway network, has a significant impact on reshaping the spatial layout of China's industrial economy [14,15]. Rapid transit network in the form of a network to link together the city, as the track of urban agglomeration is becoming more and more perfect, to enhance the degree of urban agglomeration of high speed railway network, urban agglomeration internal economic exchanges and cooperation between cities and regions would increase greatly, is conducive to break the market segmentation [16] and expand the size of the market, will affect the change of the pattern of regional development. The opening of high-speed railway has produced the "factor integration effect", which makes the factor resources of producer services integrated and significantly improves the agglomeration degree of producer services.

Through the review of existing literatures, this paper finds that although many scholars have conducted studies on the impact of transportation infrastructure on the agglomeration of service industries [17]. However, most of these studies start from the perspective of transportation cost reduction [18,19] and transportation accessibility improvement

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[20] caused by the development of a single transportation mode, and make empirical analysis using relevant data at provincial and municipal levels.

At the same time, scholars believe that comprehensive three-dimensional transportation network covers railway, highway, water transport, civil aviation and other transportation infrastructure, which is an important foundation of modern comprehensive transportation system [21]. The transportation integration of urban agglomerations mainly includes planning integration, system and mechanism integration, basic network integration, transportation organization integration and so on [21,22]. In terms of quantitative research, scholars have proposed a topology model of physical network and virtual network with "multi-network integration" covering railways and highways [23], and constructed a comprehensive index reflecting the transportation infrastructure of urban agglomeration mainly through the entropy weight method [5]. On the whole, the research on the integration of urban agglomeration still lacks the analysis technology of integrated transportation.

From the perspective of transport integration, no consensus has been reached on the mechanism of service agglomeration induced by transport infrastructure in urban agglomerations, and the corresponding empirical test still has room for expansion. Therefore, based on the Yangtze river delta urban agglomeration from 2011 to 2020 period of 41 above ground level and the panel data of the city, using spatial econometric method, from the perspective of the integration of urban agglomeration land transportation, this paper makes a research on the Yangtze river delta urban agglomeration transportation network service industry agglomeration effect in theory, to explore the Yangtze river delta urban agglomeration land transportation network affects the mechanism of action of service development.

The spatio-temporal compression effect caused by the opening of high-speed railways in urban agglomerations can effectively shorten the spatio-temporal distance between urban agglomerations [24], reduce inter-regional transportation costs, improve inter-regional accessibility [20], and accelerate the circulation speed of production factors and resources. The trade between cities and the external radiation ability of producer service enterprises are continuously enhanced, thus expanding the local market scale, affecting the spatial location choice of enterprises, and promoting the agglomeration development of regional producer service industry [25]. To be specific, after the opening of the high-speed railway in the urban agglomeration, the transportation cost of service enterprises decreases, and at the same time, they have more choices of transportation modes to reach foreign markets. In terms of product production, enterprises in high accessibility locations can gain more opportunities to communicate and cooperate with other factor markets, find better quality inputs at lower cost to produce products, help producer service enterprises, which used to rely more on the size of the local market, reduce costs and increase efficiency, and continuously expand the market size [2]. In terms of trade enterprises, enterprises can develop more frequently and fast trade activities, expand service scope of space, use lower transport costs to product sales to more foreign market and to provide various services for local and surrounding market customers, stimulate more market potential, encourage more potential producer services enterprises to enter, strengthen the agglomeration trend of service industry in urban agglomeration at finally.

Hypothesis 1. *Considering the spatial effect, the development of transportation integration level in the Yangtze River Delta urban agglomeration has a certain inhibitory effect on the agglomeration of local and other service industries. The integration of land transportation in the Yangtze River Delta urban agglomeration has a significant role in promoting the agglomeration of local wholesale and retail, transportation, storage, postal and financial industries. The integration of land transportation in the Yangtze River Delta urban agglomeration has a significant inhibitory effect on the agglomeration of information transmission, software and information technology services, scientific research and technology services, leasing and business services in other regions.*

According to traditional location theory and new economic geography theory model, location advantage is closely related to transportation cost and production factor cost [26]. Producer service enterprises are mostly knowledge-intensive enterprises, which are

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highly dependent on knowledge information and human capital. Knowledge intensity, human capital level and labor cost are all important factors affecting the agglomeration of producer services. The rapid transit network expansion of urban agglomeration is conducive to expand the scope of high-quality innovative talents district, enlarge the radius of innovation talent service, improve the labor supply and demand match, strengthen the talent links between the city [27] and enhance the competitiveness of cities along, provide more face-to-face communication opportunities and route of transmission of knowledge for the industry department, so as to promote the development of producer services cluster. The free flow of high-quality labor force in the urban agglomeration improves the frequency of talent interaction, promotes the flow and sharing of knowledge within the industry, and thus mutual learning and mutual imitation form knowledge spillover effect. Knowledge spillover is conducive to spreading highly personalized tacit knowledge based on experience, promoting knowledge exchange, strengthening regional advantages and attracting tertiary industries with strong knowledge such as high-tech, financial industry and cultural and creative industries. Urban agglomeration transportation integration level of ascension to shorten the urban agglomeration of internal inter-city "distance" of time and space, strengthened the face-to-face communication between people, improve the interpersonal communication frequency [28], reduce the cost information, reduce barriers to information, makes the urban agglomeration of cross-regional enterprise, interpersonal information communication more unobstructed [29], expanding the scope of the potential knowledge spillovers, promote the agglomeration of related industries.

Hypothesis 2. *The integration of land transport in urban agglomeration affects the agglomeration of service industry through the knowledge spillover effect caused by the improvement of accessibility, and the impact is heterogeneous.*

3. Background

The Urban agglomeration of the Yangtze River Delta, which includes Shanghai, Jiangsu, Zhejiang, and Anhui provinces, is one of the regions with the most dynamic economy, has the highest degree of openness, the strongest innovation ability, and the largest absorption of foreign populations in China. It plays an important strategic role in the overall construction and all-round opening up pattern for China. In 2020, the land area of the Yangtze River Delta urban agglomeration was 358,000 square kilometers, accounting for 3.73% of the national land area. The permanent population was 235 million, accounting for 16.64% of the national population. According to Table 1, the GDP of the Yangtze River Delta urban agglomeration was CNY 24.47 trillion, accounting for 24.09% of the national GDP in 2020.

Table 1. GDP of the Yangtze River Delta urban agglomeration from 2011 to 2020.

Year	Yangtze River Delta urban agglomeration (CNY billion)	Percentage of the national GDP (%)
2011	11,593	23.76
2012	12,612	23.42
2013	13,737	23.17
2014	14,968	23.26
2015	16,013	23.25
2016	17,723	23.74
2017	19,529	23.47
2018	21,148	23.00
2019	23,725	24.05
2020	24,471	24.09

3.1Transportation development of urban agglomeration in the Yangtze River Delta

In 2011, the 1,318-km Beijing– Shanghai high-speed railway opened, which is the first high-speed railway line in the Yangtze River Delta urban agglomeration. The Yangtze River Delta urban agglomeration had thus entered the era of high-speed rail. In 2020, the length of high-speed railway in operation in the Yangtze River Delta urban agglomeration was about 6,100 km, and the density of high-speed railway was 170.39 km / 10,000 square km, 4.3 times that of the national high-speed railway density. The Yangtze River Delta urban agglomeration has the densest high-speed railway network in China. The Yangtze River Delta urban agglomeration initially formed a multi-center 0.5–3 h high-speed rail metropolitan circle, with Shanghai, Nanjing, and Hangzhou as the center.

In 2020, the highway mileage of the Yangtze River Delta urban agglomeration was 530,581 km, of which the mileage of expressways, primary roads, and secondary roads spanned 15,770 km, 29,822 km, and 51,912 km, respectively, accounting for 2.97%, 5.62%, and 21.96%, respectively, of the highway mileage of the Yangtze River Delta urban agglomeration. In other words, the highway mileage above grade II in the Yangtze River Delta urban agglomeration accounted for 30.55% of the highway mileage in the Yangtze River Delta urban agglomeration, or 2.26 times the national proportion. The spatial distributions of highway and expressway mileage in the Yangtze River Delta Urban agglomeration in 2020 are shown in Figure 1 and Figure 2.

In 2020, the road network density, expressway network density, and first-level highway network density of the Yangtze River Delta urban agglomeration were 1.48 km/square km, 440.50 km/10,000 square km and 833.02 km/10,000 square km, which are 2.73, 2.63, and 6.50 times the national road network density, expressway network density, and first-level highway network density, respectively.

The Yangtze River Delta urban agglomeration has essentially formed a network of five vertical and five horizontal expressways, including the Shanghai–Nanjing expressway, Shanghai–Hangzhou expressway, and Hangzhou–Ningbo expressway. From 2011–2020, the 1-hour accessibility of the central cities of The Yangtze River Delta—Shanghai, Nanjing, Hangzhou, and Hefei—all expanded.

According to Table 2, from 2011–2020, road transportation was the most important mode of transportation in the Yangtze River Delta urban agglomeration. In 2020, the highway passenger volume in the Yangtze River Delta urban agglomeration accounted for 70.62% of the total passenger volume. In 2020, the highway freight volume of Yangtze River Delta urban agglomeration accounted for 59.97% of the total freight volume.

Table 2. Major transport indicators of the Yangtze River Delta urban agglomeration in 2020.

Indicator	Highway	Railway
Passenger volume (million passengers)	1,306	490
Passenger turnover (billion passenger-kilometers)	83	159
Freight volume (million tons)	6,538	213
Freight turnover (billion ton-kilometers)	983	131

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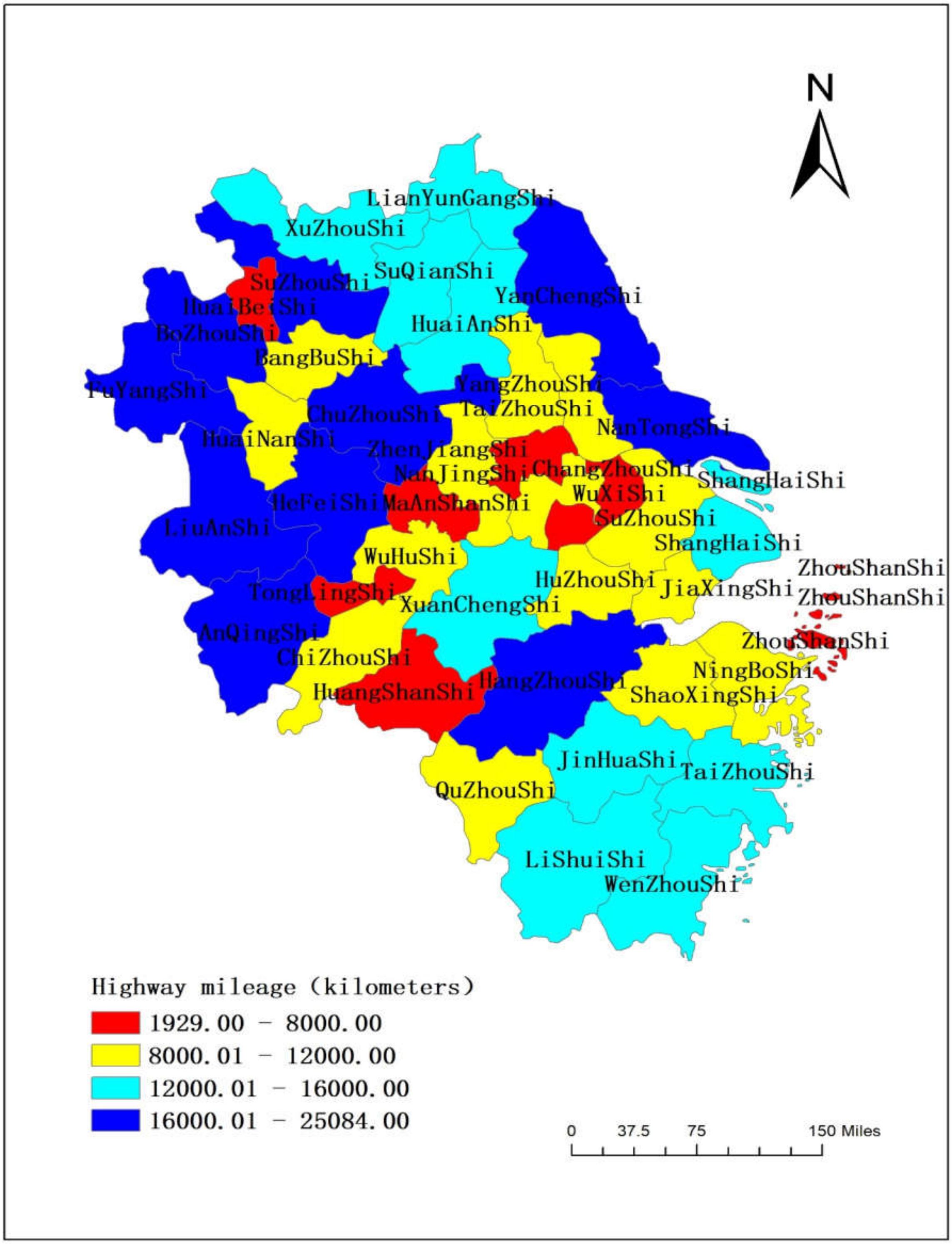

Figure 1. Spatial distribution map of highway mileage in the Yangtze River Delta urban agglomeration in 2020.

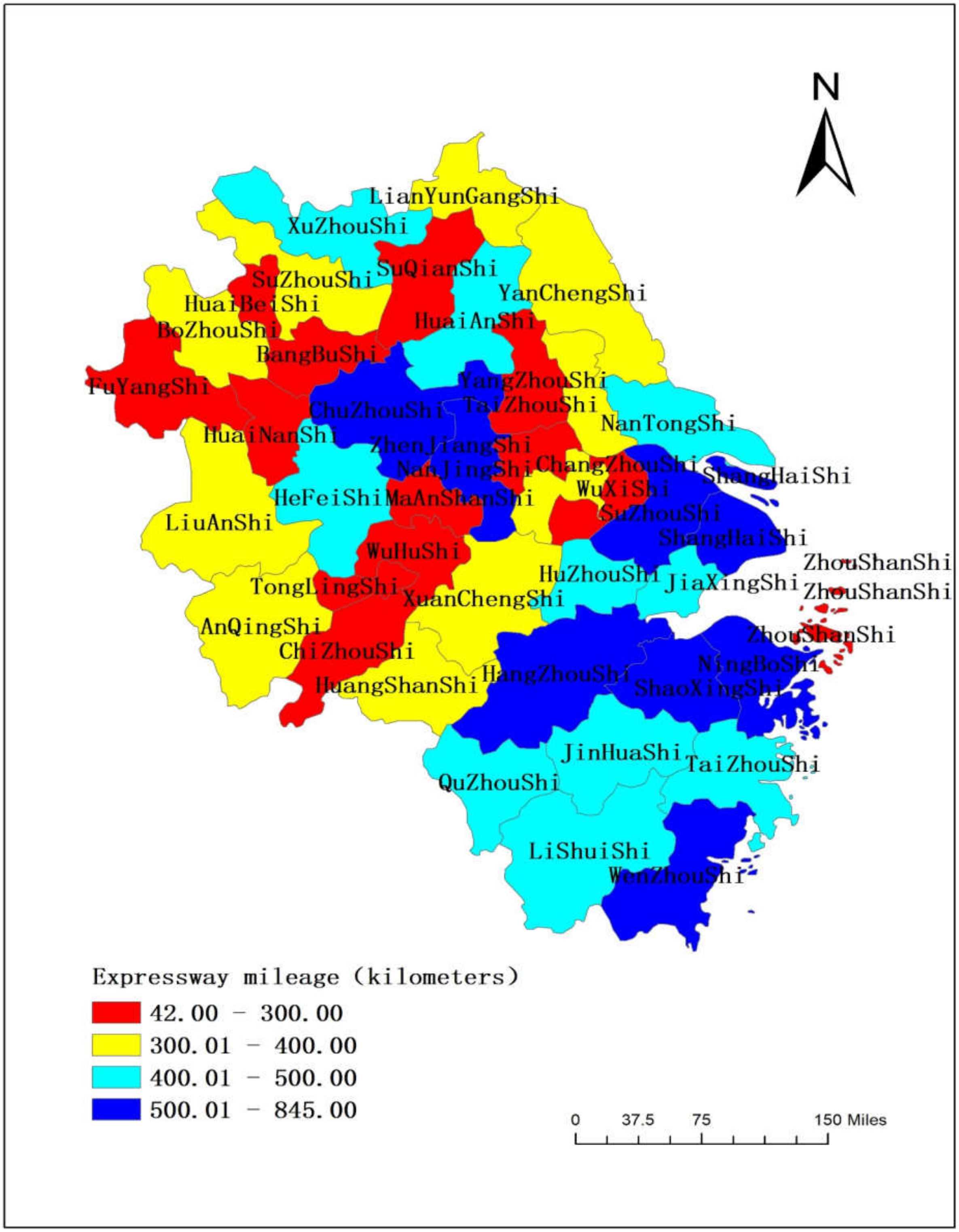

Figure 2. Spatial distribution map of expressway mileage in the Yangtze River Delta Urban agglomeration in 2020

3.2 Overview of service industry development in Yangtze River Delta urban agglomeration

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In 2020, the GDP of the service industry in the Yangtze River Delta urban agglomeration was CNY 13811.88 billion, accounting for 24.93% of the national total. That's 2.7 times the number in 2011. Among them, the service GDP of Shanghai was CNY 2,830.75 billion, accounting for 20.5% of the service GDP of the Yangtze River Delta urban agglomeration, which was 2.54 times that of 2011. The GDP of the service industry in Jiangsu Province was CNY 5,395.58 billion, accounting for 39.06% of the GDP of the Yangtze River Delta urban agglomeration, which was 2.59 times that of 2011. The GDP of the service industry in Zhejiang Province was CNY 360.32 billion, accounting for 26.09% of the GDP of the service industry in the Yangtze River Delta urban agglomeration, which was 2.54 times that of 2011. The GDP of Anhui's service industry was CNY 1,982.43 billion, accounting for 14.35% of the GDP of the Yangtze River Delta urban agglomeration, 3.98 times that of 2011.

Table 3. GDP of service industry in the Yangtze River Delta urban agglomeration from 2011 to 2020.

Year	Shanghai (CNY billion)	Jiangsu (CNY billion)	Zhejiang (CNY billion)	Anhui (CNY billion)
2011	1114.29	2084.22	1418.02	497.60
2012	1219.92	2351.80	1568.11	562.85
2013	1344.51	2642.16	1733.72	628.68
2014	1527.57	3059.95	1922.08	737.87
2015	1702.26	3408.59	2134.19	860.21
2016	1966.29	3869.16	2409.16	1001.83
2017	2119.15	4316.97	2760.23	1159.75
2018	2284.30	4720.52	3072.43	1352.67
2019	2775.23	5106.47	3368.78	1886.04
2020	2830.75	5395.58	3603.12	1982.43

4. Methods

4.1 Land transportation integration evaluation index system of Yangtze River Delta Urban agglomeration

According to relevant studies, the transportation integration of urban agglomerations mainly includes the integration of planning, system and mechanism, basic network and transportation organization [21,22]. Based on the analysis of the characteristics and functions of highway and railway network transport capacity in the Yangtze River Delta urban agglomeration in the Section 3, and considering the influence of data availability, computability and other factors, we constructed an index system based on the integration of basic network. We study the integrated development level of land transportation in the Yangtze River Delta urban agglomeration from traffic network structure and traffic network function. Then, we chose corresponding indicators [30]. See the following Table 4.

Table 4. Land transportation integration evaluation index system of Yangtze River Delta Urban agglomeration

The target layer	Rule layer	Index layer
Urban agglomeration land transportation integration evaluation index	A1 Transportation network structure	A11 In-degree Centrality
		A12 Out-degree Centrality
		A13 Eigenvector centrality
		A14 Betweenness centrality
		A15 Closeness centrality
	A2 Transportation network function	A21 Highway passenger capacity
		A22 Highway freight volume
		A23 Effective average travel time

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	A24 Economic Potential

Specific indicators are described as follows:

1. In-degree centrality and out-degree centrality is measured by degree centrality. The formula is $C_D(i) = k_i$, where k_i is the degree of city i, generally refers to the number of city i with direct rail connections in this study. Degree centrality refers to the number of points directly connected to a point and measures the central position of a node in the network. The higher the degree centrality is, the more nodes are directly connected to the point and the point is in the center. When the connection has direction, degree centrality can be divided into In-degree centrality and out-degree centrality[13].
2. The formula of eigenvector centrality is $C_{E_i} = k_i = c\sum_{j=1}^{g} a_{ij}k_j$, where k_i is the degree of city i [13].
3. The formula of betweenness centrality is $C_{B_i} = \sum_{j=1}^{N}\sum_{k=1}^{j-1}\frac{\varphi_{jk}(i)}{\varphi_{jk}}; j \neq k \neq i, j < k$, where φ_{jk} is the number of shortest paths between cities, $\varphi_{jk}(i)$ is the number of shortest paths through city i between city j and city k, $\frac{\varphi_{jk}(i)}{\varphi_{jk}}$ is the mediations of city i relative to city j and city k [13].
4. The formula of Closeness centrality is $C_{C_i} = \sum_{j=1}^{N}\frac{1}{d_{ij}}$, where d_{ij} is the shortest path length between city i and city j [13].
5. Highway passenger capacity and Highway freight volume can be obtained according to the statistical yearbook.
6. The formula of effective average travel time[31] is $A_i = \sum_{j=1}^{n}\left(T_{ij} * M_j\right) / \sum_{j=1}^{n} M_j$, where T_{ij} is the shortest travel time between two cities based on the land transport network, M_j is the economic quality of city j, which is measured by the square root of the product of the city's GDP and population.
7. The formula of economic potential is $P_i = \sum_{j=1}^{n}\frac{M_j}{T_{ij}}$, where T_{ij} is the shortest travel time between two cities based on the land transport network, M_j is the economic quality of city j, which is measured by the square root of the product of the city's GDP and population.

According to the actual situation of this study and the entropy weight method, the calculation steps of the transportation integration index of the Yangtze River Delta urban agglomeration are as follows:

1. First, all indicators need to be de-dimensionalized;
2. Use the entropy weight method to assign weights to the traffic network structure index and the traffic network function index, and calculate the traffic network structure index and the traffic network function index
3. Use the weighted equalization method to calculate the traffic integration index. The weight of both the traffic network structure index and the traffic network function index is 0.5.

4.2 The Spatial Durbin Model for Hypothesis 1

The Spatial Durbin Model is set as follows:

$$Y_{it} = \rho_1 WY_{it} + \rho_2 WX_{it} + \beta_1 X_{it} + \varepsilon_{it} \quad (1)$$

where W is the spatial weight matrix, WY is the spatial autocorrelation term of the dependent variable, WX is the spatial autocorrelation term of the independent variable, ρ_1 is the spatial lag coefficient of the dependent variable, ρ_2 is the spatial spillover effect of the independent variable, which refers to the influence of independent variables on dependent variables in neighboring areas.

The selected variables in this study are as follows:

1. Explained variable. The main indicators to measure the level of industrial agglomeration include location entropy, Herfindahl index and Gini coefficient, etc. Consider the availability and computability of statistics data, service industry location entropy (SE) is adopted in this study to reflect the degree of urban industrial agglomeration. The SE calculation formula is $SE_{it} = \frac{q_{it} / Q_{it}}{q_t / Q_t}$, where q_{it} is the service industry GDP of city i in year t, Q_{it} is the GDP of city i in year t, q_t is the national service industry GDP in year t, Q_t is the national GDP in year t. According to the requirements of the relevant state documents for service industry classification (http://www.gov.cn/zhengce/content/2012-12/12/content_3943.htm, accessed on 31 December 2020) and the development of Yangtze river delta urban agglomeration of producer service industries, we will choose the wholesale and retail services(WH), transportation, warehousing and postal services(TR), information transmission, software and information technology services(In), scientific research and technical services (SC), finance(FI), leasing and commercial service industry(LE) as the research of producer service industries. The producer service industries locational entropy takes the wholesale and retail services(WH) as an example: $WH_{it} = \frac{s_{it} / S_{it}}{s_t / S_t}$, where s_{it} is the number of people employed in wholesale and retail services of city i in year t, S_{it} is the number of people employed in producer service industries of city i in year t, s_t is the national number of people employed in the wholesale and retail services in year t, S_t is the national number of people employed in producer service industries in year t.
2. Core explanatory variable. Urban agglomeration transportation integration level (TI) is the core explanatory variable, and its related definition and calculation formula are detailed in Section 4.1.
3. Control variables. Control variables include government investment intensity (Fin), level of market size (Ma), level of labor (Wo), and level of foreign trade (Ex). In this study, these control variables are respectively measured by the ratio of general public financial expenditure to GDP of each city, The ratio of total retail sales of consumer

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goods to GDP in each city, The number of labor force in each city, and the ratio of total export to GDP of each city[32].

4. Spatial weight matrix. In this study, the geographical adjacency spatial weight matrix is constructed as follows: $\varpi_{ij}^{1} = \{ \begin{matrix} \varpi_{ij}^{1} = 1, i \text{ is adjacent to } j \\ \varpi_{ij}^{1} = 0, i \text{ isn't adjacent to } j \text{ or } i=j \end{matrix}$ [33].

Then we can obtain the Spatial Durbin Model [34].for Hypothesis 1

$$SE_{it} = \lambda \sum_{j=1}^{n} W_{ij} SE_{jt} + \beta_1 TI_{it} + \beta_2 X_{it} + \theta_1 \sum_{j=1}^{n} W_{ij} TI_{jt} + \theta_2 \sum_{j=1}^{n} W_{ij} X_{jt} + \varepsilon_{it} \quad (2)$$

X_{it} is measured by the above control variables.

The Spatial Durbin Model for producer service industries are as follows:

$$Y_{it} = \lambda \sum_{j=1}^{n} W_{ij} Y_{jt} + \beta_1 TI_{it} + \theta_1 \sum_{j=1}^{n} W_{ij} TI_{jt} + \varepsilon_{it} \quad (3)$$

$$Y_{it} = \lambda \sum_{j=1}^{n} W_{ij} Y_{jt} + \beta_1 TI_{it} + \beta_n X_{it} + \theta_1 \sum_{j=1}^{n} W_{ij} TI_{jt} + \theta_n \sum_{j=1}^{n} W_{ij} X_{jt} + \varepsilon_{it} \quad (4)$$

where Y_{it} is the producer service industries locational entropy, X_{it} is the 3. control variables.

4.3 The Spatial Durbin Model for Hypothesis 2

This section will introduce variables to measure knowledge spillovers, construct the spatial matrix of economic distance and the corresponding spatial econometric model, and study the impact of knowledge spillovers caused by transportation integration in urban agglomeration on the agglomeration of service industries for Hypothesis 2. The model is as follows:

$$\begin{aligned} SE_{it} = {} & \lambda \sum_{j=1}^{n} W_{ij} SE_{jt} + \beta_1 TI_{it} + \beta_2 RD_{it} + \beta_3 TI_{it} * RD_{it} \\ & + \theta_1 \sum_{j=1}^{n} W_{ij} TI_{jt} + \theta_2 \sum_{j=1}^{n} W_{ij} RD_{jt} + \theta_3 \sum_{j=1}^{n} W_{ij} TI_{jt} * RD_{jt} + \varepsilon_{it} \end{aligned} \quad (5)$$

$$\begin{aligned} SE_{it} = {} & \lambda \sum_{j=1}^{n} W_{ij} SE_{jt} + \beta_1 TI_{it} + \beta_2 RD_{it} + \beta_3 TI_{it} * RD_{it} + \beta_n X_{it} \\ & + \theta_1 \sum_{j=1}^{n} W_{ij} TI_{jt} + \theta_2 \sum_{j=1}^{n} W_{ij} RD_{jt} + \theta_3 \sum_{j=1}^{n} W_{ij} TI_{jt} * RD_{jt} + \theta_n \sum_{j=1}^{n} W_{ij} X_{jt} + \varepsilon_{it} \end{aligned} \quad (6)$$

where RD_{it} is the ratio of research and experimental development funds of the whole society to GDP of city i in year t. it is used to measure the level of knowledge spillover in cities in this study. $TI_{it} * RD_{it}$ is the interaction term between transportation integration and knowledge spillover level. β_3 and θ_3 will be used to reflect the impact of knowledge spillovers caused by local and foreign transport integration on local service industry agglomeration. The economic distance spatial weight matrix is constructed as follows: $\varpi_{ij}^{2} = 1/\left|x_{it} - x_{jt}\right|$, where x_{it} is the GDP of city i in year t.

4.4 Data set

1. Railway time data. In terms of time scale, since the high-speed rail in the Yangtze River Delta urban ag-glomeration had been rolled out year by year at the mu-nicipal level since 2011, and considering the impact of COVID-19, the time range of this study was selected as 2011–2019 and 2011–2020. The relevant data from the high-speed railway used were partly from the National Railway Passenger Train Schedule from 2011 to 2016, and the railway time data from 2017 to 2020 were from the official website of the National Railway Corporation (www.12306.cn, accessed from 1 January 2017 to 31 December 2020).
2. Road time data. The road time used came from the baidu-related database.

3. Highway passenger capacity and Highway freight volume can be obtained according to the Statistical Yearbook of Chinese Cities (2012-2021) and the statistical yearbook of provinces and cities.
4. Economic data. The economic data used were the economic data of 41 cities at prefecture level or above from 2011 to 2020, all from the database of the National Bureau of Statistics, China Urban Statis-tical Yearbook (2012–2021) and the relevant provincial statistical yearbook from 2011 to 2020.

In order to eliminate the heteroscedasticity of the original data and reduce the unsteadiness of the data, all data were logarithmically processed.

5. Results

5.1. Result of the Land Transportation Integration Index

According to the relevant statistical data, the structure index, function index and transportation integration index of the transportation network in the Yangtze River Delta are obtained through calculation, which can directly reflect the development level of the transportation integration of the Yangtze River Delta.

Table 5. Calculation results of land transportation integration index in Yangtze River Delta Urban agglomeration(2011-2020)

Year	Transportation structure index	Transportation function index	Transportation integration index
2011	0.5291	0.3780	0.5636
2012	0.5291	0.3871	0.5682
2013	0.5291	0.3946	0.5720
2014	0.5291	0.3895	0.5694
2015	0.5311	0.3801	0.5695
2016	0.5434	0.3762	0.5707
2017	0.5492	0.3993	0.5866
2018	0.5549	0.3900	0.5823
2019	0.5608	0.3958	0.5871
2020	0.5723	0.3742	0.5772

According to the Table 5, the transportation network structure index of the Yangtze River Delta urban agglomeration in 2020 is 0.5723, an increase of 8.16% compared with 2011. On the whole, the transportation network structure index of Yangtze River Delta urban agglomeration showed an upward trend from 2011 to 2020. In 2019 and 2020, the transportation network function index of Yangtze River Delta urban agglomeration was 0.3958 and 0.3742 respectively, which decreased by 5.45% in 2020 compared with 2019. On the whole, the transportation network function index of the Yangtze River Delta urban agglomeration showed a certain upward trend from 2011 to 2020.

In 2019 and 2020, the transportation integration index of the Yangtze River Delta urban agglomeration was 0.5871 and 0.5772, respectively, increasing by 4.17% and 2.14% compared with 2011 respectively. Due to the impact of COVID-19, passenger and cargo transportation in the Yangtze River Delta urban agglomeration in 2020 was impacted to a certain extent, but overall, the transportation integration index of the Yangtze River Delta urban agglomeration from 2011 to 2020 showed a certain upward trend.

Table 6. Land transportation integration Index of cities in Yangtze River Delta urban agglomeration in 2020

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Rank	City	Transportation structure index	Rank	City	Transportation function index	Rank	City	Transportation integration index
1	Shanghai	1.0000	1	Shanghai	0.8379	1	Shanghai	0. 9189
2	Nanjing	1.0000	2	Suzhou(Jiangsu)	0.7383	2	Hangzhou	0. 8613
3	Hangzhou	1.0000	3	Hangzhou	0.7227	3	Hefei	0. 8351
4	Xuzhou	0.9298	4	Hefei	0.6980	4	Suzhou(Jiangsu)	0. 8179
5	Jiaxing	0.9298	5	Ningbo	0.6417	5	Nanjing	0. 8177
6	Hefei	0.8956	6	Nanjing	0.6355	6	Xuzhou	0. 7801
7	Wenzhou	0.8517	7	Xuzhou	0.5858	7	Ningbo	0. 7329
8	Zhenjiang	0.8318	8	Wuxi	0.5549	8	Wuxi	0. 7262
9	Wuhu	0.8248	9	Fuyang	0.5089	9	Jiaxing	0. 7036
10	Wuxi	0.7133	10	Bengbu	0.4767	10	Fuyang	0. 6902
11	Suzhouj	0.7133	11	Jiaxing	0.4329	11	Bengbu	0. 6854
12	Changzhou	0.7133	12	Changzhou	0.4303	12	Changzhou	0. 6639
13	Huainan	0.6615	13	Shaoxing	0.4133	13	Zhenjiang	0. 6367
14	Bengbu	0.6615	14	Chuzhou	0.4045	14	Wuhu	0. 6257
15	Yanzhou	0.6457	15	Huzhou	0.3957	15	Jinghua	0. 6142
16	Fuyang	0.6352	16	Liuan	0.3830	16	Huainan	0. 6118
17	Huaian	0.6045	17	Jinghua	0.3809	17	Wenzhou	0. 6117
18	Jinghua	0.5836	18	Suzhoua	0.3698	18	Huzhou	0. 5998
19	Chizhou	0.5718	19	Zhenjiang	0.3473	19	Chuzhou	0. 5808
20	Huzhou	0.5545	20	Huainan	0.3295	20	Xuancheng	0. 5748
21	Ningbo	0.5449	21	Xuancheng	0.3266	21	Suzhoua	0. 5629
22	Xuancheng	0.5279	22	Nantong	0.3230	22	Yanzhou	0. 5614
23	Liuan	0.5114	23	Taizhou	0.3158	23	Liuan	0. 5612
24	Lianyungang	0.4835	24	Maanshan	0.3067	24	Shaoxing	0. 5506
25	Anqing	0.4746	25	Wuhu	0.3050	25	Taizhou	0. 5136
26	Chuzhou	0.4628	26	Yanzhou	0.2923	26	Chizhou	0. 5023
27	Tongling	0.4492	27	Bozhou	0.2908	27	Huaian	0. 5019
28	Suzhoua	0.4491	28	Quzhou	0.2864	28	Nantong	0. 4872
29	Lishui	0.4436	29	Yancheng	0.2864	29	Anqing	0. 4840
30	Huangshan	0.4423	30	Wenzhou	0.2752	30	Lianyungang	0. 4783
31	Nantong	0.4176	31	Taizhou(Jiangsu)	0.2467	31	Quzhou	0. 4756
32	Huaibei	0.3982	32	Lianyungang	0.2396	32	Bozhou	0. 4679
33	Taizhouj	0.3950	33	Huaian	0.2381	33	Tongling	0. 4643
34	Taizhou	0.3902	34	Suqian	0.2215	34	Maanshan	0. 4547
35	Shaoxing	0.3446	35	Anqing	0.2103	35	Lishui	0. 4520
36	Bozhou	0.3115	36	Chizhou	0.1994	36	Taizhou(Jiangsu)	0. 4382
37	Quzhou	0.3011	37	Tongling	0.1931	37	Huangshan	0. 4348
38	Maanshan	0.2854	38	Huangshan	0.1754	38	Huaibei	0. 4111
39	Suqian	0.2824	39	Lishui	0.1483	39	Yancheng	0. 3818

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40	Yancheng	0.2255	40	Huaibei	0.1308	40	Suqian	0. 3714
41	Zhoushan	0.0000	41	Zhoushan	0.0426	41	Zhoushan	0. 0213

According to the Table 6, Shanghai, Nanjing, Hangzhou, Xuzhou, Jiaxing and Hefei were the top six cities in terms of transportation network structure index of Yangtze River Delta urban agglomeration in 2020. In 2020, Quzhou, Maanshan, Suqian, Yancheng and Zhoushan ranked the lowest five cities in the transportation network structure index of Yangtze River Delta urban agglomeration.

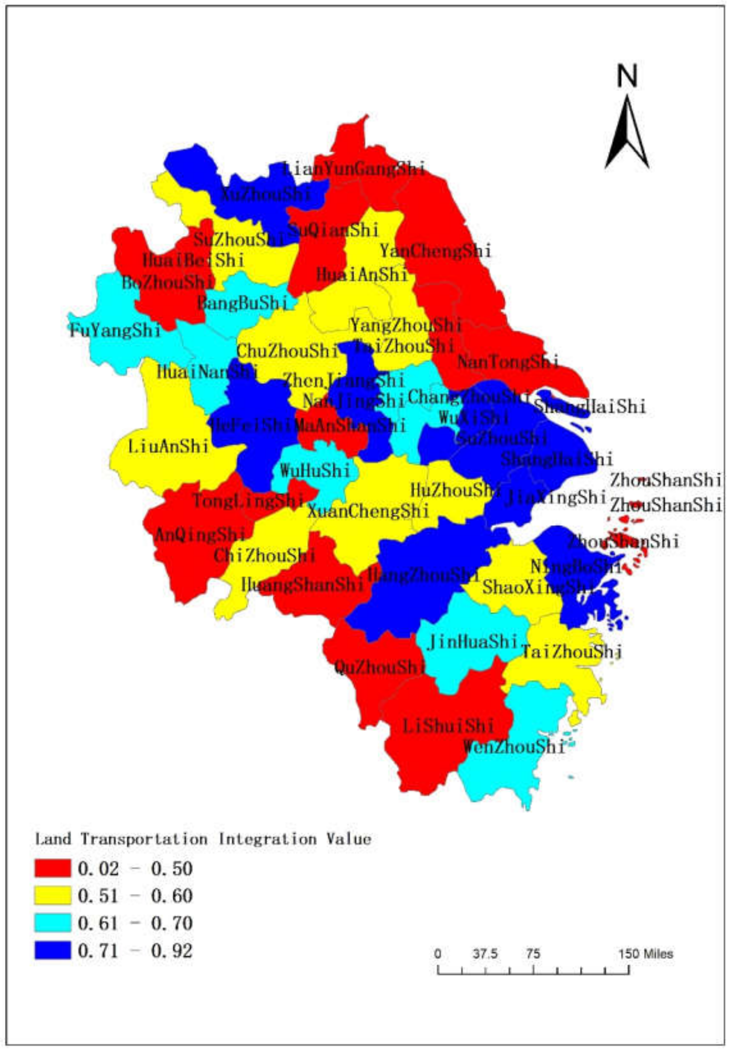

Figure 3. Spatial distribution map of land transportation integration value in the Yangtze River Delta urban agglomeration in 2020

In 2020, Shanghai, Suzhou, Hangzhou, Hefei, Ningbo and Nanjing ranked the top six cities in the transportation network function index of Yangtze River Delta urban agglomeration, respectively. In 2020, Tongling, Huangshan, Lishui, Huaibei and Zhoushan ranked the bottom 5 cities in the transportation network function index of Yangtze River Delta urban agglomeration, respectively.

The spatial distributions of transportation integration index value of Yangtze River Delta urban agglomeration in 2020 are shown in Figure 3. The transportation integration index value of Yangtze River Delta urban agglomeration in 2020 ranked the top five cities, namely Shanghai, Hangzhou, Hefei, Suzhou and Nanjing. The cities with the transportation integration index values in the Yangtze River Delta in 2020 were Huangshan, Huaibei, Yancheng, Suqian and Zhoushan.

5.2. Result of The Spatial Durbin Model for Hypothesis 1

This section details the spatial autocorrelation analysis and LM test that was carried out on relevant data by Excel and R software to determine the spatial model (2). Then, R software was used for the spatial metering operation and case analysis.

This section firstly studies the impact of the integrated development level of transportation in urban agglomeration on the agglomeration of service industry as a whole, and then further studies the impact of the integrated development level of transportation in urban agglomeration on the agglomeration of different subsectors of production line service industry.

5.2.1. Spatial autocorrelation test

This study first used the Moran index to test the spatial correlation of service industry location entropy in the Yangtze River Delta urban agglomeration as a whole, and the corresponding Moran index could be obtained, as shown in the Table 7. As can be seen from the table, the Moran index of service industry location entropy of urban agglomerations in the Yangtze River Delta from 2011–2018 was significant at the level of 10%, and the Moran index from 2019 to 2020 fails to pass the significance test, revealing that the industrial location entropy of urban agglomerations in the Yangtze River Delta from 2011–2020 had obvious spatial autocorrelation. Overall, the degree of spatial agglomeration of industrial location entropy in the Yangtze River Delta Urban agglomeration improved. The industrial location entropy of the urban agglomeration of the Yangtze River Delta was not in a completely random state, but it was affected by the economic behaviors of other regions with similar spatial characteristics, revealing a certain phenomenon of agglomeration in geographical space. Therefore, in order to study and analyze the impact of transportation integration on industrial agglomeration in the Yangtze River Delta, the spatial factors should not be ignored.

Table 7. Spatial autocorrelation test of service industry location entropy under the geographical adjacency spatial weight matrix.

Year	Moran index	Year	Moran index
2011	0.2619***	2016	0.1973***
2012	0.3173***	2017	0.1624***
2013	0.3245***	2018	0.2093***
2014	0.3130***	2019	-0.0594
2015	0.2758***	2020	-0.0287

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

5.2.2. LM test

In this study, LM statistics and Robust LM statistics were tested on the corresponding spatial econometric models using R software.

Table 8. Test of spatial autocorrelation of service industry location entropy

Test parameters	Statistics(2011-2019)	Statistics(2011-2020)
LM-ERR	0.54	125.02***
LM-LAG	3.16**	64.18***
RLM-ERR	0.88	61.59***

RLM-LAG	3.50*	0.75

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

According to the Table 8, Based on the data of the Yangtze River Delta urban agglomeration from 2011 to 2020, the LM-ERR and LM-LAG tests both passed the significance test at the 10% level, indicating that the lag term and residual series of the dependent variable both had spatial autocorrelation. Furthermore, the Robust LM test was performed, and the results showed that the Robust LM-ERR passed the significance test at the 10% level, while the Robust LM-LAG did not. Based on the data of Yangtze River Delta urban agglomeration from 2011 to 2019, both LM-LAG and Robust LM-LAG passed the significance test at the 10% level, while neither LM-ERR nor Robust LM-ERR passed the significance test at the 10% level.

In view of the above test results, this study adopted the Spatial Durbin Model (2) to study the impact of transportation integration on service industry agglomeration in urban agglomerations.

5.2.3. The empirical analysis

This section examines the impact of transportation integration in urban agglomerations on service industry agglomeration. Based on statistical data at the municipal level, 41 cities in urban agglomerations in the Yangtze River Delta were selected as research samples, and the spatial Durbin model (2) was used to conduct regression analysis from 2011–2019 and 2011–2020, respectively, considering the impact of COVID-19. The model estimation results are shown in the table below.

Table 9. The Spatial Durbin Model (2) regression estimation results

Variable	2011-2019	2011-2020
λ	0.0359***	0.0406***
TI	-0.0553	-0.0326
Fin	0.0839***	0.0911***
Con	0.3703***	0.3252***
Wo	0.0148	0.0156
Ex	0.0176**	0.0213***
W* Ti	-0.0297**	-0.0283*
W*Fin	-0.0522***	-0.0524***
W*Con	0.0231***	0.0349***
W*Wo	-0.0136***	-0.0157***
W*Ex	-0.0009	-0.0013

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

As Table 9 suggests, λ had ideal statistics, indicating that SDM can accurately reflect the spatial correlation between the transportation integration of urban agglomerations and service industry agglomeration. According to SDM's spatial regression coefficient, the estimation results of λ have passed the test of significance level, indicating that the service industry agglomeration of other cities plays an important role in the development of local service industry agglomeration. When the spatial effect was considered, the improvement of service industry agglomeration in neighboring regions has a positive spillover effect on service industry agglomeration in the region. By comparing the model estimation results of the two time periods, the statistical value of the period from 2011 to 2020 is larger than that of the period from 2011 to 2019. The results show that there is a strong spillover effect in geospatial or relatively developed areas of service industry. The results of the comparison between the two periods show that the impact of COVID-19 is even negligible.

The estimation results of TI of the two models are negative and fail to pass the significance test. The estimation results of W*TI of the two models pass the significance test and are negative. This shows that at the present stage, in the Yangtze River Delta urban agglomeration, the development of the integration level of local and foreign transportation has a certain degree of inhibiting effect on the agglomeration of the local tertiary industry.

The estimated coefficients of Con and W*Con are both significantly positive. This indicates that consumption market development in local and other regional markets has a significant role in promoting service industry agglomeration.

The estimated coefficients of Wo are all positive, but failed to pass the significance test. The estimated coefficients of W*Wo are all negative and pass the significance test. This indicates that the increase of local labor force promotes the agglomeration of local service industry to some extent, but it is not significant. The increase of labor force in other regions has a significant inhibitory effect on local service industry agglomeration.

The estimated coefficients of Fin are all significantly positive, and those of W*Fin are all significantly negative. This shows that the local tertiary industry agglomeration is significantly affected by local and other regional financial input, and the local financial input will significantly promote the local tertiary industry agglomeration. The estimated coefficients of Ex are all significantly positive, while the estimated coefficients of W*Ex are negative and fail the significance test. This shows that the local foreign trade level has a significant positive impact on the local tertiary industry agglomeration, while the foreign trade level of other regions has a certain negative impact on the local tertiary industry agglomeration.

The impacts of transportation integration on the agglomeration of different producer services in the Yangtze River Delta urban agglomeration are different. According to Table 10 and Table 11, the empirical results show that the TI estimated coefficients of wholesale and retail trade, transportation, storage and postal services are significantly positive, which means that the transportation integration of the Yangtze River Delta urban agglomeration has a significant promoting effect on the agglomeration of local wholesale and retail trade, transportation, storage and postal services. The estimated coefficient of TI in the financial industry is positive and fails the significance test. The TI estimated coefficients of leasing and business services are significantly negative, while the TI estimated coefficients of information transmission, software and information technology services, scientific research and technology services are negative, which fail to pass the significance test. The transportation integration of the Yangtze River Delta urban agglomeration has a restraining effect on the agglomeration of local leasing and business services, information transmission, software and information technology services, scientific research and technology services to varying degrees.

According to Table 11, wholesale and retail trade, information transmission, software and information technology services, scientific research and technical services, finance, leasing and business services space regression coefficient estimation results through the test of significance level, that other cities of the industrial agglomeration plays an important role in the development of local industry agglomeration.

Table 10. The Spatial Durbin Model (3) regression estimation results

Variable	WH	TR	IN	SC	FI	LE
λ	0.1192***	-0.0008	0.1290***	0.0883***	0.0335*	0.0338*
TI	0.8078***	0.3597***	-0.1180	-0.2870*	0.0845	-0.4962*
W* Ti	-0.3654***	0.0172	-0.3126***	-0.3270***	0.1806***	0.1403

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

Table 11. The Spatial Durbin Model (4) regression estimation results

Variable	WH	TR	IN	SC	FI	LE

λ	0.1125***	-0.0068	0.1182***	0.0587***	0.0294*	0.0364*
Ti	0.7945***	0.4083***	-0.0957	-0.2217	0.0919	-0.4814*
Fdi	-0.0419*	0.0042	-0.0327	-0.0317*	0.0161*	-0.0499*
Fin	-0.3321*	-0.1077	0.1560	-0.0896	0.1111	-0.3664
Con	-0.4390*	-0.0628	-0.2532	-0.3061*	0.0608	0.1710
W*Ti	-0.2389***	0.0716	-0.2152*	-0.1816***	0.1364***	0.0738
W*Fdi	0.0085*	0.0007	0.0104*	0.0033	-0.0022	0.0165*
W*Fin	-0.0516	-0.0752*	-0.1974***	-0.0516	-0.0364	-0.3077***
W*Con	0.0279	-0.0240	-0.0526	-0.1146***	0.0161	0.1163

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

5.3. Result of the Spatial Durbin Model for Hypothesis 2

5.3.1. Spatial autocorrelation test

Table 12. Spatial autocorrelation test of service industry location entropy under the economic spatial matrix.

Year	Moran index	Year	Moran index
2011	0.1984*	2016	0.1760*
2012	0.2233*	2017	0.1020
2013	0.2269*	2018	0.1400
2014	0.2199*	2019	0.0494
2015	0.2169*	2020	0.0515

Note: the significance of *, ** and * are 10%, 5% and 1% respectively**

According to Table 12, the Moran index of the location entropy of the service industry in the Yangtze River Delta urban agglomeration from 2011 to 2016 is all significant at the level of 10%, and the Moran index from 2017 to 2020 fails to pass the significance test, indicating that the location entropy of the service industry in the Yangtze River Delta urban agglomeration from 2011 to 2020 has obvious spatial autocorrelation on the whole. Therefore, the SDM model based on economic distance spatial matrix can be built for relevant research.

5.3.2. LM test

Table 13. Test of spatial autocorrelation of service industry location entropy in Yangtze River Delta Urban agglomeration.

Test parameters	Geographic adjacency spatial matrix	Economic distance spatial matrix
LM-ERR	115.6529***	89.2937***
LM-LAG	61.8625***	31.4280***
RLM-ERR	53.9340***	57.9919***
RLM-LAG	0.1435	0.1262

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

According to Table 13, both LM-ERR and LM-LAG tests passed the significance test at the 10% level, indicating that the lag term and residual sequence of dependent variables are spatially autocorrelated. The results show that the Robust LM-Err passed the significance test at 10% level, while the Robust LM-lag failed the significance test at the 10% level.

Considering the above test results, we adopted spatial Durbin model (5) and (6) to study the impact of transportation integration on industrial agglomeration in urban agglomerations.

5.3.3. The empirical analysis

In this study, 41 cities in the Yangtze River Delta urban agglomeration were taken as research samples, and the spatial Durbin model (5) and (6) was used for regression analysis. The model estimation results are shown in the table below.

Table 14. The Spatial Durbin Model (5) and (6) regression estimation results

Variable	Geographic adjacency spatial matrix		Economic distance spatial matrix	
	Model (5)	Model (6)	Model (5)	Model (6)
λ	0.0585***	0.0327***	-0.8379	-1.7582***
TI	0.2320**	0.0079	0.3086***	0.1334*
RD	0.1128***	0.0073	0.1304***	0.0138
TI*RD	0.0693***	0.0137	0.0880***	0.0409**
Fin		0.1016***		0.0880***
Fdi		-0.0037		-0.0015
Con		0.3299***		0.3516***
W*TI	0.0114	-0.1168**	0.0384*	-0.0304**
W*RD	0.8283***	-0.0241*	1.0618***	0.4099*
W*TI*RD	-0.0709	-0.0177*	-0.0683	-0.0008
W*Fin		-0.0569***		-0.0530***
W*Fdi		0.0025***		0.0019**
W*Con		0.0381***		0.0341***

Note: the significance of *, ** and ***are 10%, 5% and 1% respectively

According to Table 14, knowledge spillovers caused by local transport integration have a positive impact on service industry agglomeration. The regression results show that under the geographical adjacency matrix, the TI*RD term of model (5) has a positive impact at the 1% level, and the estimated coefficient of TI*RD term of model (6) fails to pass the significance level test. Under the economic distance spatial matrix, the estimated coefficients of TI*RD pass the significance level test. Knowledge spillovers caused by transport integration in other regions have a negative impact on service industry agglomeration. The regression results show that the TI*RD terms are negative under the geographical adjacency matrix and economic matrix. Only model 6 under the geographical adjacency matrix passed the significance test at the 10% level.

The level of local knowledge spillovers has a positive effect on service industry agglomeration. The regression results show that under the geographical adjacency matrix and economic matrix, the estimated coefficient of RD term in model (5) has a positive impact at the 1% level, while the estimated coefficient of Rd term in model (6) fails to pass the significance level test. The effect of knowledge spillover level on service agglomeration in other regions is different. The regression results show that under the geographical adjacency matrix, the W*RD term of model (5) has a positive influence at the 1% level, and the estimated coefficient of W*RD term of model (6) is negative, which does not pass the significance level test. Under the economic matrix, the estimated coefficients of the W*RD terms are all significantly positive.

6. Discussion

According to Table 3, The first experimental study shows that the transportation integration index of the Yangtze River Delta urban agglomeration shows an upward trend from 2011 to 2020, and the transportation network of the Yangtze River Delta urban agglomeration is increasingly optimized. The total running time of high-speed railways and expressways in the Yangtze River Delta urban agglomeration has been shortened, and the frequency of high-speed railways and the traffic flow of expressways between Shanghai and Suzhou, Jiaxing, Nanjing and Suzhou, Danyang, Changzhou, Kunshan and other cities have significantly increased, accelerating the flow of factors. In 2020, passenger and cargo transportation in the Yangtze River Delta urban agglomeration was affected by the COVID-19 epidemic to a certain extent. With the support of national policies, the transportation integration level of the Yangtze River Delta urban agglomeration has been improved, and the high-speed transportation network has produced a time compression effect, forming an overall development pattern of linkage between core cities and daily communication around them.

The results of Table 6 and Figure 3 show that the transportation network of urban agglomerations in Yangtze River Delta mainly took "Shanghai–Nanjing-Hangzhou" as the core, and Suzhou and Hefei as the secondary cores in the periphery, presenting a spatial pattern of multi-center structure. The level of transportation integration in the marginal regions of the Yangtze River Delta urban agglomeration is low. These regions need to accelerate the construction of relevant transportation infrastructure and improve regional accessibility, so as to promote the integrated development of transportation in the Yangtze River Delta urban agglomeration to a higher quality.

The first model experiment on hypothesis 1 shows that the transportation integration level of the Yangtze River Delta urban agglomeration has been continuously improved under the promotion of various national policies, which has accelerated the flow of relevant factors, enabled the development of relevant enterprises to break through geographical restrictions and administrative barriers, promoted the formation of the service industry chain, and boosted the transformation and upgrading of the service industry in the Yangtze River Delta urban agglomeration. The service industries of different cities in the Yangtze River Delta urban agglomeration are highly connected and interdependent, showing a positive effect of mutual promotion.

The TI estimations indicate that the agglomeration of service industry would produce diffusion effect with the development of the integration of the Yangtze River Delta urban agglomeration. The supporting materials, talents, technology, capital and other factors related to the service industry in the Yangtze River Delta urban agglomeration spread from the core cities to the surrounding cities through the transportation network of the urban agglomeration, promoting the diffusion and development of related industries, and constantly expanding the boundary between industries and the urban agglomeration. At the same time, the relationship among industries, cities and between industries and cities is becoming closer, which will further promote the deepening of industrial division of labor in urban agglomeration and the high-quality development of economy.

The estimated coefficients of Con and W*Con indicate that the development of local and other regional consumer markets has contributed to the agglomeration of local service industries in the Yangtze River Delta urban agglomeration. On the one hand, the development of the local consumer market increases the market demand of the local service industry, thus promoting the development and agglomeration of the service industry. On the other hand, thanks to the convenient land transportation network of the Yangtze River Delta urban agglomeration, the service industries in the Yangtze River Delta learn from each other and improve the labor productivity of related industries, which also promotes the development of the local service industry.

The estimated coefficients of Wo and W*Wo indicate that the impact of local and other regional labor force changes on local service agglomeration is not consistent in the Yangtze River Delta urban agglomeration. The increase of local labor force will provide corresponding labor force for the development of local service industry and promote the agglomeration of local service industry. The increase of labor force in other regions will reduce the matched labor force required by local related industries, and thus exert a certain inhibitory effect on the agglomeration of local service industries. At the same time,

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most of the service industries are knowledge-intensive enterprises and technology-intensive enterprises, which need to invest a large number of high-quality talents with rich professional knowledge in the operation process. The increase in the number of labor force does not represent the increase in the number of high-quality talents, so its impact on the agglomeration of local service industries is not significant.

The second model experiment on hypothesis 1 shows that wholesale and retail are the industries most relevant and closely related to the daily life of residents, and will gather along with the agglomeration of consumers. The wholesale and retail industries are characterized by decentralized transactions, low turnover and low relocation costs. Wholesale and retail industries are more affected by traffic conditions than other industries. The integrated development of transportation in the Yangtze River Delta urban agglomeration makes producers and consumers flow more freely, and promotes the agglomeration of wholesale, retail and related supporting industries attracted by the huge potential consumer market. Local transportation, storage, and postal services have converged with the development of transportation infrastructure. The integrated development of transportation in the Yangtze River Delta has reduced the inter-regional transportation cost and promoted the trade between different regions. The financial demand brought by these trade made the financial human capital accumulate in the core areas, and promoted the financial industry agglomeration to a certain extent.

The estimation results of spatial coefficient show that the development of wholesale and retail industry, information transmission, software and information technology services, scientific research and technology services, financial industry, leasing and business services have broken through the geographical restrictions and administrative barriers with the integrated development of transportation in the Yangtze River Delta urban agglomeration. It makes the upstream and downstream related enterprises of different cities in the urban agglomeration interdependent and coordinated development.

Model experiments on hypothesis two show that the development of transportation integration in urban agglomeration leads to knowledge spillover effect, local knowledge spillovers can drive and lead the development of the service industry. Relevant knowledge breaks through the geographical restrictions through the transportation network of the urban agglomeration and spreads from the core cities to the surrounding cities, promoting the diffusion and development of relevant industries. The boundary of industries is constantly expanded, and the service industry is further promoted to gather locally. The development of the service industry in the Yangtze River Delta urban agglomeration has entered the industry chain era. The extension of the industry chain is consistent with knowledge learning and the dissemination of scientific and technological innovation to a certain extent, which has a positive impact on the agglomeration of the service industry. All regions in the Yangtze River Delta urban agglomeration are vigorously promoting the transformation and upgrading of the service industry. The development of the service industry is moving toward deep integration, and the industrial chain of related industries is gradually developing and improving, thus promoting the aggregation of related industries. At the same time, this kind of aggregation will also have a siphon effect on other cities in the urban agglomeration region.

7. Conclusions

From the perspective of transportation integration, this study studies the effects and mechanisms of transportation infrastructure on service industry agglomeration in urban agglomeration. This study selected the Yangtze River Delta urban agglomeration as the research area, combined with the current situation of traffic development in the Yangtze River Delta urban agglomeration, constructed the index system of land transportation integration in the urban agglomeration, and evaluated the current situation of land transportation integration in the Yangtze River Delta urban agglomeration. This study constructed the spatial econometric models to quantitatively analyze the impact of transportation integration in urban agglomeration on service industry agglomeration, and explore the impact mechanism of land transportation integration in urban agglomeration on service industry agglomeration.

The transportation integration index of Yangtze River Delta urban agglomeration in 2019 and 2020 was 0.3937 and 0.3906, respectively, 4.62% and 3.8% higher than that in 2011. In 2020, both passenger and freight transportation in the Yangtze River Delta urban agglomeration were affected by the COVID-19 epidemic. However, on the whole, the land transportation integration index of the Yangtze River Delta urban agglomeration showed an obvious upward trend from 2011 to 2020.The transportation integration index value of Yangtze River Delta urban agglomeration in 2020 ranked the top five cities as Shanghai, Hangzhou, Hefei, Suzhou, and Nanjing. This indicates that the transportation network of urban agglomerations in Yangtze River Delta mainly takes "Shanghai–Nanjing–Hangzhou" as the core, and Suzhou and Hefei as the secondary core in the periphery, presenting a spatial pattern of a multi-center structure. The cities with TI values in the Yangtze River Delta in 2020 were Huangshan, Huaibei, Yancheng, Suqian, and Zhoushan. These cities are located at the edge of Shanghai, Hangzhou, Nanjing, Hefei, and other metropolitan areas, and their transportation integration level is low.

The development of local transport integration level has a certain degree of inhibition on the agglomeration of local service industry. The development of transport integration in other regions has a significant impact on the agglomeration of local service industries. Considering the spatial effect, the improvement of the level of service industry agglomeration in neighboring regions has a positive spillover effect on the level of service industry agglomeration in the region. The comparison between the two periods shows that the impact of COVID-19 is negligible.

The impacts of land transportation integration on the agglomeration of different producer services in the Yangtze River Delta urban agglomeration are different. The transportation integration of the Yangtze River Delta urban agglomeration plays a significant role in promoting the agglomeration of local wholesale and retail industry, transportation, storage and postal industry. It inhibits the agglomeration of local rental and business services, information transmission, software and information technology services, scientific research and technology services to varying degrees. The estimation results of the spatial regression coefficient indicate that the industrial agglomeration of wholesale and retail, information transmission, software and information technology services, scientific research and technology services, financial industry, leasing and business services in other cities have spillover effects on the development of local related industry agglomeration. Labor force and market size also have a significant impact on service agglomeration.

The integration of land transport in urban agglomeration affects the agglomeration of service industry through the knowledge spillover effect caused by the improvement of accessibility, and the impact is heterogeneous. The knowledge spillover effect caused by local transportation integration can promote the agglomeration of local service industry to a certain extent. The knowledge spillover effect caused by transportation integration in other regions has a restraining effect on local service industry agglomeration to a certain extent.

The peripheral areas located in Shanghai, Hangzhou, Nanjing, Hefei and other metropolitan areas urgently need to accelerate the construction of relevant transportation infrastructure to promote the integrated development of transportation in the Yangtze River Delta urban agglomeration to a higher quality.

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References

1. Li, Y., Phelps, N. Megalopolitan glocalization: the evolving relational economic geography of intercity knowledge linkages within and beyond China's Yangtze River Delta region, 2004-2014. *Urban Geography*. 2019, 40, 1310-1334.
2. Wang, L., Zhang, W., Duan, X. Understanding Accessibility Changes from the Development of a High-Speed Rail Network in the Yangtze River Delta, China: Speed Increases and Distance Deductions. *Applied Spatial Analysis and Policy*. 2019, 12, 1011-1029.
3. Wu, Q., Zhang, C., Wang, H., Hao, J. Study on the relationship between agglomeration of service industry and economic growth in Yangtze River Delta based on spatial econometric models. *Journal of Physics: Conference Series*. 2019, 1324, 012089-012089.
4. Peng, D., Li, R., Shen, C., Wong, Z. Industrial agglomeration, urban characteristics, and economic growth quality: The case of knowledge-intensive business services. *International Review of Economics and Finance*. 2022, 81, 18-28.
5. Wang, J., Yang X., Qalati, S., Deng, Y. Spatial Spillover Effect and Spatial Distribution Characteristics of Transportation Infrastructure on Economic Growth: A Case of the Yangtze River Delta. *Frontiers in Environmental Science*. 2022.
6. Miao, Y., Ni, A. Vulnerability Analysis of Intercity Multimode Transportation Networks; A Case Study of the Yangtze River Delta. *Sustainability*. 2019, 11(8), 2237-2237.
7. Liu, W., Cao, Y., Wu, W., Guo, J. Spatial impact analysis of trans-Yangtze highway fixed links: A case study of the Yangtze River Delta, China. *Journal of Transport Geography*. 2020, 88.
8. Marshall, A. *Principles of Political Economy.* Maxmillan Press, London, 1890.
9. Krugman, P. *Geography and Trade*. MIT Press, Cambridge, MA. 1993.
10. Jones, C. *Urban economy and Real Estate Economics and Public Policy.* Routledge Press, London, 2021.
11. Xiao, F., Zhou, F., Deng, W., Gu, H. Did high-speed rail affect the entry of automobile industry start-ups? Empirical evidence from Guangdong Province, China. *Travel Behaviour and Society*. 2020, 19, 45-53.
12. Tian, M., Li, T., Ye, X., Zhao, H., Meng, X. The impact of high-speed rail on service industry agglomeration in peripheral cities. *Transportation Research Part D: Transport and Environment*. 2021, 93, 102745.
13. Niu, F., Wang, F. Economic Spatial Structure in China: Evidence from Railway Transport Network. *Land.* 2022, 11(1), 61-61.
14. Chen, Z., Hanynes, K. Impact of high-speed rail on regional economic disparity in China. *Journal of Transport Geography.* 2017, 65, 80-91.
15. He, D., Chen, Z., Pei, T., Zhou, J. The Regional and Local Scale Evolution of the Spatial Structure of High-Speed Railway Networks—A Case Study Focused on Beijing-Tianjin-Hebei Urban Agglomeration. *ISPRS International Journal of Geo-Information*. 2021, 10(8), 543-543.
16. He, Y., Lv, B., Yu, D. How does spatial proximity to the high-speed railway system affect inter-city market segmentation in China: a spatial panel analysis. *Eurasian Geography and Economics*. 2022, 63(1), 55-81.
17. Dong, X. High-speed railway and urban sectoral employment in China. *Transportation Research Part A: Policy and Practice*. 2018, 116, 603-621.
18. Percoco, M. Highways, local economic structure and urban development. *Journal of Economic Geography.* 2016, 16(5), 1035-1054.
19. Holl, A. Highways and productivity in manufacturing firms. *Journal of Urban Economics*. 2016, 93, 131-151.
20. Wang, X., Zhang, W. Efficiency and Spatial Equity Impacts of High-Speed Rail on the Central Plains Economic Region of China. *Sustainability*. 2019, 11(9), 2583-2583.
21. Lu, C., Lu, W. Development strategies of comprehensive stereoscopic transportation system. *Journal of the China Railway Society*. 2022, 44(01):1-7.
22. Zeng, Q. Research of Regional Economy and Regional Traffic Integration Development Modes. *Journal of Wuhan University of Technology*. 2006, 12, 133-136.
23. Wang, W., Hua, X., Zheng, Y. Multi-network integrated traffic analysis model and algorithm of comprehensive transportation system. *Journal of Traffic and Transportation Engineering*. 2021, 02, 159-172.
24. Yao, S., Fang, J., He, H. Can Time-Space Compression Promote Urban Economic Growth? Evidence from China's High-speed Rail Projects. *China & World Economy*. 2020, 28(5), 90-117.
25. Shao, S., Tian, Z., Yang, L. High speed rail and urban service industry agglomeration: Evidence from China's Yangtze River Delta region. *Journal of Transport Geography*. 2017, 64, 174-183.
26. Fujita, M., Krugman, P., Venables, A. *The Spatial Economy: Cities, Regions and International Trade.* MIT Press, Cambridge, MA. 1999.
27. Niu, D., Sun, W., Zheng, S. Travel Costs, Trade, and Market Segmentation: Evidence from China's High-Speed Railway. *Papers in Regional Science*. 2020, 99(6), 1799-1825.
28. Ma, L., Niu, D., Sun, W. Transportation infrastructure and entrepreneurship: Evidence from high-speed railway in China. *China Economic Review*. 2021, 65.
29. Zhao, T., Xiao, X., Dai, Q. Transportation Infrastructure Construction and High-Quality Development of Enterprises: Evidence from the Quasi-Natural Experiment of High-Speed Railway Opening in China. *Sustainability*. 2021, 13(23), 13316-13316.

30. Wei, G., Li, X., Yu, M., Lu, G., Chen, Z. Influence Mechanism of Transportation Integration on Industrial Agglomeration in Urban Agglomeration Theory—Taking the Yangtze River Delta Urban Agglomeration as an Example. *Applied Sciences*. 2022, 12(16):8369-8369.
31. Diao, M. Does growth follow the rail? The potential impact of high-speed rail on the economic geography of China. *Transportation Research Part A: Policy and Practice*. 2018, 113, 279-290.
32. Liu, L., Zhang, M. High-speed rail impacts on travel times, accessibility, and economic productivity: a benchmarking analysis in city-cluster regions of China. *Journal of Transport Geography*. 2018, 73, 25-40.
33. He, Y., Lv, B., Yu, D. How does spatial proximity to the high-speed railway system affect inter-city market segmentation in China: a spatial panel analysis. *Eurasian Geography and Economics*. 2022, 63(1) , 55-81.
34. Guan, H., Li, Q. Spatial Spillover Effects of Economic Growth Based on High-Speed Railways in Northeast China. *Complexity*. 2021, 2021.