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Exploring the Coupling Coordination and Spatial Correlation of Logistics Industry and Regional Economy in the Context of Sustainable Development: Evidence from the Yangtze River Delta Region

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Abstract: As the economy develops, the level of logistics required means many activities become increasingly dependent on transportation, which leads to the deterioration of the ecological environment, aggravates air pollution, causes urban traffic jams, and has a negative influence on sustainable development. Therefore, in the context of sustainable development, how to coordinate the development of the logistics industry and regional economy has become a governmental and academic focus. The coupling coordination degree model and spatial autocorrelation analysis model were applied to empirically analyze the coupling and coordination of the logistics industry and economy in each city in YRDR and the relationship of mutual influence. The research results show that, for economically developed cities, economic development had more influence on the coupled and coordinated degree of the two, and for the less developed cities, the development of logistics drove the improvement of the coupled and coordinated degree of the two. The analysis of the Anhui Province showed that the coupling and coordination degree of its own logistics industry and economy was driven by strong radiation, and the impact on that degree of the logistics industry and economy of cities in Jiangsu, Zhejiang, and Shanghai was not significant. The development of the coupling and coordination degree of the two variables of cities in Jiangsu Province was more balanced. The divergence degree of that of the logistics industry and economy of cities in Zhejiang Province exhibited a tendency to increase, and the divergence mainly came from the endogenous development of each city. The variability was mainly due to the endogenous dynamics of each city's development. Finally, suggestions for the coordinated and sustainable development of the logistics industry and regional economy are provided.

Keywords: Yangtze River Delta city cluster; regional logistics; regional economy; coupling coordination degree; sustainable development

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1. Introduction

As China continues to open up and develop, as a result of strong market demand, the logistics industry is becoming more and more important in ensuring the normal production of society and social life. Moreover, it is becoming a strategic industry in terms of supporting national economic development. The logistics industry plays a key role in the market, and the rapid development of e-commerce has led to the gradual expansion of the logistics scale. Shen [1] believes that the regional economy and regional logistics are mutually influential, coordinated and inextricably linked. Yin [2] considers the logistics system conducive to the expansion of industrial clusters in Beijing, Tianjin and Hebei. In general, in the early stage of economic development, due to various factors, the industry develops rapidly, and the industrial structure is relatively reasonable, which are mainly characterized by heavy industry. Furthermore, the development of the flow of goods has also led to the growth of GDP. They are closely related to each other, and enhancing the logistics supply capacity has attracted great attention of enterprises. However, it should be pointed out that the rapid growth of logistics has also brought a series of problems, such as the increase in warehousing demand and the substantial increase of goods flow, which adds to atmospheric pollution and causes traffic jams and other phenomena, thus reducing transportation efficiency and negatively impacting the environment. The high level of logistics leads to an increased dependence on automobiles for logistics activities and a further increase in the share of auto transport. So despite the logistics level does not increase obviously, the environment is seriously impacted by the increased frequency and proportion of trucking. The logistics industry runs counter to ecological environmental protection, as it aggravates air pollution, and is very harmful to the environment and sustainable socio-economic conditions. Therefore, under this context, how to coordinate the coordinated the logistics industry and regional economy has become a governmental and academic focus. Adepetu [3] believes that the rapid development of the economy is driving the logistics industry to evolve towards a higher level and more efficient intelligence. In March 2019, a document on improving logistics service capability jointly issued by many departments in China, emphasized the need to view the progress of the logistics as key to enhancing the comprehensive competitiveness of regional and national economies [4]. Thus, the government, enterprises, and other social entities are increasingly focusing on enhancing regional logistics development and the economy, as well as realizing a high level of coupling to them in terms of spatio-temporal patterns.

The Yangtze River Delta Region (YRDR) plays an important role in China's economic development and the process of reform and opening up. In December 2019, the Chinese government, in combination with the current economic development situation, issued the Comprehensive Development Plan for the region, which elevates the integrated development of theYRDR and proposes to promote the formation of a new pattern of linked collaboration and coordinated interactive development in the YRDR, with Shanghai as the leader and Jiangsu, Zhejiang, and Anhui each bringing their own strengths. The release of the outline provides strategic positioning and policy assurance for the coordinated development of the YRDR, and also proposes requirements for the logistics and economy of the YRDR. The outline addresses the problem of unbalanced and insufficient development, promotes coordination and the economy in the YRDR, enhances the coupling and coordination of the two, and promotes the sustainable development of the YRDR through common prosperity.

This paper takes the YRDR as the object, constructs the evaluation index system of the logistics industry and regional economy in the YRDR, based on the evaluation index data of 41 cities in the YRDR in 2010, 2015, and 2020, uses the coupling coordination degree model and the spatial autocorrelation analysis model, empirically analyzes the coupling and coordination of logistics industry and economy in each city in the region and the relationship between the influence of each other. On the basis of data analysis, the mechanism of the coordinated development of logistics and regional economy in the YRDR is elaborated, the influencing factors for improvement are identified, and the influence of different percentages of the logistics industry and economy on the coupling coordination degree in cities of different development levels in the YRDR is further explored, and whether the joining of Anhui Province in the YRDR brings positive influence on the coupling and coordination degree of the logistics industry and economy in three provinces and one city, hoping to provide a decision basis for cities with different development levels in improving the coupling and coordination degree of the urban logistics industry and economy, and put forward policy suggestions based on index weights, which are of great practical significance in promoting the coordinated and sustainable development of logistics and regional economy in the YRDR.

In terms of theoretical value, the discussion of the coefficients to be determined in the coordination index expands and improves the existing research, fills the gaps in the existing literature, and provides theoretical references for scholars; in terms of practical value, this paper adopts targeted strategies for cities at different levels of development to improve the coordination of logistics industry and economy, and empirical analysis of regional integration development strategy, which can provide a reference for policy practice of countries around the world.

2. Literature Review

2.1. Study of the Relationship between Logistics Infrastructure and the Economy

Foreign scholars mostly focus on the intrinsic link between facilities and the economy. Popov et al. [5] and others describe the positive influence of logistics infrastructure development on the regional economy and quantitatively analyze the impact of warehouse location and infrastructure development according to socio-economic indicators. Gafurov et al. [6] argue that infrastructure such as regional logistics centers can effectively improve logistics and transportation conditions, improve logistics efficiency, and increase regional economic benefits. Tally [7] constructed a model to study the link between transport infrastructure and economic production, showing that economic production affects transport infrastructure investment while, in turn, affecting economic production. Wang [8] researched the relationship between port logistics cluster effects and economic development using a gray correlation model. Varnavskii [9] analyzed the key factors in logistics transport progress and infrastructure development in the context of economic globalization and found that the importance of seaports is increasing. Wang C et al. [10] conducts research investigating whether or not the port integration would be able to realize the coordinated development between the port cluster and its hinterland economic system more smoothly. Kim et al. [11] found through the analysis of port logistics development in Korea that port logistics can create added value to trade and expand regional employment. Andres A-T et al. [12] studied the input-output of the port of Cartagena and found that cargo volume has a large impact on the local economy. Domestic scholars have conducted some research using quantitative analysis. Liu [13] found that the condition of the transportation infrastructure affects regional logistics and thus regional economic development. Xin [14] and others believe that perfect infrastructure construction can promote the logistics exchange of bilateral countries and enhance the competitiveness of national trade. Wang [15] used a model to demonstrate the positive spillover effect of it on the economy and the differences that exist between regions. Kou [16] showed that the logistics infrastructure can promote the adjustment of the industrial structure to a tertiary industry by simulating and optimizing the regional logistics system in Heilongjiang Province. Wang [17] considered the logistics operational mode, industrial structure, and transportation network as the main factors influencing port logistics and the economy. Through an empirical analysis, Yang [18] argued that freight volume is the main factor influencing the coordinated development quality of logistics and the economy in inland port cities of the country.

From the above literature, it is known that the construction of logistics infrastructure can improve logistics efficiency and freight volume and create trade-added value, thus increasing regional economic benefits, while promoting the adjustment of industrial structure to the tertiary industry and increasing employment, which provides theoretical support for the construction of the subsequent part of evaluation indexes.

2.2. The Interrelationship between Logistics and Economic Development

Preliminary studies by domestic and international scholars focus on qualitative studies from a macro perspective. Donald [19] et al. pointed out the two-way interactive influence relationship between the two variables by comparing supply chain logistics operation modes and development trends in different regions. Huang [20] et al. found a strong link between logistics and economic development through a study of 26 hotspot economic regions and logistics development. Nguyen C D T [21] et al. analyzed the role of logistics factors in positively influencing the economy after Vietnam's accession to the WTO. Popkova E G [22] et al. suggest that the digital economy can bring new opportunities to

Russian logistics and that the use of digital technologies will be key to the logistics industry's progress in Russia, Eastern Europe, and Asia. Wang [23] believes that the regional logistics capacity and regional economy promote each other. Chen [24] et al. reveal that upgrading the industrial structure is closely correlated with the high-quality growth of regional logistics in China. Ju [25] et al. studied the connection between China's regional logistics industry and the economy, highlighting the dominant factors affecting both and making suggestions that are conducive to the smooth progress of logistics in the west.

Recently, scholars' research tends to be quantitative. Skjott-Larsen [26] and others empirically analyzed and demonstrated the pulling effect of the logistics industry on regional economic development. Ma [27] studied the relationship between international trade and logistics development based on entropy and the gravity model. Jiang [28] analyzed the key factors affecting economic and logistics development using the grey DANP model. Through a multi-year panel data study of 34 countries, Zheng [29] et al. analyzes the current situation of manufacturing and logistics efficiency, presents a way to improve the linkage efficiency of the manufacturing and logistics industry, and use Tobit regression to analyze the environmental factors that affect the linkage efficiency. Pablo [30] et al. found that the improvement of logistics micro-performance indicators has an obvious influence on the technical efficiency improvement of regional economic output. Through a study of panel data from thirty provinces, Chu Z F [31] et al. showed that logistics investment has a significant contribution to economic growth. Hooi Hooi Leana [32] The dynamic structure model is introduced to deeply analyze and discuss the correlation between economic growth and logistics. The conclusion is that economic growth drives the continuous improvement and optimization of logistics services, and makes the logistics industry develop rapidly. The relationship between the two is complementary. In other words, economic growth creates an environment for the development of the logistics industry, while the logistics industry improves the income level of urban residents, which in turn promotes economic growth. Li [33] used a spatial econometric model to empirically demonstrate that logistics industry agglomeration can accelerate the speed of economic growth and improve the efficiency of operation, showing that it has the greatest impact on the tertiary industry. Yue [34] used a gray correlation model to empirically show that a mutually reinforcing relationship exists between logistics industry development and economic growth in Shanxi Province, and that this mutually reinforcing effect is more significant when the scale and efficiency of logistics are improved and the economic structure is optimized. Yang [35] et al. established a system dynamics model using Beijing and Guangzhou as examples and found that regional logistics was positively correlated with local economic development. Li [36] used the DEA-BCC model to measure the operational efficiency of the logistics industry in the YEDR, concluding that the scale reward of the logistics industry exhibited a development trend of first increasing and then decreasing, and analyzed the existence of a long-term mutual promotion relationship between these two factors.

Both domestic and foreign literature show that there is a two-way positive correlation between the logistics industry and the economy, logistics investment can promote economic growth, and economic growth will increase the demand for logistics services, thus driving the development of the logistics industry, which has laid a solid foundation for the study of coordinated development of logistics and the economy.

2.3. Research on the Coordinated Development of Logistics and the Economy

As regards macroscopic aspects, Peter and Catherine [37] argue that there is a two-way synergistic association between regional economic agglomeration development and regional logistics clusters using relevant data from the United States. Chen [38] used the DEMATEL-Bayesian model to obtain methods and paths for the coordinated development of the logistics industry and the economy in large cities along the Road. Yang [39] et al. studied the relationship between logistics and the economy in five Chinese cities using big data and the Harken model. Song [40] calculated the synergy and synergy sensitivity and regional logistics using the entropy value method and the composite system model and concluded that the current level of synergistic development of the two is high, but their combined development is low. Yan [41] et al. analysis shows that there are great regional differences in high-quality economic development, high-quality logistics development, and their coupling coordination degree in China, the coordination between the logistics industry and high-quality economic development is poor. Zhang [42] measured 21 national logistics node cities in China based on the gray correlation method and found that the coordinated progress and economy showed a decreasing trend from the east to the middle and west. On a provincial scale, using panel data of Jiangxi Province from 2008–2017, Huang [43] et al. empirically analyzed the coupling and coordination between the regional logistics industry and regional economy and concluded that the coupling between the two is not high, but the coupling and coordination is high. He [44] used the CRITIC-DEA model to argue that there is a stage difference in coordinated development conditions in Sichuan Province with relatively stable development in the early stage and a declining trend in the later stage. Guo [45] based on the case study in Anhui Province, proposes a data-driven method that can be used to measure, evaluate, and identify the coupled and coordinated development (CCD) of the logistics industry (LI) and the digital economy (DE) in order to promote the integrated development of the LI and DE. According to the view of urban clusters, based on the data in the Silk Road Economic Belt from 2006–2015, Yang [46] et al. evaluated the coordination between the two variables using the coupled evaluation model and spatial autocorrelation model. Gao [47] et al. constructed a coupled synergy degree model to study the coupled coordination level of economic and logistics conditions in the nine interior provinces of the Pan-Pearl River Delta, and analyzed its changes and characteristics based on a time-series and spatial perspective. Guo [48]. In order to improve the reliability and validity of the research conclusions, in this study, the coupling degree model is introduced to deeply discuss the correlation between the regional logistics and regional economic development of YRDR in the period from 2001 to 2016, indicating that the level of that between the two systems has been increasing and is currently at an intermediate stage.

Through the methods in the literature, we understand the coordinated development of the regional logistics industry and economy of different research objects, analyze their changes and characteristics, it has made corresponding reserves for determining the research object, the research method of coordinated development, and finding the method and path of coordinated development of logistics and economy.

2.4. Research on the Impact of Logistics on Sustainable Economic and Social Development

Lan [49] considers the coordinated development of logistics and the economy to be an important path to achieving sustainable economic development, and the level of development of the logistics industry and the economy itself is a dominant factor affecting the coordinated development of that and the economy. Aimovi [50] researched the influence of logistics activities on the sustainability of urban systems and the lives of residents, concluding that urban logistics management is critical to the sustainability of urban systems and the impact on the daily operations of urban residents. Cherenkov V I [51] et al. revealed the important role of logistics in the sustainable development of the Russian Arctic. Basarab [52] studied the influence of the quality of logistics industry development on sustainable economic development in 42 countries using an econometric model and found that logistics industry infrastructure, platform operations, and logistics performance improvement contribute to sustainable economic development. Rudra P. Pradhan [53] used the vector error correction model to prove that the expansion of transportation infrastructure is the main factor stimulating India's economic growth, and the introduction of appropriate policies to promote the construction of transportation infrastructure is an effective path to realizing the sustainable growth of India's economy. Khan S [54] et al. found that green logistics has a positive impact on social and environmental sustainability in SAARC countries and the economic development quality of the country. Using Wuhan as an example, Liu [55] et al. empirically analyzed the synergistic relationship to their use of the marginal and elasticity theory, demonstrating the importance of the proper planning and management of the logistics industry to promote sustainable progress of the regional economy. Chen [56] established the development of the modern logistics industry on the basis of sustainable economics and combined this with the circular economy model, elucidating the sustainable development association of the circular economy and green logistics and proposing countermeasures for sustainable development.

Su [57] evaluates the ecological efficiency of the logistics industry (LEE) and manufacturing industry (MEE) in the YRDR from 2006 to 2019 by using the unexpected slacks-based measure (SBM) model, considers the coupling coordination of the logistics industry and manufacturing industry conducive to the sustainable development of logistics and manufacturing and the stability of sustainable supply chain. In order to understand the status of regional sustainable development in China, Tian [58] studied the level of coordinated development of regional logistics and the ecological environment and determined which variables will affect their coordinated development. In order to promote the sustainable and coordinated development of the logistics industry and the manufacturing industry in the Yangtze River Economic Belt of China, Gong [59] explored the spatio-temporal evolution of the coupling coordination development level of the two industries; the results show that the overall level of the coordination between the two industries was at a stage of limited coordination, the regional differences were significant, environmental factors affected the input efficiency of the logistics industry and the manufacturing industry.

According to the latest research results of scholars, some new ideas have been drawn. The integration of logistics infrastructure can effectively improve the coupling and coordination of its hinterland economic system; the upgrading of industrial structure is closely related to the high-quality growth of regional logistics; while vigorously improving the high-quality level of the logistics industry, it should strengthen the high-quality connection between the logistics industry and the economy, so as to form a situation of mutual promotion and common development; the coupling and coordination of logistics industry and the economy are conducive to the sustainable development of both. These findings are important inspirations for this paper, sustainable economic development is a goal, and the coordinated development of logistics and economy is an important path to achieve this goal, there are differences in the factors influencing the degree of coordination between the logistics industry and the economy in different regions, so we should conduct targeted analysis and adopt localized and coordinated development strategies, which can be detailed in the planning and management of logistics activities, improvement of logistics infrastructure, etc. Especially for the regions where the gap between the coupling and coordination of the logistics industry and the economy is relatively large, this is a problem to be solved, and the answer is also in the problem, only by making targeted adjustments in some specific indicators, the coupling and coordination of logistics industry and economy can be improved and the "common wealth" among regions can be realized.

3. Methodology

To understand the hierarchical classification, distribution, and aggregation characteristics of the coupling coordination degree of the studied object, exploring the influence of the different percentages of the logistics industry and economy in cities of different development levels in the YRDR on the coupling coordination degree, and the influence of the later joined provinces on the coupling coordination degree of the regional logistics industry and economy in themselves and the original provinces, we try to study the coupling coordination of the logistics industry and the economy in each city of the YRDR with the coupling coordination degree model and the spatial autocorrelation analysis model, so as to prepare the data for further analysis afterward, and the steps and formulas of the model are listed as follows.

3.1. Entropy Value Method to Determine the Index Weights

In order to more objectively describe and effectively reflect the weight values of the respective indicators of the two relatively independent subsystems of the logistics industry and regional economy, the entropy method was chosen as the evaluation method as it avoids the influence of human subjectivity, i.e., it is an objective calculation method. Its specific calculation steps are as follows: the original data matrix $X = \left(X_{ij}\right)_{m\times n}$ of the $j(j=1,\ 2,\ \cdots,\ n)$ evaluation index of the $i(i=1,\ 2,\ \cdots,\ m)$ evaluation object is dimensionless, therefore obtain the normalization matrix $Y = \left(Y_{ij}\right)_{m\times n}$, and calculate the proportion of Y_{ij};

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}} \quad (1)$$

Then, determine the entropy e_j, information utility value d_j of the j indicator:

$$e_j = -\frac{1}{lnm}\sum_{i=1}^{m} p_{ij} ln p_{ij} \quad (2)$$

$$d_j = 1 - e_j \quad (3)$$

Thereafter, determine the weight w_j of the j:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \quad (4)$$

3.2. Coupling Coordination Degree Model

To better evaluate the strength of the interaction of the logistics industry and the regional economy, but also to reflect the overall effect of that, the coupling coordination degree model was used to study the strength of coordination of the two. Let U_1 and U_2 denote the calculated values of the evaluation indexes of the logistics industry and regional economic progress level of any city, respectively. This is also known as orderliness as it describes the contribution of different order parameters to orderliness, as shown in Equation (5):

$$U_x = \sum_{j=1}^{m}\left(w_j * Y_j\right) \quad (5)$$

Let C be the coupling level, and use the orderliness of the logistics industry and regional economy in Equation (5) to express the intensity of interaction between the logistics industry and regional economy, as shown in Equation (6):

$$C = 2 * \sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \quad (6)$$

The index C in Equation (6) reflects the relatively static coupling coordination state between the systems. Considering the growth and evolution level of the system, to prevent the phenomenon of "pseudo-coordination", the T is proposed to calculate the index D. The coupling coordination degree D characterizes the development level of dynamic coupling between systems, as shown in Equation (7):

$$D = \sqrt{T \times C} \quad (7)$$

The coordination index T in Equation (7) reflects the overall development level influence of the two systems on the coordination index, as shown in Equation (8):

$$T = \alpha U_1 + \beta U_2 \quad (8)$$

In Formula (8), α and β are coefficients to be determined, and in the study of the basic development of that of the 41 cities in the YRDR, the logistics industry is considered to be of basically equal importance to the regional economy, taking $0.4 \leq \alpha$ and $\beta \leq 0.6$.

According to the derivation of the coupling coordination degree in Equation (7), the greater the $D \in [0,1]$, the greater the D, and the development level of coupling coordination between the regional logistics and the economic system. The smaller the D, the lower the development level of the coupling coordination between the two.

3.3. Spatial Autocorrelation Analysis Model

(1) Global spatial autocorrelation analysis

This model describes the overall spatial distribution of attribute value in the region, and determines whether the attribute value has aggregation characteristics in space. A commonly used global metric to measure spatial autocorrelation is the I index, while the formula for the global spatial autocorrelation index is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}\left(D_i - \overline{D}\right)\left(D_j - \overline{D}\right)}{s^2 \sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}} \tag{9}$$

where $S^2 = \frac{1}{n}\sum_{j=1}^{n}\left(D_i - \overline{D}\right)^2$; D_i and D_j refer to the coupling coordination level of cities i and j of the YRDR, respectively; n means samples number; w_{ij} corresponding to the spatial weight matrix between study objects i and j.

When I is greater than zero, the whole region is positively correlated, and the larger I is, the higher the degree of positive correlation. This shows that cities with high coupling coordination between the two are clustered together in spatial distribution, and cities with low coupling coordination between the two are clustered together in spatial distribution. On the contrary, cities with a high coupling coordination level between the logistics industry and the regional economy tend to gather together with cities with a lower level, showing a spatially dispersed distribution.

(2) Local spatial autocorrelation analysis

This model is used to reflect the similarity of impact values of neighboring or adjacent spatial units after this analysis, which is the decomposition of the global autocorrelation Moran's I index to each regional unit. The formula of the local autocorrelation index is as follows:

$$I_i = \frac{D_i - \overline{D}}{s}\sum_{j=1}^{n} w_{ij}\left(D_j - \overline{D}\right) \tag{10}$$

The significance of the variables shown in Equation (10) is the same as those shown in Equation (9) and is usually reflected by a Moran scatter plot. Moran scatter diagrams classify spatial association patterns into four types, positive spatial associations include spatial units with above-average attribute values surrounded by neighbors with above-average attribute values (i.e., "high-high" associations) and spatial units with below-average attribute values surrounded by neighbors with below-average attribute values (i.e., "low-low" associations). There are also two types of negative spatial associations, i.e., spatial units with attributes above the mean are surrounded by neighbors with attributes below the mean (i.e., "high-low" associations), or spatial units with attributes below the mean are surrounded by neighbors with attributes above the mean (i.e., "low-high" associations). These four types correspond to each of the four quadrants of the Moran scatter plot.

4. Results

4.1. Indicator Evaluation Index Construction

After referring to a large amount of literature and considering the specific situation of the YRDR, we selected the logistics evaluation indexes and the regional economic evaluation index systems as shown in Tables 1 and 2.

Table 1. Logistics industry evaluation index system.

System	Tier 1 Indicators	Secondary Indicators	Unit
Logistics industry evaluation indicators	Shipping Scale	A1 Road mileage	km
		A2 Road mileage	(billion tons km)
		A3 Passenger traffic	10,000 people
		A4 Civilian freight vehicle ownership	Vehicle
	Logistics Resources	A5 Transportation financial expenditure	million yuan
		A6 Transportation, storage, and postal workers	People
		A7 Total postal business	Billion
		A8 Number of mobile phone users	10,000 households

Table 2. Regional economic evaluation index system.

System	Tier 1 Indicators	Secondary Indicators	Unit
Regional Economic Evaluation Indicators	Economic Scale	B1 GDP	Billion
		B2 Total retail sales of social consumer goods	Billion
		B3 GDP per capita	Yuan
		B4 Disposable income per capita	Yuan/person
	Economic Potential	B5 Value added of tertiary industry	Billion
		B6 Local revenue	Billion
		B7 Import and export volume	Billions of dollars
		B8 Total social fixed asset investment	Billion

4.2. Entropy Value Method to Calculate Weights

(1) Raw data

The original data of each city indicator system were obtained from Shanghai, Jiangsu, Zhejiang, Anhui Statistical Yearbook in 2010, 2015, and 2020.

(2) Results of entropy value method calculation

The values of the weights of each indicator for each year were calculated for the raw data in Table 3 according to Equations (1)–(4), as Table 3.

Table 3. Evaluation index weights of the coordinated development of the regional logistics system and economic system.

	A1	A2	A3	A4	A5	A6	A7	A8	B1	B2	B3	B4	B5	B6	B7	B8
2010	0.032	0.364	0.062	0.102	0.101	0.175	0.073	0.091	0.114	0.156	0.263	0.165	0.115	0.053	0.050	0.085
2015	0.027	0.284	0.061	0.109	0.111	0.202	0.124	0.082	0.121	0.145	0.254	0.182	0.118	0.062	0.048	0.072
2020	0.027	0.299	0.064	0.098	0.135	0.155	0.113	0.108	0.121	0.144	0.178	0.171	0.118	0.158	0.048	0.061

According to the result in Table 3, the value of A2 (freight turnover) can reach approximately 0.3 each year, and the value of A6 is approximately 0.2 each year. This shows that the two indicators have a greater positive influence on the logistics industry's progress. Among the values of regional economic evaluation index weights, B3 (GDP per capita) and B4 are weighted at approximately 0.2 each year, indicating the importance of the regional output creation level and disposable income per capita on the regional economic impact.

4.3. Coupling Coordination Degree Measurement and Result Analysis

(1) Coupling coordination degree level classification

In the specific study, since the calculation results of coordination degree are mainly within the range of [0, 1], in order to better describe the coordination degree of the two systems and facilitate readers' understanding, it is divided into ten coordination degrees, which refer to one class of the synergy state, in accordance with relevant research results. The specific division criteria are shown in Table 4.

Table 4. Classification criteria for the level of coupling coordination.

Coupling Coordination	Coupling Coordination Level	Coupling Coordination	Coupling Coordination Level
0–0.1	Extreme disorder	0.5001–0.6	Barely Coordinated
0.1001–0.2	Severe disorders	0.6001–0.7	Primary Coordination
0.2001–0.3	Moderate disorder	0.7001–0.8	Intermediate Coordination
0.3001–0.4	Mild disorders	0.8001–0.9	Good Coordination
0.4001–0.5	On the verge of disorder	0.9001–1	High-quality Coordination

(2) Analysis of the coupling coordination level result

From Equations (5)–(8), α and β in Equation (8) are taken as 0.5, and the coupling coordination degree D between the two variables of the 41 cities in that region for each year can be calculated, as shown in Table 5 and Figure 1.

Table 5. Statistics on the results of coupling coordination in the YRDR.

	2010	2015	2020
0–0.1 extreme disorder	None	None	None
0.1001–0.2 Severe disorders	Maanshan 0.167, Tongling 0.175, Chizhou 0.141, Huainan 0.197, Huangshan 0.138, Bozhou 0.183, Huaibei 0.145, Suzhou 0.195	Tongling 0.131, Chizhou 0.143, Huangshan 0.151, Huaibei 0.163	Maanshan 0.183, Tongling 0.125, Chizhou 0.161, Huangshan 0.152, Huaibei 0.136
0.2001–0.3 Moderate disorder	Huaian 0.278, Suqian 0.222, Zhoushan 0.296, Quzhou 0.278, Lishui 0.241, Wuhu 0.267, Anqing 0.236, Chuzhou 0.221, Xuancheng 0.207, Fuyang 0.218, Bengbu 0.205, Anqing 0.234	Suzhou 0.211, Huaian 0.27, Zhenjiang 0.284, Suqian 0.247, Quzhou 0.229, Lishui 0.205, Maanshan 0.229, Anqing 0.228, Chuzhou 0.225, Xuancheng 0.226, Huainan 0.219, Fuyang 0.247, Bozhou 0.201, Bengbu 0.236, Liu'an 0.225	Suzhou 0.232, Yangzhou 0.296, Lianyungang 0.245, Huaian 0.265, Zhenjiang 0.233, Suqian 0.22, Zhoushan 0.294, Quzhou 0.205, Lishui 0.201, Anqing 0.236, Xuancheng 0.206, Huainan 0.211, Fuyang 0.266, Bozhou 0.234, Bengbu 0.219, Liu'an 0.236
0.3001–0.4 Mild disorders	Nantong 0.393, Yangzhou 0.309, Lianyungang 0.326, Taizhou 0.303, Yancheng 0.324, Zhenjiang 0.305, Xuzhou 0.373, Huzhou 0.341, Jiaxiing 0.362, Hefei 0.392	Changzhou 0.365, Yangzhou 0.318, Lianyungang 0.305, Taizhou 0.317, Yancheng 0.336, Xuzhou 0.37, Taizhou 0.376, Huzhou 0.361, Jiaxing 0.349, Jinhua 0.37, Zhuoshan 0.318, Wuhu 0.306	Changzhou 0.339, Taizhou 0.314, Yancheng 0.318, Shaoxing 0.38, Huzhou 0.347, Jiaxing 0.325, Jinhua 0.394, Wuhu 0.306, Chuzhou 0.308
0.4001–0.5 On the verge of disorder	Changzhou 0.401, Shaoxing 0.412, Taizhou 0.405, Jinhua 0.41, Wenzhou 0.454	Wuxi 0.471, Nantong 0.401, Shaoxing 0.41, Wenzhou 0.441, Hefei 0.441	Wuxi 0.425, Nantong 0.409, Xuzhou 0.414, Taizhou 0.4, Wenzhou 0.447
0.5001–0.6 Barely coordinated	Nanjing 0.55, Wuxi 0.504, Hangzhou 0.563, Ningbo 0.519	Nanjing 0.536, Hangzhou 0.581, Ningbo 0.509	Nanjing 0.577, Suzhou 0.537, Ningbo 0.524, Heifei 0.553
0.6001–0.7 Primary Coordination	Suzhou 0.63	Suzhou 0.618	Hangzhou 0.624
0.7001–0.8 Intermediate Coordination	None	None	None
0.8001–0.9 Good Coordination	None	None	None
0.9001–1 Quality Coordination	Shanghai 0.968	Shanghai 0.968	Shanghai 0.933

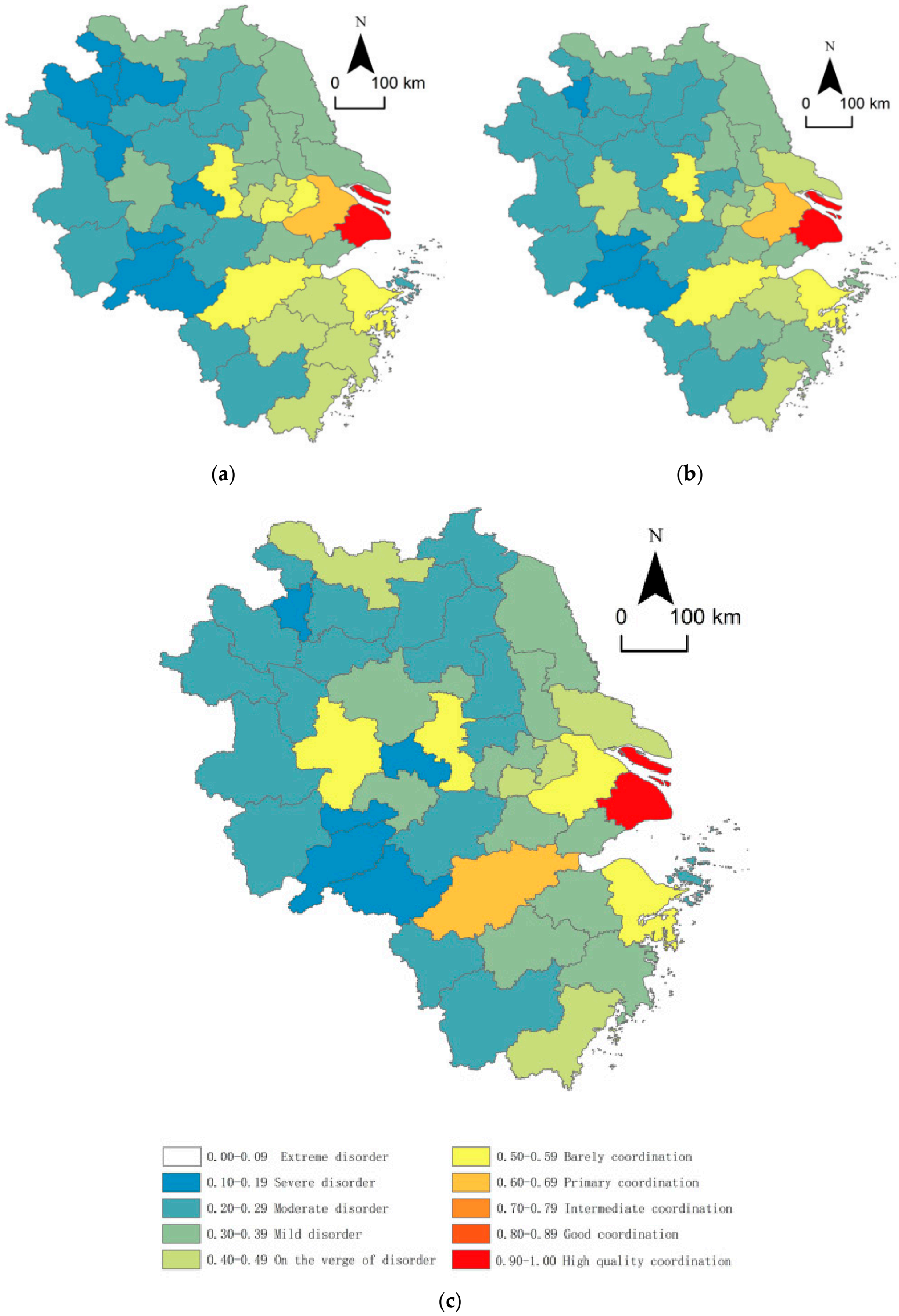


Figure 1. Spatial and temporal evolution of the coupling coordination between the logistics industry and the economy in the YRDR. (**a**) The 2010 spatial and temporal evolution of annual coupling coordination; (**b**) The 2015 spatial and temporal evolution of annual coupling coordination; (**c**) The 2020 spatial and temporal evolution of annual coupling coordination.

In order to facilitate the spatio-temporal evolutionary characterization, the coupled coordination levels in 2010, 2015, and 2020 were visually depicted. On the basis of Tables 4 and 5, the ArcGIS software was used to plot Figure 1.

From the above chart, we can see that none of the 41 cities were in a state of 0–0.09 extreme disorder, indicating that the interaction between the logistics industry and the regional economy in that region is generally in a state of coordinated development. By Suzhou and Hangzhou two cities after the primary coordination across two levels before the emergence of high-quality coordination of Shanghai, we can see that there is still a large gap between the cities, but also shows that the 40 cities other than Shanghai logistics industry in coordination with each other has a huge room for improvement. Comparing the coupling coordination data between 2015 and 2020, it was found that the coupling coordination in 2020 was not as high as in 2015 because the logistics and economic development of certain cities were hindered by the COVID-19 epidemic; however, it can be seen that the difference between the 2015 and 2020 value was not large and remained in a stable coupled and coordinated state, indicating that the interaction and coordinated development of the logistics industry and the regional economy in that region is very resilient and will not fluctuate massively due to external factors.

Through the level (Table 5) and distribution (Figure 1) of the coupling coordination degree of the studied objects, we need to further understand the agglomeration dynamics, spatial agglomeration distribution pattern, and the agglomeration type to which each city belongs respectively, in order to propose suitable countermeasures for the coordinated development of the logistics industry and the regional economy in the YRDR.4.4. Spatial autocorrelation analysis of the coupling coordination degree.

(1) Global spatial autocorrelation analysis

According to Equation (9), Moran's I values of coupling coordination between the logistics industry and the regional economy in the YRDR in 2010, 2015, and 2020 were calculated using the GeoDa v1.20 software, as shown in Table 6.

Table 6. Global Moran's I values of coupling coordination between the logistics industry and the regional economy in the YRDR in 2010, 2015, and 2020.

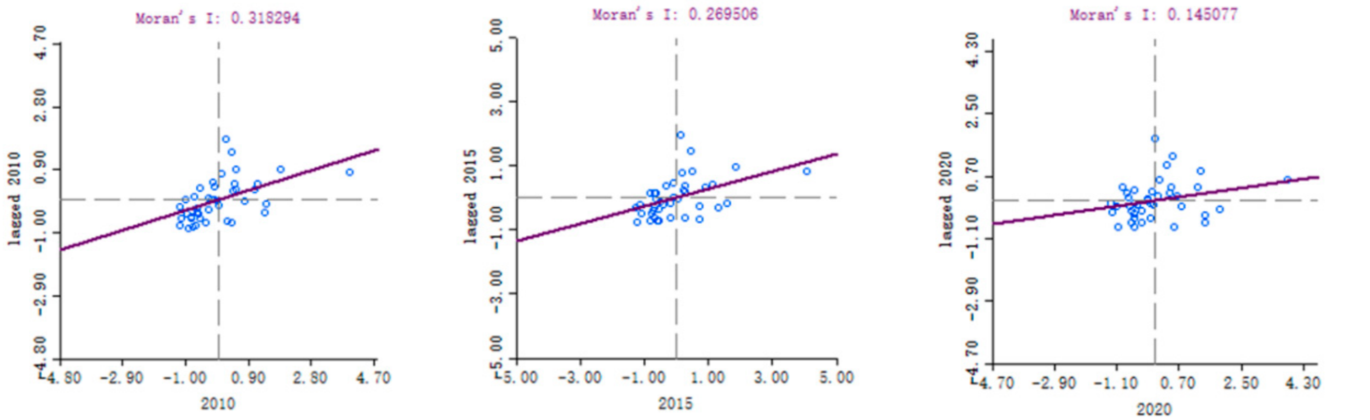
Year	2010	2015	2020
Moran's I value	0.319	0.270	0.145

From Table 6, we can see that the I values for all three years were positive, reflecting that cities with a high coordination degree between the logistics industry and the regional economy cluster with each other and cities with a lower coordination cluster degree with each other. The overall Moran's I value tended to decrease, implying that, with the difference in the development rate of each city, the density of mutual agglomeration among cities with high coordination and low coordination was gradually decreasing, and the degree of regional agglomeration tended to be balanced.

(2) Local spatial autocorrelation analysis

The I values were calculated according to Equation (10) and the scatter plots and distributions of coupling coordination in 2010, 2015, and 2020 were obtained, as shown in Figure 2 and Table 7.

From Figure 2 and Table 7, we can see that in the I quadrant, Suzhou and Ningbo exhibited well-developed industrial and logistics industries. This is because they are adjacent to Shanghai, and are surrounded by Wuxi, Nantong, Changzhou, Taizhou, and other cities with a high coupling coordination degree between logistics and the regional economy, thus they belong to the "high-high" aggregation type. The interaction between Hangzhou, Nanjing, Hefei, Wenzhou, Xuzhou, and other cities in quadrant IV, which have a high degree of that between the logistics industry and the regional economy, and the surrounding cities with a low degree of that between the logistics industry and the regional economy, is not obvious, thus they belong to the "high-low" aggregation type. Yangzhou, Zhenjiang, Taizhou, Lishui, Xuancheng, Zhoushan, and Maanshan are located in quadrant II. Although these cities are adjacent to cities with a high D, they are not significantly driven, thus they belong to the "low-high" aggregation type. Lianyungang, Huai'an, Wuhu, Chuzhou, Suqian, and a dozen other cities are located in quadrant III, which is significantly more than in other quadrants. There are significantly more cities in the main northern Jiangsu region and Anhui Province, approximately 1/4 and 3/4 of cities, respectively, and these cities are limited in terms of resources and geographical conditions and are subject to less radiation, thus they belong to the "low-low" aggregation type. More than 80% of the cities in the region exhibit very obvious spatial locking as regards the coordination, and the coupling and coordination degree exhibits a "Matthew effect", decreasing from the southeast to the northwest with obvious hierarchical heterogeneous spatial clustering. This is not conducive to the coupled and coordinated progress of the logistics industry and the regional economy in the YRDR.



(**a**) (**b**) (**c**)

Figure 2. Local Moran's I scatter plot of the coupling coordination between the logistics industry and the regional economy in the YRDR.

Table 7. Local Moran's I distribution of coupling coordination between the logistics industry and regional economy in the YRDR in 2010, 2015, and 2020.

	First Quadrant	Quadrant II	Quadrant III	Quadrant IV
2010	Shanghai, Suzhou, Ningbo, Wuxi, Nantong, Changzhou, Shaoxing, Jiaxing, Huzhou, Taizhou, Jinhua	Ynagzhou, Zhenjiang, Taizhou, Lishui, Xuancheng, Hengzhou, Zhoushan, Maanshan	Yancheng, Lianyungang, Huai'an, Wuhu, Chuzhou, Suqian, Liu'an, Anqing, Huainan, Suzhou, Tongling, Chizhou, Huaibei, Bengbu, Bozhou, Fuyang, Huangshan	Hangzhou, Nanjing, Hefei, Wenzhou, Xuzhou
2015	Shanghai, Suzhou, Ningbo, Wuxi, Nantong, Changzhou, Shaoxing, Jiaxing, Huzhou, Taizhou, Jinhua	Yangzhou, Zhenjiang, Taizhou, Lishui, Xuancheng, Zhoushan, Maanshan	Quzhou, Lianyungang, Huai'an, Wuhu, Chuzhou, Suqian, Liu'an, Anqing, Huainan, Suzhou, Tongling, Chizhou, Huaibei, Bengbu, Bozhou, Fuyang, Huangshan	Hangzhou, Nanjing, Hefei, Wenzhou, Xuzhou, Yancheng
2020	Shanghai, Suzhou, Ningbo, Wuxi, Nantong, Changzhou, Shaoxing, Huzhou, Taizhou, Jinhua	Yangzhou, Zhenjiang, Taizhou, Lishui, Xuancheng, Zhoushan, Maanshan	Yancheng, Lianyungang, Huai'an, Wuhu, Chuzhou, Suqian, Liu'an, Anqing, Huainan, Suzhou, Tongling, Chizhou, Huaibei, Bengbu, Bozhou, Fuyang, Huangshan	Hangzhou, Nanjing, Hefei, Wenzhou, Xuzhou

By using the coupling coordination degree model and spatial autocorrelation model, the degree of coupling coordination between the logistics industry and the regional economy of 41 cities in YRDR from 2010 to 2020 is measured, and its temporal evolution characteristics and spatial variation characteristics are visualized and analyzed. The results show that: ① from 2010 to 2020, the overall coupling and coordination level between the logistics industry and the regional economy of the YRDR has improved, and the coupling and coordination situation has been improving, but the gradient difference in the coordination degree is still relatively significant. ② The spatial clustering pattern of the coupling and coordination between the logistics industry and the regional economy in the YRDR in 2010, 2015, and 2020 remains basically unchanged, with slightly decreasing spatial autocorrelation and still obvious heterogeneity of the spatial clustering distribution pattern. Next, we study the effects of the direct parameters logistics industry orderliness U1, regional economic orderliness U2, and the addition of Anhui province that causes their changes on the coupled logistics industry-economy coordination in YRDR according to the derivation process of the coupling coordination degree model in Section 3.2.

4.4. Analysis of the Variation of Coupling Coordination by Region

Through the calculation of the coupling coordination degree of the logistics industry and economy in the cities of YRDR with different percentages, the differences in the influence of the two on cities with different levels of economic development respectively, as well as the influence of cities in Anhui Province joining the YRDR one after another on the coupling coordination degree of the logistics industry and regional economy in Jiangsu Province and Zhejiang Province, provide theoretical support to improve the coupling coordination degree of the logistics industry and regional economy in the YRDR and promote the high-quality and sustainable development of commonwealth in the YRDR, which is also the main innovation point of this paper.

4.4.1. Analysis of the Calculation Results of Different Percentages of the Two Indicators

To understand the influence of different percentages of the logistics industry and the economy on the coupling coordination level of the YRDR cities themselves, and to offer a reference basis for each city to develop regional logistics industry and economy in a targeted manner, in calculating the coordination index T, the coupling coordination results were calculated and compared between logistics industry and the economic evaluation index in two cases, A and B respectively (A: 0.4 for logistics and 0.6 for the economy, B: 0.6 for logistics and 0.4 for economy), See Table 8.

According to the result in Table 8, the regional economic development of 21 cities, including Shanghai, Nanjing, Wuxi, Yangzhou, Zhenjiang, Ningbo, Taizhou, Hefei, Wuhu, and Tongling, exerted more influence on the improvement of their coupling coordination than the development of the logistics industry. Yancheng, Huai'an, Lianyungang, Xuzhou, Suqian, Huzhou, Quzhou, Lishui, Anqing, Chuzhou, Xuancheng, Chizhou, Huainan, Huangshan, Fuyang, Bozhou, Liu'an, Suzhou are the 20 cities in which the logistics industry development level was shown to exert more influence on their coupling coordination than regional economic development. In general, it can be concluded that, for economically developed cities, it is more beneficial to focus on improving the coupling coordination between the urban logistics industry and the regional economy by vigorously developing the regional economy, while for the less economically developed cities, it is more effective to promote the logistics industry progress than to strengthen the economic construction.

4.4.2. Analysis of the Change in Coupling Coordination among Three Provinces and One City after Anhui Province Joined the YRDR

(1) Changes in the coordination of the logistics industry and economic coupling in Jiangsu, Zhejiang cities after Anhui Province joined the YRDR.

In 2009, Anhui attended the symposium of major leaders in that region and the joint meeting on cooperation in the YRDR as a full member. In 2010, Hefei and Maanshan joined the YRDR "circle of friends". In 2013, Wuhu, Chuzhou, and Huainan became full members. In 2018, the Yangtze River Delta City Economic Coordination Council accepted Tongling, Anqing, Chizhou, and Xuancheng as members. Finally, in 2019, Bengbu, Huangshan, Lu'an, Huabei, Suizhou, Bozhou, Fuyang officially became members of the city economic coordination council, so that all 16 prefecture-level cities in Anhui joined the YRDR one after another during the time period. The changes in the development of the coupling and coordination between the logistics industry and the economy of each city in Jiangsu, Zhejiang, and Shanghai can be seen in Table 9.

Table 8. Logistics industry and regional economic indicators of different percentages of the calculation results of statistics.

Economy 0.6, Logistics 0.4 (A)	2010	2015	2020	Economy 0.6, Logistics 0.4 (B)	2010	2015	2020	Contrast
Shanghai	0.973	0.974	0.927	Shanghai	0.963	0.963	0.938	A > B
Nanjing	0.555	0.547	0.575	Nanjing	0.544	0.524	0.539	A > B
Wuxi	0.514	0.486	0.433	Wuxi	0.494	0.456	0.416	A > B
Changzhou	0.406	0.381	0.349	Changzhou	0.395	0.349	0.329	A > B
Suzhou	0.651	0.64	0.556	Suzhou	0.61	0.594	0.518	A > B
Nantong	0.397	0.414	0.425	Nantong	0.389	0.388	0.393	A > B
Yangzhou	0.314	0.328	0.307	Yangzhou	0.305	0.307	0.285	A > B
Zhenjiang	0.312	0.299	0.243	Zhenjiang	0.298	0.269	0.223	A > B
Taizhou	0.307	0.324	0.314	Taizhou	0.3	0.309	0.313	A > B
Yancheng	0.322	0.341	0.318	Yancheng	0.326	0.331	0.319	A < B
Huai'an	0.272	0.27	0.265	Huai'an	0.283	0.27	0.266	A < B
Lianyungang	0.316	0.299	0.239	Lianyungang	0.335	0.311	0.251	A < B
Xuzhou	0.367	0.372	0.411	Xuzhou	0.379	0.369	0.417	A < B
Suqian	0.216	0.244	0.22	Suqian	0.228	0.249	0.22	A < B
Hangzhou	0.562	0.584	0.636	Hangzhou	0.564	0.578	0.612	A > B
Shaoxing	0.412	0.42	0.392	Shaoxing	0.412	0.4	0.368	A > B
Ningbo	0.528	0.528	0.528	Ningbo	0.51	0.489	0.52	A > B
Taizhou	0.396	0.378	0.398	Taizhou	0.413	0.374	0.402	A > B
Huzhou	0.333	0.355	0.339	Huzhou	0.348	0.367	0.354	A < B
Jiaxing	0.369	0.36	0.343	Jiaxing	0.356	0.337	0.306	A > B
Jinhua	0.403	0.376	0.4	Jinhua	0.417	0.363	0.388	A > B
Zhoushan	0.295	0.327	0.3	Zhoushan	0.297	0.308	0.287	A > B
Wenzhou	0.445	0.443	0.447	Wenzhou	0.463	0.439	0.447	A > B
Quzhou	0.265	0.231	0.206	Quzhou	0.292	0.226	0.204	A < B
Lishui	0.236	0.203	0.2	Lishui	0.246	0.208	0.202	A < B
Hefei	0.394	0.448	0.564	Hefei	0.389	0.435	0.542	A > B
Maanshan	0.178	0.238	0.193	Maanshan	0.155	0.22	0.172	A > B
Wuhu	0.267	0.309	0.307	Wuhu	0.266	0.304	0.304	A > B
Tongling	0.177	0.141	0.131	Tongling	0.173	0.121	0.117	A > B
Anqing	0.227	0.224	0.233	Anqing	0.244	0.233	0.239	A < B
Chuzhou	0.209	0.246	0.301	Chuzhou	0.233	0.265	0.315	A < B
Xuancheng	0.199	0.225	0.2	Xuancheng	0.216	0.228	0.212	A < B
Chizhou	0.138	0.14	0.155	Chizhou	0.144	0.146	0.166	A < B
Huainan	0.19	0.21	0.195	Huainan	0.204	0.228	0.225	A < B
Huangshan	0.139	0.152	0.151	Huangshan	0.138	0.151	0.153	A < B
Fuyang	0.2	0.23	0.254	Fuyang	0.234	0.262	0.278	A < B
Bozhou	0.169	0.187	0.218	Bozhou	0.197	0.214	0.25	A < B
Bengbu	0.197	0.233	0.219	Bengbu	0.213	0.239	0.218	A < B
Liu'an	0.215	0.209	0.217	Liu'an	0.252	0.24	0.253	A < B
Huaibei	0.143	0.162	0.134	Huaibei	0.146	0.164	0.137	A < B
Suzhou	0.18	0.2	0.218	Suzhou	0.208	0.222	0.244	A < B

According to the result in Table 9, the mean value of coupling coordination between the two variables of 25 cities in Jiangsu, Zhejiang, and Shanghai decreased at a rate of approximately 0.01 per five years from 2010 to 2020, and the variance gradually increased, probably due to the successive entry of cities in Anhui Province having a slight dilution effect on that of cities in Jiangsu, Zhejiang, and Shanghai; however, the effect was not significant, thus we cannot exclude the influence of the COVID-19 epidemic in 2020. The increase in variance reflects the increase in the degree of divergence between cities in the development of coupled logistics and economic coordination.

Table 9. Changes in the coordination of the logistics industry and economic coupling in Jiangsu, Zhejiang, and Shanghai cities in the YRDR before and after the accession of Anhui Province.

City	2010	2015	2020	Difference between 2015 and 2010	Difference between 2020 and 2015
Shanghai	0.968	0.968	0.933	0	−0.035
Nanjing	0.55	0.536	0.557	−0.014	0.021
Wuxi	0.504	0.471	0.425	−0.033	−0.046
Changzhou	0.401	0.365	0.339	−0.036	−0.026
Suzhou	0.63	0.618	0.537	−0.012	−0.081
Nantong	0.393	0.401	0.409	0.008	0.008
Yangzhou	0.309	0.318	0.296	0.009	−0.022
Zhenjiang	0.305	0.284	0.233	−0.021	−0.051
Taizhou	0.303	0.317	0.314	0.014	−0.003
Yancheng	0.324	0.336	0.318	0.012	−0.018
Huai'an	0.278	0.27	0.265	−0.008	−0.005
Lianyungang	0.326	0.305	0.245	−0.021	−0.06
Xuzhou	0.373	0.37	0.414	−0.003	0.044
Suqian	0.222	0.247	0.22	0.025	−0.027
Hangzhou	0.563	0.581	0.624	0.018	0.043
Shaoxing	0.412	0.41	0.38	−0.002	−0.03
Ningbo	0.519	0.509	0.524	−0.01	0.015
Taizhou	0.405	0.376	0.4	−0.029	0.024
Huzhou	0.341	0.361	0.347	0.02	−0.014
Jiaxing	0.362	0.349	0.325	−0.013	−0.024
Jinhua	0.41	0.37	0.394	−0.04	0.024
Zhoushan	0.296	0.318	0.294	0.022	−0.024
Wenzhou	0.454	0.441	0.447	−0.013	0.006
Quzhou	0.278	0.229	0.205	−0.049	−0.024
Lishui	0.241	0.205	0.201	−0.036	−0.004
Total difference				−0.212	−0.309
Average value	0.40668	0.3982	0.38584		
Variance	0.024702	0.025093	0.025837		

As can be seen from Table 10, the coordination level of the logistics industry and economic coupling in 13 cities in Jiangsu Province in 2015 did not change much as compared with the average value in 2010, and the variance decreased by 0.0018. The mean value in 2020 was 0.02 lower and the variance was the same as compared to 2015. The overall average level of coupling and coordination between them in Jiangsu did not decrease in 2015, while the gap between cities narrowed, especially when other cities had different levels of decrease. The coupling degree of Nantong, Yangzhou, Taizhou, Yancheng, and Suqian improved, indicating that the gap between the coupling coordination between the two variables in each city in Jiangsu narrowed and the development was more balanced. By 2020, the variance of the coupling coordination between the two variables of each city in Jiangsu Province had not changed since 2015, but the mean value had significantly decreased, except for Nanjing, Nantong, and Xuzhou. Furthermore, the coupling coordination between the two variables of the other 10 cities decreased to different degrees, as compared to the situation in the previous 5 years, which indicates that the COVID-19 pandemic may have indeed had a significant effect. Generally speaking, Anhui Province joined the YRDR, which will lead to a more balanced development of the logistics industry and economic coupling coordination among cities in Jiangsu Province.

For Zhejiang Province, the mean value of that between the two variables in 11 cities decreased by 0.01 in 2015 as compared to 2010, and, in 2020, this value was the same as in 2015. However, in terms of variance, 2010, 2015, and 2020 increased continuously. This indicates that the coupling and coordination level in Zhejiang province was not affected to a great extent by Anhui joining the YRDR, that the endogenous development dynamics of each city are very different, and that the degree of divergence in the development of that degree of the logistics industry and economy is increasing.

Table 10. Changes in coordination between the urban logistics industry and economic coupling in Jiangsu and Zhejiang provinces before and after the accession of Anhui Province.

Province	Jiangsu Province			Zhejiang Province		
Year	2010	2015	2020	2010	2015	2020
Average value	0.3783	0.3722	0.3517	0.3892	0.3772	0.3765
Variance	0.0138	0.0120	0.0121	0.0099	0.0120	0.0159

(2) Changes in the degree of coordination in its own logistics industry and economic coupling after Anhui Province joined the YRDR.

From Table 11, the mean and variance of that between the logistics industry and the economy in Anhui Province increased continuously in the three years 2010, 2015, and 2020. Since 2010, when cities in Anhui Province started to join the YRDR, the majority of cities have achieved positive growth in coupling and coordination between the logistics industry and the economy, and despite the epidemic in 2020, some of them still achieved continuous positive growth, with their growth basically coinciding with the point in time when cities in Anhui Province joined the YRDR. As compared with cities in Jiangsu, Shanghai, cities in Anhui Province exhibited significantly faster improvement in terms of the coupling and coordination of the two, as evidenced by the comparison of the difference between the two in 2015 and 2010 and in 2020 and 2015. The study shows that after Anhui Province joined the YRDR, its coupling and coordination were driven by the stronger radiation of other cities in the YRDR, which further proves that the coupled and coordinated development of the logistics industry and regional economy in the YRDR highlights the role of main functional area.

Table 11. Changes in self-coupling coordination after Anhui Province joined the YRDR.

City	2010	2015	2020	Difference between 2015 and 2010	Difference between 2020 and 2015
Hefei	0.392	0.441	0.553	0.049	0.112
Maanshan	0.167	0.229	0.183	0.062	−0.046
Wuhu	0.267	0.306	0.306	0.039	0
Tongling	0.175	0.131	0.125	−0.044	−0.006
Anqing	0.236	0.228	0.236	−0.008	0.008
Chuzhou	0.221	0.255	0.308	0.034	0.053
Xuancheng	0.207	0.226	0.206	0.019	−0.02
Chizhou	0.141	0.143	0.161	0.002	0.018
Huainan	0.197	0.219	0.211	0.022	−0.008
Huangshan	0.138	0.151	0.152	0.013	0.001
Fuyang	0.218	0.247	0.266	0.029	0.019
Bozhou	0.183	0.201	0.234	0.018	0.033
Bengbu	0.205	0.236	0.219	0.031	−0.017
Liu'an	0.234	0.225	0.236	−0.009	0.011
Huaibei	0.145	0.163	0.136	0.018	−0.027
Suzhou	0.195	0.211	0.232	0.016	0.021
Total difference				0.291	0.152
Average value	0.2076	0.2258	0.2353		
Variance	0.0037	0.0054	0.0101		

5. Conclusions and Recommendations

5.1. Conclusions

The coupling coordination degree model is used to measure, classify and visualize the spatial and temporal evolution characteristics of the coupling coordination degree between the logistics industry and the regional economy in 41 cities of the YRDR from 2010 to 2020. The spatial autocorrelation analysis model was used to further understand the aggregation trend, spatial agglomeration distribution pattern, and the type of agglomeration to which each city belongs; in order to improve the current situation, analyze and explore the direction of improving the coupling and coordination between the logistics industry and the economy in the YRDR cities, a comparative analysis of the data from 2010 to 2020 found the following three results. ① For cities whose economic level is more developed, the economic development is more likely to influence the coupling coordination level of their urban logistics industry and economy, while for less developed cities, the development of logistics is more likely to drive the improvement of that degree of their urban logistics industry and economy. ② The cities in Anhui Province joined the YRDR one after another but had little impact on the coupling coordination level of the logistics industry and the economy in Jiangsu, Zhejiang, and Shanghai. Jiangsu appeared to be relatively stable and was probably influenced to a slightly greater extent by the COVID-19 epidemic in 2020. Moreover, the differences in the endogenous development dynamics of cities in Zhejiang Province will lead to an increase in the degree of divergence in the development of the logistics industry and the economy, especially in cities with more developed e-commerce such as Hangzhou, where the coupling and coordination degree of the logistics industry and the economy maintains a continuous growth in the process of Anhui Province joining the YRDR. ③ After Anhui Province joined the YRDR, the coordination degree of its own economic coupling was driven by the stronger radiation of other cities in the YRDR.

Therefore, cities with different levels of development can take more favorable measures for their own cities in improving their own logistics industry and economic coupling coordination according to the above conclusions; theory and practice both prove that the less developed region of Anhui joins the developed region of YRDR, and the mutual needs of both sides at different levels and in different fields, especially the radiation-driven effect of YRDR on Anhui Province, significantly improve the regional logistics industry and economic coupling coordination, and make useful exploration for promoting the sustainable development of YRDR. Appropriate adjustment of the evaluation index system according to the research needs provides a methodological reference for similar analysis and research by domestic and foreign scholars; however, since this paper mainly studies the influencing factors of the coupled and coordinated development of regional logistics and economy, it does not consider the legal environment, administrative efficiency, and human factors, which is the limitation of this paper and the direction of the next research.

The research method and ideas are not only applicable to China, but can also serve as a good reference for other countries, especially the less developed countries. Less developed countries (regions) and developed countries (regions) should continue to promote strategic interaction, strengthen economic and logistics ties, weaken the "Matthew effect" of coupled economic and logistics development, and developed countries (regions) with better coupled economic and logistics development should play the "catfish effect", break through regional boundaries, realize the efficient flow of logistics production factors, and form spatial spillover and radiation-driven effects on neighboring countries (regions), and less developed countries (regions) should take advantage of the development to achieve coordinated and sustainable development based on the common construction of logistics infrastructure, sharing of logistics resources and logistics policies throughout the region.

5.2. Recommendations

Based on the aforementioned conclusions, suggestions are given to improve the coordination of the logistics industry and the economy coupling in YRDR cities by taking into account the root cause of the evaluation index weights in Table 3 and adopting targeted measures according to the development level of the cities themselves, in the hope of providing references for the management departments to make decisions.

5.2.1. Optimization of Industrial Clusters

For economically developed cities, the two indicators of GDP per capita and disposable income per capita in the economic system have the greatest impact on the coupling coordination. Both are closely associated with the GDP, thus the effective improvement of the GDP cannot be achieved without the transformation and upgrading of industrial clusters. The regions should make joint efforts to guide the reasonable layout of industries, and further strengthen the level of industrial agglomeration in core regions. Moreover, the government should focus on the layout of Shanghai, Suzhou, Nanjing, Hangzhou, Hefei, and other central economic areas, with a focus on R&D, high-quality manufacturing, and other industrial chain links, and jointly creating a highly competitive and dynamic industrial innovation highland. For example, cities should join local research institutes to build major scientific and technological innovation bases, further gather high-quality resources from across the country and around the world, promote the organic integration of production, the city, people, and the coexistence of multiple industries, and continuously amplify the agglomeration effect and radiation of industrial platforms.

5.2.2. Coordinate the Organic Combination of New Infrastructure and Traditional Infrastructure to Enhance Freight Capacity

The infrastructure supports the logistics industry development, and new infrastructure is the guarantee to improve the efficiency of logistics. At present, the highway network of the YRDR city cluster is relatively complete, but the railroad network and waterway network density in less developed areas such as northern Jiangsu, southwest Anhui, and southwest Zhejiang are poor. Through the organic combination of new infrastructure and traditional infrastructure, we can address the shortcomings of the railroad and waterway logistics network in northern Jiangsu, southwest Anhui, and southwest Zhejiang. Furthermore, we should promote the integration of YRDR intelligent logistics sharing of logistics data resources. Moreover, we should deepen regional transport coordination and supervision by actively carrying out pilot technology innovation in vehicle networking and vehicle-road coordination, improving integrated logistics hubs of highways, railroads, waterways, civil aviation, and other multimodal transport, and building a modern logistics system of “intelligence + hubs + channels”. This can be achieved through intelligent scheduling and digital empowerment of logistics resource elements. Finally, digital diversion, intelligent gathering, and intelligent diversion will help promote the efficient synergy of economic factors and sustainable development in the logistics industry.

5.2.3. Accelerate the Construction of Logistics “Digital Intelligence” and Improve the Relative Number of Logistics Industry Employees

The number of employees in the logistics industry in the evaluation index has a greater impact on the coupling and coordination degree, and the transformation and upgrading of the industrial clusters in the YRDR city cluster, especially the cities with less developed economic levels, need to put forward new requirements for the high-quality development of the logistics industry. The region should jointly cultivate a new industry with the deep integration of “digital technology + smart logistics”, and the progress of a smart digital logistics industry is inseparable from sourcing and employing high-skilled logistics talent. Regional governments and enterprises should focus on the cultivation and retention of middle- and high-level logistics talent and the construction of a unified and open professional logistics talent resource market. Enterprises should pay attention to school-enterprise cooperation with colleges and universities, and encourage colleges and universities to cultivate intelligent logistics talents through corresponding theoretical and practical courses and internship opportunities in logistics enterprises. In this manner, the organic sharing of employment positions and encouragement policies for the introduction of high-level logistics talents will be promoted.

5.2.4. Optimize the Allocation of Logistics Resources

At present, the YRDR logistics industry and regional economic coupling and coordination degree exhibit a "high in the east and low in the west" pattern, and the "poor-rich" gap between regions is large and will create an imbalance. However, through the optimal allocation of logistics resources, the YRDR city cluster can establish a new pattern of sustainable and coordinated development, thus promoting the radiation drive from different regions and the active integration of the western region, strengthening the circular flow of logistics resources, and boosting the coordinated level of that region. Shanghai should take economic and scientific innovation as the core, giving full play to its leading role and enhancing the high-quality service functions of the YRDR. Jiangsu Province, with its developed manufacturing industry and rich scientific and educational resources, should further promote the intelligent links between the logistics industry and economy, accelerate the construction of a regional logistics park demonstration area, and build a scientific research center and an intelligent logistics base with a focus on international influence. With the leading digital economy in Zhejiang Province, logistics enterprises should optimize resource allocation with the help of digital technology, reasonably plan logistics networks to reduce logistics operational costs, ensure accurate and effective docking of logistics operation links, enhance their operational efficiency, and create a digital logistics innovation highland. Anhui Province, with its vast inland hinterland and abundant labor resources, should actively undertake industrial transfer from the eastern region, connect the logistics transportation trunk lines between the east and west, develop and lay out logistics transit bases with locational advantages, and drive local labor employment.

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