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Spatial Econometric Analysis of Digital Economy Development to Promote Regional Industrial Chain Optimization and Upgrading—Empirical Study of Yangtze River Delta Central City Cluster Based on SDM

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Abstract: *"The 14th Five-Year Plan period requires China to develop a digital economy and vigorously promote the digital transformation of industries. Therefore, the development process of combining digital economy and regional industrial chain has attracted much attention. Taking 26 central city clusters in the Yangtze River Delta (YRD) region from 2011 to 2020 as the research object, on the one hand, the global spatial correlation and local spatial autocorrelation of industrial chain agglomeration among the YRD region are examined by Moran's I index and scatter plot. On the other hand, the spatial panel Durbin model is used to examine the factors and effects of digital economy on regional industrial chain agglomeration. The results show that the indirect effect of regional industrial chain linkage is greater than the direct effect, indicating that the deepening degree of regional industrial chain linkage in the Yangtze River Delta city cluster is conducive to the development of regional industrial chains in neighboring cities and to the promotion of regional industrial chain integration in the Yangtze River Delta city cluster. The development of digital economy can significantly accelerate the pace of upgrading the industrial chain in the Yangtze River Delta region. Digital economy is a new engine for the transformation and upgrading of traditional industries and economic development and growth.*

Keywords: *Yangtze River Delta, Digital economy, Regional industrial chain, Spatial correlation, SDM*

1. Introduction

The Yangtze River Delta Digital Economy Development Report (2021) shows that the Yangtze River Delta seizes the time window of digital economy change. 2020 digital economy scale of the Yangtze River Delta accounts for about 44% of the regional GDP and about 28% of the total national digital economy scale. In addition, the Yangtze River Delta region has notable performance in many dimensions such as digital industry upgrading, digital infrastructure, digital governance and digital trade. The development of digital economy has become an important driving force to promote the transformation and upgrading of the regional industrial chain in the Yangtze River Delta region. Since the 21st century, China's economic development has entered a new normal. Many traditional enterprises have gradually entered the decline of their life cycle. How to accelerate the integration of digital economy with traditional regional industrial chain and accelerate the transformation and upgrading of regional industrial chain has become a new issue that needs to be explored urgently[1].

In China, Chen and Yang (2021) proposed that the impact of digital economy on China's industrial structure upgrading has obvious stage characteristics based on gray correlation entropy and dissipative structure theory[2]. Chen Xiaohui et al. (2020) measured the development level index of the digital economy through the CRITIC method. The empirical analysis using panel data concluded that as the level of development of digital economy increases, the level of industrial structure is improved, and the rate of improvement is marginally increasing[3]. Shuai-Tao Jiao and Qiu-Bi Sun (2021) [4] and Rui Zang (2019) [5] both conducted empirical studies on the impact of China's digital economy industry development on industrial structure optimization and upgrading. The former is mainly based on the instrumental variable method, double difference method, and mediating effect model, while the latter is mainly based on the social network analysis method. Based on the construction of spatial global Moran

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index and local spatial autocorrelation index test, spatial error model and spatial lag model, Wang Yu (2021) obtained the existence of spatial dependence and regional aggregation characteristics of digital economy development and industrial structure upgrading. And there is no significant effect of information technology market on industrial structure upgrading in China and other research results[6]. Based on the empirical analysis of panel data, Shaofu Zhou et al. (2021) concluded that the impact of digital inclusive finance on technological innovation efficiency showed an "inverted U-shaped" structural feature. As the efficiency of technological innovation increases, the role of digital inclusive finance in promoting the efficiency of technological innovation gradually decreases[7].

In many developed countries abroad, digital technology, as a tool of the digital economy, provides labor productivity of more than half a million dollars. While in developing countries, this digital productivity is ten times smaller[8-11]. A.V. Kolesnikov et al. (2020) attribute this to the low purchasing power of the developing world population, low R&D and R&D expenditures related to ICT, and the lack of incentives, motivation, and organizational and economic mechanisms to encourage the use of digital technologies by organizations and citizens in the developing world[12].

In summary, domestic and international literature has demonstrated that the digital economy has different dimensions of contributing to the optimization and upgrading of industrial structure. However, there is little research literature on the regional industrial chain in the Yangtze River Delta region. This paper explores the impact mechanism of the digital economy on the transformation and upgrading of regional industrial chains in the Yangtze River Delta region through spatial econometric analysis based on the panel data of 26 central cities in the Yangtze River Delta region from 2011 to 2020.

2. Variable selection and model design

2.1 Data sources and variable selection

2.1.1 Data sources

Based on data availability and research necessity, the Yangtze River Delta region from 2011 to 2020 is selected as the study area, including 26 major cities in Shanghai, Jiangsu Province, Anhui Province and Zhejiang Province. The index data used are mainly from the China City Statistical Yearbook, the Shanghai Statistical Yearbook, the statistical yearbooks of each province and the statistical bulletins of each city. Among them, some missing data are completed by interpolation method.

2.1.2 Variable selection

➢ Explained variable

The optimization and upgrading of the industrial chain in the Yangtze River Delta region is a transformation and upgrading of economic, political, cultural, social and ecological civilization. Through combing a large number of papers, we found that politics and economy have the most profound influence on the industrial chain. Therefore, it is proposed to select the economic related index - the degree of rationalization of output value structure (YN) - as the index to measure the optimization of regional industrial chain. Specifically, it is the ratio of the added value of tertiary industry to the added value of secondary industry in the Yangtze River Delta.

➢ Explanatory variables

Digital economy development is the integration of regional traditional economic development level and the development of resource platforms such as the Internet, while the application of Internet construction has a close positive relationship with the level of infrastructure construction and the development and potential of digital industries. The development level of education and economy has a positive influence on the environment of its development. After referring to relevant literature, the first-level indicators are constructed from four dimensions: digital infrastructure, digital environment, digital industry, and digital innovation. And 13 secondary indicators are selected to measure the development level of digital economy. The specific indicators are listed in Table 1.

Table 1: Digital Economy Development Indicator System

Level 1 Indicators	**Level 2 Indicators**	**Unit**	**Direction**
Digital Infrastructure	Cell phone penetration rate	Department/100 people	Positive
	Number of fixed-line year-end subscribers	10,000 households	Positive
	Number of Internet broadband access subscribers	10,000 households	Positive
Digital Environment	Number of students enrolled in general higher education institutions	Person	Positive
	GDP per capita	Yuan/person	Positive
	Tertiary industry value added	Billion	Positive
	Education expenditure in the general budget expenditure of the finance	million	Positive
Digital Industry	Total online retail sales/total retail sales of social consumer goods	million	Positive
	Total post and telecommunications business	million	Positive
	Transportation, storage and postal workers	Person	Positive
	Number of employees in the information transmission, computer services and software industry	Person	Positive
Digital Innovation	R&D funding	million	Positive
	Number of patent applications	Piece	Positive

The composite digital economy development score (*O*), calculated by the entropy weighting method, is used as the core explanatory variable of the study.

➢ Control variables

In order to more comprehensively consider the influencing factors affecting the optimization and upgrading of regional industrial chains, GDP (Z_1), labor force level (employed population/total population) (Z_2), and foreign direct investment (actual amount of foreign capital utilized, in USD billion) (Z_3) are selected as control variables. The variables are all logged to eliminate the differences in the magnitudes. The results of descriptive statistics on the data are shown in Table 2.

Table 2: Descriptive statistics of variables

Variables	N	Range	Min	Max	Mean	Standard Deviation
YN	260	2.4741	0.3133	2.7873	1.0027	0.3889
O	260	80.1988	0.6605	80.8593	10.7458	12.6950
Z_1	260	38328.51	372.49	38701.00	5706.91	6082.10
Z_2	260	2415.2257	73.1343	2488.3600	582.0334	446.9126
Z_3	260	201.8585	0.4715	202.3300	25.4897	34.4390

2.2 Construction of spatial weight matrix

The geographical distance matrix *W* is chosen to construct to study the influence mechanism and spatial influence factors of regional digital economy on the optimization and upgrading of regional industrial chain. It indicates that the closer the distance is, the more closely connected economic things are. The elements of the matrix satisfy:

$$\omega_{ij} = \begin{cases} 1/d^2 & i \neq j \\ 0 & i = j \end{cases}$$, where d is the distance between the locations of the enters of the two regions (1)

2.3 Spatial correlation test

2.3.1 Global spatial correlation

The global spatial autocorrelation reflects the overall distribution of digital economy development level in the Yangtze River Delta region. It can be used to determine whether the overall level of digital development in the Yangtze River Delta region is related to adjacent spaces. The global Moran's I index can be calculated to quantify the overall spatial correlation of the digital economy development level.

The global Moran's I index is calculated by the formula:

$$I=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}} \tag{2}$$

where I is Moran's I index. x_i, x_j is the observed value of digital economy development level of central cities i and j in Yangtze River Delta. S^2 is the variance of the observed value of digital economy development level. W_{ij} is the spatial weight matrix. $\bar{x}$ is the mean value of digital economy development level of Yangtze River Delta central cities. n is the number of Yangtze River Delta central cities.

2.3.2 Local spatial correlation

To further highlight the economic association characteristics of the Yangtze River Delta city cluster, a local Moran's I diagram is used to visualize the evolution of the economic association pattern of the city cluster. The local Moran's I index is calculated as follows:

$$I_i = Z_i\sum_{j=1}^{n}W_{ij}Z_j \tag{3}$$

where $Z_i = x_i - \bar{x}$, $Z_j = x_j - \bar{x}$.This index is a good measure of the degree of spatial correlation between regions *i* and *j*.

2.4 Spatial Durbin model

One way to model the spatial effect is to assume that the explanatory variable *y* of the region *i*, which depends on the independent variables of its neighbors:

$$y = X\beta + WX\delta + \varepsilon \tag{4}$$

Where, $WX\delta$ denotes the influence from neighboring independent variables, and δ is the corresponding coefficient vector. This model is called Spatial Durbin Model, abbreviated as SDM. Combining the spatial Durbin model with the spatial autoregressive model, we can get

$$y = \lambda Wy + X\beta + WX\delta + \varepsilon \tag{5}$$

3. Results

3.1 The level of digital economy development in the central cities of the Yangtze River Delta

The scores of each level of indicators and the comprehensive development level of digital economy by entropy weighting method are shown in Figure **1**. It can be seen that Shanghai has the best comprehensive development of digital economy among the central cities. Jiangsu Province and Zhejiang Province have comparable development, among which Nanjing, Suzhou and Hangzhou have better development. Anhui Province is obviously lagging behind in the development level of digital economy, which is closely related to the population of digital industry, capital investment and the degree of education and technology development.

For the development level of digital economy in Shanghai and Nanjing, the most influential factor is the scale of digital industry, followed by the development of digital environment, and the least influential factor is digital innovation. Shanghai, as the "active leader" in the development of the digital economy in the Yangtze River Delta, the total number of postal and telecommunications services and the number of employees related to the digital economy are the core factors for the development of the digital economy level. However, for other central cities, the digital environment is the biggest factor affecting the development of the digital economy. The development of the tertiary sector, the improvement of higher

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education and the increase of investment in educational innovation have better effects on the development of the digital economy.

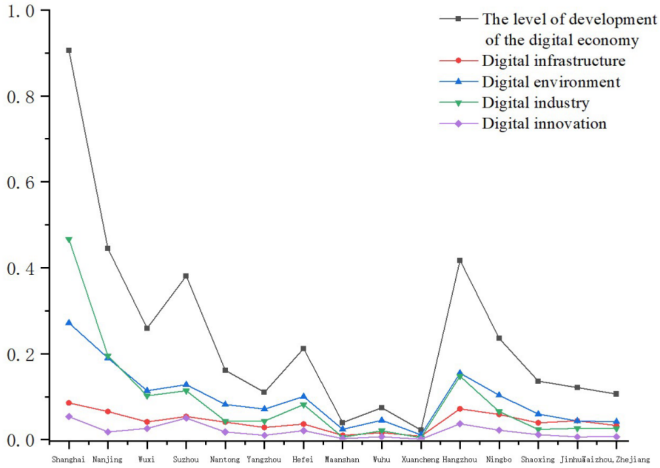
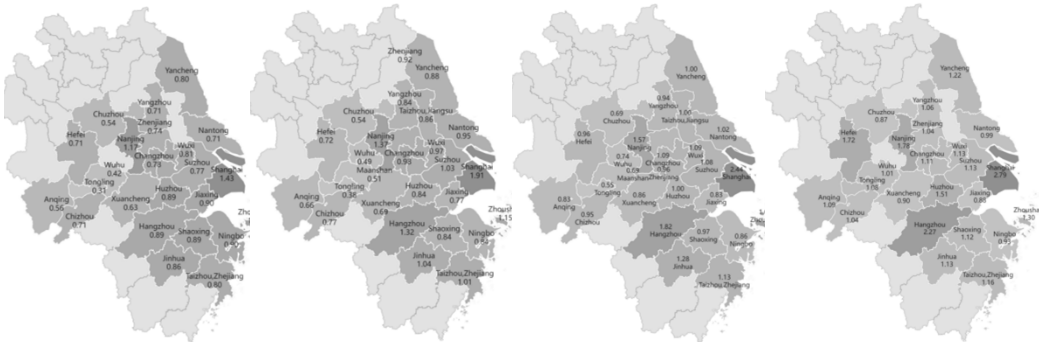


Figure 1: Digital Economy Development Status

3.2 Spatial autocorrelation test of regional industrial chain

3.2.1 Global autocorrelation analysis



(a) 2011 *(b) 2014* *(c) 2017* *(d) 2020*

Figure 2: The spatial distribution pattern of regional industrial chains in the Yangtze River Delta city cluster during the four years

Four time sections in 2011, 2014, 2017 and 2020 are selected to analyze the spatial clustering characteristics of the regional industrial chain optimization and upgrading levels of 26 cities in the Yangtze River Delta using the natural fracture method. As shown in Figure 2, the darker the color, the higher the level of economic development, and vice versa, the lower. It can be seen that the development of regional industrial chains in the Yangtze River Delta urban agglomeration is very uneven, showing a gradient decreasing pattern of coastal, riverine and inland areas in general. And the economic development of neighboring regions is basically consistent with a certain degree of spatial agglomeration. Thus, it can be intuitively found that the industrial chain development of the Yangtze River Delta city cluster has significant spatial distribution characteristics. The global Moran's I index is calculated and the results are shown in Table **3**. the Moran's I index I>0, and the p-value is less than 0.01, which passes the 1% significance test, indicating that the regional industrial chain development of the Yangtze River Delta city cluster has a significant positive spatial correlation.

Table 3: Global Moran's I index table

Variable	I	E(I)	sd(I)	Z	P
YN	0.190	-0.004	0.027	7.186	0.000

3.2.2 Local autocorrelation analysis

In order to further highlight the economic linkage characteristics of the Yangtze River Delta city cluster,

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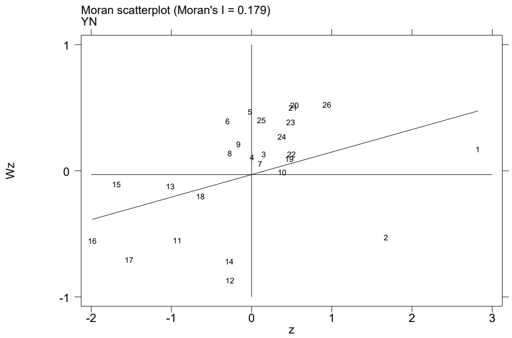
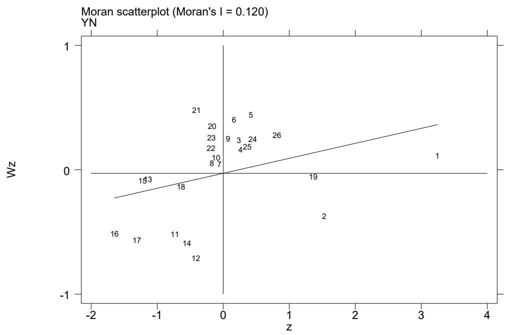
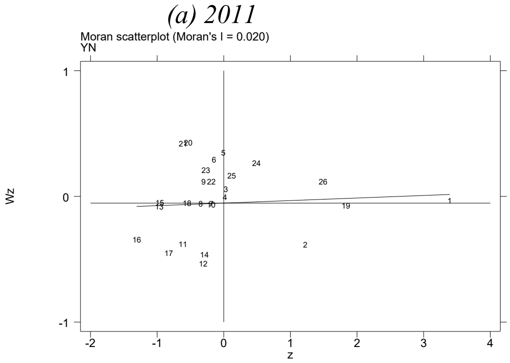
the local Moran's I index and Moran's I diagram are used to visualize the evolution of the local linkage pattern of regional industry chains in the city cluster. Moran's I scatter diagram can analyze local spatial instability, and the four quadrants of the scatter diagram correspond to four types of regional economic linkage types. Quadrant I represents the double-high type of spatial linkage form (HH). Quadrant II represents low-high spatial linkages (LH). Quadrant III represents the double-low spatial linkage (LL). Quadrant IV represents the high-low spatial connection (HL). The quadrant I and quadrant III represent the positive spatial correlation of the same feature observation, while quadrant II and quadrant IV represent the negative spatial correlation between different feature observations.



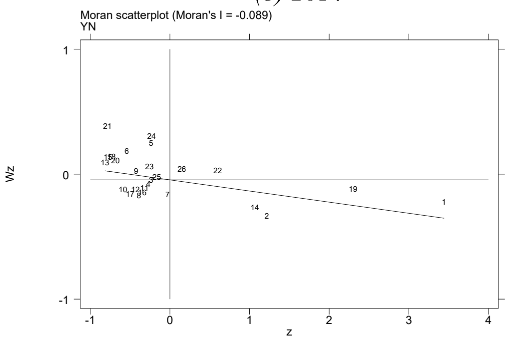
(a) 2011



(b) 2014



(c) 2017



(d) 2020

Note: Numbers 1 denotes Shanghai. Numbers 2-10 denote Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, Taizhou in Jiangsu Province, respectively. Numbers 11-18 denote Anqing, Chizhou, Chuzhou, Hefei, Ma'anshan, Tongling, Wuhu, Xuancheng in Anhui Province and the remaining numbers denote Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Jinhua, Taizhou, Zhoushan in Zhejiang Province respectively.

Figure 3: Scatterplot of local Moran's I index of regional industrial chains in the Yangtze River Delta city cluster over four years

The local Moran's I index scatter plots for the regional industrial chains of the Yangtze River Delta city cluster for 2011, 2014, 2017 and 2020 are plotted, as shown in Figure **3**. It can be seen that the Moran's I index varies from year to year. 13 of the 26 cities in 2011 are in quadrant I and 8 in quadrant III. 80.8% of the cities in the Yangtze River Delta urban agglomeration show significant spatial correlation in regional industrial chain growth, indicating that significant spatial heterogeneity in the economic growth of the Yangtze River Delta urban agglomeration. Analyzing the distribution characteristics of cities, it can be found that cities with faster regional industrial chain development are mainly located in the waterfront region, while cities with relatively weaker regional industrial chain development are mainly in the inland region. And there are close spatial dependence and agglomeration characteristics among these cities.

Further analysis reveals that the local Moran's I index of regional industrial chain gradually decreases again in the past ten years, indicating that the positive spatial correlation gradually weakens. Cities with high-high agglomeration and low-low agglomeration still account for a large part in 2014. Most cities are concentrated in quadrant II and quadrant III during 2017 and 2020, while the local Moran's I index after 2018 shows negative numbers, indicating that regional industrial chain development has shown negative spatial correlations. From the overall analysis, it can be seen that the impact on the industrial chain has been greater under the influence of multiple factors such as the trend of counter-globalization, trade protectionism, and the new crown pneumonia epidemic in recent years. Therefore, it is urgent to promote the optimization and upgrading of the regional industrial chain in the Yangtze River Delta region and the development of digital economy.

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3.3 Spatial econometric model

3.3.1 Spatial Durbin model

Table 4: SDM fixed effects model table

	(1)Ind	(2)Time	(3)Both
Main			
o	0.017*** (0.000)	0.027*** (0.000)	0.017*** (0.000)
lnz1	-0.494* (0.087)	-0.124 (0.199)	-0.293 (0.313)
lnz2	0.451** (0.020)	-0.011 (0.906)	0.462** (0.015)
Lnz3	0.156*** (0.009)	-0.083** (0.044)	0.171*** (0.003)
Wx			
o	-0.026*** (0.000)	-0.044*** (0.000)	-0.027*** (0.004)
lnz1	1.594*** (0.000)	1.142*** (0.002)	4.101*** (0.001)
lnz2	-0.510 (0.301)	0.263 (0.594)	-0.286 (0.591)
Lnz3	0.028 (0.867)	-0.335** (0.020)	0.401** (0.044)
Spatial			
rho	0.408*** (0.000)	0.237* (0.065)	0.117 (0.394)
Note: * indicates significance probability p≤0.1. ** indicates significance probability p≤0.05. *** indicates significance probability p≤0.01.			

The LR and Wald tests are performed in turn. The test results indicate that the fixed-effects spatial Durbin model (SDM) outperforms the spatial error model (SEM) as well as the spatial lag model (SAR). The fixed-effects model of SDM is then developed. The results are shown in Table 4.

From Equation (5), λ in Table 4 is the spatial autoregressive coefficient rho. The coefficient statistics are shown in the Main column of the table. The coefficient statistics of Wx are shown in the Wx column of the table. As a result of the above comparison, the individual fixed effects model is analyzed since it is optimal. The spatial autoregressive coefficient p-value of 0.000 is less than 0.01, significant at the 1% level. Its coefficient is 0.408, which is positive, indicating that the level of rationalization of output value structure (*YN*) has a positive spatial spillover effect on itself. From the value β of the statistics in Main, the digital economy indicator (*O*) reaches significance at the 1% level with a coefficient of 0.017, indicating that there is a positive influence of digital economy development on the optimization and upgrading of regional industrial chains.

The coefficient of the Wx term is more indicative of the spatial transmission effect than the coefficient of the Main term. Both the digital economy indicator (*O*) and GDP (Z_1) reach significance at the 1% level with coefficients -0.026 and 1.594, respectively, which can indicate that the development of digital economy has a negative spatial spillover effect on the optimization and upgrading of the regional industrial chain. The peripheral areas have a negative transmission effect on the optimization of the local industrial chain. The positive coefficient of logarithmic GDP, on the other hand, indicates that the increase of GDP level has a positive spatial spillover effect on the optimization and upgrading of the regional industrial chain.

3.3.2 Decomposition effects of spillover effects

The direct effect is the degree of influence of the variable x in the region on the explanatory variable y in the region. The total effect is the extent to which a one-unit change in the variable in all regions affects the explained variable y in this region. The indirect effect is calculated as the total effect minus the direct effect, in the sense of the degree of influence of a one-unit change in the variable x in the surrounding region on the explained variable y in the region.

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Table 5: Spillover effect decomposition effect table

		Coefficient	Std. err.	z	P>|z|	[95% conf. interval]	
Direct							
	o	0.016	0.002	6.450	0.000	0.011	0.020
	lnz1	-0.449	0.236	-1.900	0.058	-0.913	0.014
	lnz2	0.449	0.208	2.160	0.031	0.042	0.856
	lnz3	0.167	0.064	2.620	0.009	0.042	0.291
Indirect							
	O	-0.034	0.013	-2.650	0.008	-0.059	-0.009
	lnz1	2.369	0.419	5.66	0.000	1.549	3.190
	lnz2	-0.586	0.789	-0.740	0.458	-2.132	0.96
	lnz3	0.113	0.300	0.380	0.707	-0.475	0.701
Total							
	O	0.018	0.013	-1.370	0.071	-0.045	0.008
	lnz1	1.920	0.353	5.440	0.000	1.228	2.612
	lnz2	-0.137	0.817	-0.170	0.867	-1.739	1.466
	lnz3	0.280	0.309	0.900	0.366	-0.326	0.886

As shown in Table 5, O and Z_1 are significant in the direct, indirect and total effects. It shows that a 1-unit increase in O and a 1% increase in Z_1 in the region in the direct effect can lead to a change of 0.016 and -0.449 units in the output value structure rationalization coefficient YN of the Yangtze River Delta urban agglomeration, respectively. In the indirect effect, a 1-unit increase in O and a 1% increase in Z_1 in the neighboring regions can lead to a change of -0.034 and 2.369 units in the coefficient YN, respectively. In the total effect, a 1-unit increase in O and a 1% increase in Z_1 in all regions can cause a 0.018 and 1.920-unit change in coefficient YN of the Yangtze River Delta urban agglomeration.

The indirect effect of regional industrial chain linkage is greater than the direct effect, while the total effect is significantly positive. This indicates that the deepening degree of regional industry chain association in the Yangtze River Delta city cluster is conducive to the development of regional industry chain in neighboring cities and to the promotion of the integrated development of regional industry chain in the Yangtze River Delta city cluster. It is necessary to further promote the transformation of the degree of regional industrial chain association to a high and high type, releasing the direct driving effect of regional industrial chain association.

4. Main Conclusions and Policy Recommendations

4.1 Main Conclusions

First, by constructing the index system for measuring the development level of digital economy and regional industrial chain, and analyzing spatial data with model selection, the development level of digital economy and regional industrial structure is measured. It is found that Shanghai has the most prominent level of digital economy development among the central cities of Yangtze River Delta. Nanjing, Suzhou and Hangzhou have higher development levels. The development level of digital economy in the rest of the cities needs to be improved. The overall development level of regional industrial chain structure in Jiangsu, Zhejiang and Shanghai is higher than that in Anhui Province area. The provincial capitals of each province have a higher level of development of regional industrial chain structure compared with other cities.

Second, due to the significant spatial heterogeneity of economic growth in the Yangtze River Delta city cluster, the spatial correlation among the central cities of the Yangtze River Delta is further considered. The analysis of the spatial and temporal pattern of regional industrial chain optimization and upgrading in the Yangtze River Delta city cluster reveals that the regional industrial chain development in the Yangtze River Delta city cluster has a significant positive spatial correlation. However, the positive spatial correlation has gradually weakened in the last decade. By 2020, the local regional industrial chain development has shown negative spatial correlation.

Finally, by constructing a spatial Durbin panel model analysis, it is found that there is a positive influence of digital economy development on regional industrial chain, as well as the indirect effect of regional industrial chain association is greater than the direct effect. It indicates that the deepening degree of regional industrial chain association in the Yangtze River Delta city cluster is conducive to the development of regional industrial chains in neighboring cities at present. It is conducive to promoting

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the integrated development of regional industrial chains in the Yangtze River Delta city cluster.

4.2 Policy Recommendations

Combining the current situation analysis, empirical analysis and path research, the following suggestions are made in order to improve the development of China's digital economy and further promote the optimization and upgrading of regional industrial chains:

- Improve the construction of infrastructure for digital economy development.
- Promote the synergistic development of digital economy and regional industrial chain.
- Comprehensively enhance the independent innovation capability of digital technology.
- Give full play to the spatial spillover effect of digital economy.
- Continuously optimize the institutional environment for the development of digital economy.

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