Research on the impact and mechanism of the development of digital economy on synergistic industrial agglomeration

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Abstract. This paper discusses the impact of digital economy development on the level of industrial synergistic agglomeration and the mechanism of its role based on the panel data of 110 cities in the Yangtze River Economic Belt from 2011-2019. The results show that: (1)The development of digital economy in the Yangtze River Economic Zone has an "inverted U-shape" effect on the synergistic agglomeration of manufacturing and productive service industries, which is first promoted and then inhibited; (2)Digital economy development affects the level of industrial synergistic agglomeration by reducing transaction costs. (3)There is a significant spatial spillover effect of the impact of digital economy development on the level of industrial synergistic agglomeration in the Yangtze River Economic Belt.The research in this paper provides theoretical support and decision-making reference for the digital economy to promote industrial synergistic agglomeration and reshape the spatial distribution of industries in the Yangtze River Economic Belt.

Keywords: Yangtze River Economic Belt, digital economy, industry synergistic agglomeration, inverted U-shaped spatial effect.

1 Introduction

Industrial synergistic clustering is an important means to optimize industrial spatial layout, promote industrial structural transformation and enhance urban productivity, and it is also a realistic spatial platform for industrial integration and mutual promotion. Improving the degree and quality of industrial synergistic agglomeration is an inherent requirement for promoting the deep integration of advanced manufacturing and modern service industries, and building a modernized industrial system and a new development pattern. The digital economy has become a new engine to promote the high-quality growth of China's economy and a new track for global industrial competition. The China Digital Economy Development Report (2022) published by the China Academy of Information and Communications Technology shows that the scale of China's digital economy will reach 45.5 trillion yuan in 2021, with a nominal year-on-year growth of 16.2%, and the proportion of GDP will reach 39.8%, which shows that the digital

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economy has become a key force driving China's economic development. In the context of the digital economy, new production factors such as digital data and digital technology are fused and reorganized with traditional factors, penetrating into all fields of the whole industry, and bringing about subversive changes in the mode of production, lifestyle, and governance, and at the same time, they also play a key role in promoting the industrial agglomeration of the city, constructing a high-quality regional economic layout and cross-regional industrial dynamic linkage, and the digital economy has become a reshaping of the economic geography pattern. The digital economy has become an important force in reshaping the economic geography.[1] The digital economy has become an important force in reshaping the economic geography. Therefore, how to effectively bring into play the positive effect of digital economy development on industrial synergistic agglomeration and promote the optimization of regional industrial layout has become an issue of wide concern for scholars at home and abroad in recent years.

Existing research focuses on the influencing factors[2-6]and economic effects[7-12]of the development of digital economy and industrial synergistic agglomeration, and there are fewer studies on the relationship between the two, and the conclusions are not yet unified. Then, what kind of impact will the development of digital economy bring to the industrial cooperative clustering? What is the mechanism behind this impact? Is there any spatial effect? These questions lack in-depth analysis and clear answers. This paper will expand the existing research in the following aspects: Firstly, clarify the inverted U-shape relationship between digital economy development and industrial synergistic agglomeration, and select the city-level data of the Yangtze River Economic Belt for a more detailed scale test; Secondly, introduce the transaction cost and factor cost to conduct a mechanism test and a threshold effect test to explore the role of the digital economy in influencing the synergistic agglomeration of industries and the threshold conditions; Finally, based on the significant spatial spillover of data elements, this paper also innovatively adopts spatial econometric modeling to examine the spatial interaction between digital economy and industrial cooperative clustering.

2 Theoretical mechanisms and research hypotheses

The development of the digital economy will have both agglomeration and diffusion effects on industrial synergistic agglomeration. On the one hand, the digital economy has agglomeration effect, which can promote the collaborative agglomeration of manufacturing industry and productive service industry in the region. First of all, the external economy brought by the digital economy attracts the synergistic agglomeration of industries within the region. Advanced digital technologies such as big data, the Internet, and the Internet of Things greatly reduce the information asymmetry between upstream and downstream enterprises, promote high-quality and high-efficiency exchanges and cooperation among enterprises, and facilitate the linkage of manufacturing and productive service enterprises in the region into a highly specialized, functional, and institutionalized research and development, production, sales, and service network; second, the development of the digital economy eases the mismatch of resources in the

region, and lowers the agglomeration congestion effect, thus enhancing the level of collaborative industrial agglomeration. The development of digital economy promotes the networkization and datatization of traditional elements, the application of cloud computing, big data and other information technology reduces the disorderly flow of elements and improves the allocation efficiency of resources, and the application of the Internet and the Internet of Things can greatly release the potential of energy storage in society and create a larger resource space for the synergistic agglomeration of industries in the region.

On the other hand, the digital economy has a diffusion effect, with the continuous improvement of the level of development of the digital economy, the manufacturing industry and the productive service industry will derive new ways of mutual cooperation and transaction, when the industrial synergy is no longer completely dependent on geographic proximity, and there is a pattern of virtual spatial agglomeration and geographic spatial dispersion. First of all, the development of digital economy improves the convenience of knowledge overflow and increases the feasibility of cross-regional exchange and cooperation. The development of 5G, AR and VR technologies, and multimedia technologies in the digital economy has greatly reduced the spatial limitations of knowledge and technology overflow, and non-codable information can be perceived face-to-face due to the development of digital technologies.[13]Second, the development of the digital economy has brought about changes in employment patterns and carriers, and promoted the sharing of labor across regions. The ubiquitous connectivity feature of the digital economy enables traditional work to be carried out in more spatial and temporal states, which promotes the elasticity of employment and the expansion of employment boundaries, and allows enterprises to obtain human resources and technical resources from all nodes of society with the help of digital platforms.[14] ,which break the limitation that talent can only be brought together by neighboring agglomerations.

It can be seen that when the level of digital economy development is low, the agglomeration effect of digital economy is greater than the diffusion effect, and the development of digital economy will promote the synergistic agglomeration of manufacturing industry and productive service industry, and vice versa, it will cause the spatial non-integration of manufacturing industry and productive service industry.

Hypothesis 1: The development of the digital economy has an "inverted U-shaped" impact on the level of industrial synergistic agglomeration.

The spatial distribution pattern of manufacturing and productive service industries is the result of the game of complementary and crowding out effects between industries, and transaction costs and factor costs play an important role in this process.[15] On the one hand, the application of digital technology, such as industrial Internet platform, can effectively solve the information asymmetry between industries, greatly improve the convenience of information search, matching and exchange between industries, and reduce the cost of information search and acquisition cost;On the other hand, the construction of digital government can improve the relationship between the government and the market, and reduce the cost of business governance. Secondly, the theory of new economic geography proposes that transaction costs and the spatial distribution of industries present a non-linear inverted U-shaped relationship[3]The reduction of

transaction costs is both the seeking motive of industrial agglomeration and the determining factor for the transformation of industrial organization form and industrial spatial distribution.[16] Therefore, the digital economy reduces the transaction cost and thus affects the level of industrial synergistic agglomeration

Hypothesis 2: The digital economy affects the level of industrial synergistic agglomeration by reducing inter-industry transaction costs.

Data elements have the characteristics of low-cost replication and high-speed dissemination, which distinguishes them from traditional elements with natural mobility attributes, and the development of the digital economy breaks through the limitations of geographic distance through high-speed and efficient information transmission, thus enhancing the spatial linkage of inter-regional economic activities.[17]

Hypothesis 3: The impact of the level of digital economy development on industrial synergistic agglomeration has a spatial spillover effect.

3 Model design and data sources

3.1 Model Building

3.1.1. Ordinary panel model and Mechanism test model. In order to test the above hypotheses, this paper first builds an ordinary panel regression model. After that,builds a mechanism test model with reference to Jiangting[18].

$$Coagg_{it}=\alpha_0+\alpha_1 Deco_{it}+\alpha_2 Deco_{it}^2+\alpha_3 Control_{it}+\mu_i+\gamma_t+\varepsilon_{it} \quad (1)$$

$$M=\alpha_0+\alpha_1 Deco_{it}+\alpha_2 Deco_{it}^2+\alpha_3 Control_{it}+\mu_i+\gamma_t+\varepsilon_{it} \quad (2)$$

where Coagg denotes the level of industrial synergistic agglomeration, M denotes the mechanism variable. Deco and $Deco^2$ denote the level of digital economy development and its quadratic term, and μ and γ denote the individual effect and time effect, respectively.ε is random perturbation terms.

Table 1. Results of the selection of spatial measurement models

	P-value
SEM Lagrange Multiplier	0.0000
SAR Lagrange Multiplier	0.0000
LR test SAR	0.0075
LR test SEM	0.0423
Wald test SAR	0.0002
Wald test SER	0.0001
Hausman test	0.0000

3.1.2. Spatial measurement models. In this paper, the inverse geographic matrix is constructed as the spatial weight matrix with the latitude and longitude of each city in

the Yangtze River Economic Belt. After LM test, LR and Wald test and Hausmann test, it is determined that the spatialDurbin model with fixed effects is used, and theselection results of spatial econometric model are shown in Table 1, and the specific settings of the Spatial Durbin model are as follows:

$$\begin{aligned}\mathrm{Coagg}_{it} = \theta \sum_{j=1}^{n} W_{ij}\mathrm{Coagg}_{jt} + \beta_0 + \beta_1 \mathrm{Deco}_{it} + \beta_2 \mathrm{Deco}_{it}^2 + \beta_3 \mathrm{Control}_{it} + \\ \varphi \sum_{j=1}^{n} W_{ij}\,\mathrm{Deco}_{it} + \delta \sum_{j=1}^{n} W_{ij}\,\mathrm{Deco}_{it}^2 + \pi \sum_{j=1}^{n} W_{ij}\,\mathrm{Control}_{it} + \mu_i + \gamma_t + \varepsilon_{it}\end{aligned} \quad (3)$$

where θ、φ、δ 、π denote the spatial lag items coefficient of the industrial synergistic agglomeration, digital economy and its quadratic term and the control variable respectively.μ、γ denote the individual effect and time effect respectively.ε denotes randomized perturbation terms.

3.2 Variable setting and data sources

3.2.1. Explanatory variables. This paper adopts the digital economy development level (Deco) of 110 cities in the Yangtze River Economic Belt as the explanatory variable. For the measurement of digital economy development level, this paper refers to Zhao Tao et al.[17] 's practice of constructing an index system for measuring the level of digital economic development of 110 cities in the Yangtze River Economic Belt.

3.2.2. Explained Variables. In this paper, the level of collaborative industrial agglomeration (Coagg) of the cities in the Yangtze River Economic Belt is selected as an explanatory variable. The measurement of the level of industrial coagglomeration refers to Chen[19] et al.'s method. Six industries, namely transportation, storage and postal services, information transmission, computer services and software, finance, leasing and business services, scientific research, technical services and geological exploration, and wholesale and retail trade, are selected as representatives of productive service industries. The specific formulas for the measurement of the level of industrial synergistic agglomeration are as follows:

$$LQ_{ij}=\frac{q_{ij}/e_i}{q_j/e} \quad (1) \quad ; \quad \mathrm{Coagg}=\left(1-\frac{\left|LQ_{manu}-LQ_{pros}\right|}{LQ_{manu}+LQ_{pros}}\right)+\left(LQ_{manu}+LQ_{pros}\right) \quad (4)$$

where LQ_{ij} denotes the location entropy of industry j in region i, the q_{ij} and e_i are the number of employees in industry j in region i and the location entropy in region i the number of all employees.q_j and e denote the number of employees in industry j and the total number of employees in the country.

3.2.3. Control variables. According to the existing research, this paper selects the following control variables: a. Government support (gov), expressed by the proportion of fiscal general budget expenditure to GDP; b. Openness to the outside world (open), expressed by the proportion of actual utilization of foreign investment to GDP; c. Fixed asset investment (Invest), expressed by the proportion of fixed asset investment to

GDP; d. Transportation conditions (Traffic), expressed by the d. Transportation conditions (Traffic), expressed in terms of the number of buses per 10,000 people; e. Infrastructure level (Infra), expressed in terms of road area per capita.

Table 2. Overall regressivity test and mechanism test results

Variable	(1) Coagg	(2) Tcost
Deco	0.211*** (0.065)	-0.436*** (0.076)
$Deco^2$	-0.101*** (0.029)	
Gov	-0.005 (0.026)	0.002 (0.085)
Open	-0.003 (0.003)	-0.013 (0.009)
Invest	0.021 (0.017)	-0.056 (0.054)
Traffic	-0.031* (0.017)	-0.123** (0.055)
Infra	-0.015 (0.021)	0.036 (0.070)
cons	0.679*** (0.206)	2.234*** (0.683)
R2	0.63	0.55

Note: *, **, and * represent the significant at the level of 1%, 5%, 10%, respectively**

3.2.4. Mechanisms variable. In this paper, transaction costs (Tcost) is used as mechanism variable, and the proportion of the number of private and self-employed persons in each city to the total number of employed persons is selected to measure the transaction cost.

3.2.5. Data sources. The data for the above variables come from the China Urban Statistical Yearbook, China Urban Yearbook, and the statistical yearbooks of each city and the National Bureau of Statistics, and some missing data are interpolated.

4 Empirical results

4.1 Ordinary panel model test results

4.1.1. Overall regressivity test. In this paper, we first test the inverted U-shaped relationship between the digital economy and industrial synergistic agglomeration with

an ordinary panel model, and the results are shown in column (1) of Table 2. The primary term of the level of development of the digital economy is significantly positive, and the coefficient of the quadratic term is significantly negative, which indicates that the development of the digital economy has a significant inverted U-shape Type Impact on the level of industrial synergi-stic agglomeration. Hypothesis 1 holds.

4.1.2. Mechanism of action test. Table 2 column (2) shows the effect of digital economic development on the mechanism variable transaction cost, it can be seen that the digital economic development significantly reduces the transaction cost, combined with the theoretical analysis in the previous section, there are sufficient reasons to believe that the digital economic development significantly affect the level of synergistic industrial agglomeration by reducing the transaction.

4.1.3. Robustness Test. In order to determine the reliability of the empirical results, this paper adopts the method of replacing core explanatory variables and instrumental variables to conduct robustness tests. The results are still significant.

4.2 Spatial Durbin model testing

Column (1) of Table 3 shows the overall regression results of the Spatial Durbin model, which shows that a significant inverted U-shaped relationship between the level of digital economy development and industrial cooperative agglomeration is still revealed after considering the spatial effect. In terms of spatial interaction, the coefficients of the spatial autoregressive term of industrial synergistic agglomeration and the coefficient of the spatial lagged term of the level of digital economy development are both significant, indicating that the sample cities have both the endogenous interaction effect of industrial synergistic agglomeration and the exogenous spillover effect of the development of the digital economy in space. In order to avoid the wrong estimation of spatial effects by simple point regression, this paper decomposes the total effect into direct and indirect effects[20] ,respectively, to study the impact of digital economy development on the level of synergistic agglomeration of local and neighboring industries, and the decomposition results are shown in Columns (2) to (4), which can be seen in the coefficients of the direct effect and indirect effect coefficients of Deco and$Deco^2$,the direct effect coefficient and indirect effect coefficient are both significant, indicating that the digital economy development not only affects the local industrial synergistic agglomeration, but also affects the level of neighboring industrial synergistic agglomeration. The regression results of the spatial Durbin model indicate that the digital economy development of the cities in the Yangtze River Economic Belt has produced obvious spatial spillover effects, which partially verifies hypothesis three.

Table 3. Spatial Durbin Model estimation and spatial effect decomposition results

Variable	(1) SDM	(2) Direct effects	(3) Indirect effects	(4) Total effect
Deco	0.216*** (0.078)	0.232*** (0.076)	2.101* (1.059)	2.334** (1.054)
$Deco^2$	-0.066** (0.032)	-0.079** (0.031)	-1.492** (0.601)	-1.571** (0.606)
W∗ Deco	0.857** (0.407)			
W*$Deco^2$	-0.623*** (0.191)			
Spatialrho	0.523***			
Sigma2_e	0.006***			
R2	0.39			
Likelihood	1135.97			

Note:The blank space indicates that it does not need to be verified or cannot be verified

5 Conclusions and Research recommendations

Through theoretical and empirical analysis, this paper verifies the relationship between the development of digital economy and industrial synergistic agglomeration in the Yangtze River Economic Belt, and the conclusions are as follows: First, the development level of digital economy and the level of industrial synergistic agglomeration in the Yangtze River Economic Belt show an inverted U-shaped relationship. When the digital economy develops to a certain extent, the manufacturing and producer services industry will change from geographical synergy and agglomeration to spatial non-integration. Second, the development of the digital economy affects the level of industrial synergistic and agglomeration by reducing transaction costs. Thirdly, there is a significant spatial spillover effect on the impact of the development of the digital economy on the level of industrial synergistic agglomeration in the Yangtze River Economic Belt. Based on the above research, this paper puts forward the following policy insights:

1. Accelerate the promotion of the development of the digital economy and deepen the clustering effect of the digital economy in the middle and upper reaches of the Yangtze River. First of all, it is necessary to realize the sharing of digital basic technology and data element resources. Build a "Digital Yangtze River" service platform, integrate various policies, factors, technologies and other data information in the Yangtze River Economic Zone, and gradually realize the interconnection and interoperability of digital infrastructure, digital services and data governance. Secondly, it is necessary to promote the application of digital technology, continuously deepen and

develop digital application scenarios, formulate a "scenario application list" and make reference to and promote it; promote the integration of emerging digital technology and industries with advantages in different regions, and accelerate the bridging of the digital divide between regions.

2. Give full play to the role of the digital economy in promoting regional industrial synergy and linkage. The first step is to make use of digital technology to realize the optimal allocation of factors, upgrading the way of obtaining information at both the supply and demand ends with digital technologies such as big data, artificial intelligence, cloud computing and blockchain, broadening the way of resource allocation and enhancing the efficiency and effectiveness of factor allocation. The next step is to actively promote cooperation in city clusters based on the division of labor in the industrial chain, build a city network with spatial decentralization of the industrial chain, and promote the formation of a complementary industrial system between the Yangtze River Delta region and the middle and upper reaches of the Yangtze River.

3. Establish a virtual space clustering platform for manufacturing and service industries, and rely on the industrial Internet to develop virtual industrial parks that can effectively connect physical and virtual space. Firstly, it is necessary to realize the data resourceization and online information of the virtual clustering platform, and explore the cross-regional and cross-platform cooperation mode based on virtual space clustering. Secondly, it is necessary to promote the interconnection and cooperation between virtual parks and physical parks, achieve online and offline resource sharing, and construct an industrial agglomeration form in which the virtual and real coexist and promote each other.

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