

Original Paper

Research on the Economic Effect of Coupling Industrial Synergy Agglomeration and Scientific and Technological Innovation

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Abstract

The urban agglomeration in the middle reaches of the Yangtze River constitutes a critical foundation for the development of the Yangtze River Economic Belt and the rise of central China, as well as a pivotal growth pole for high-quality national development. This study investigates the mechanism through which the coupling of industrial collaborative agglomeration and technological innovation influences economic growth. Drawing on panel data from 28 prefecture-level cities within the urban agglomeration of the middle reaches of the Yangtze River (2010–2019), a coupling coordination degree model is constructed to evaluate the level of coupling coordination. The economic effects of the coupling between industrial collaborative agglomeration and technological innovation are further analyzed using the generalized method of moments (GMM), and the findings are validated through a threshold model. The results reveal the following: (1) Between 2010 and 2019, the coupling coordination degree exhibited a fluctuating upward trend, generally characterized by low coupling and high imbalance, with Wuhan achieving the highest level of coupling coordination. (2) The coupling coordination between industrial collaborative agglomeration and technological innovation exerts a nonlinear “inverted U-shaped” effect on economic growth. (3) Threshold model validation demonstrates that the impact of industrial collaborative agglomeration and technological innovation on economic growth evolves over time, exhibiting a “strong-weak-strong” pattern. When the level of industrial collaborative agglomeration surpasses a specific threshold, firms may encounter diseconomies of scale. Similarly, technological innovation fails to effectively contribute to economic growth within certain threshold intervals of coupling coordination.

Keywords

Urban agglomeration in the middle reaches of the Yangtze River, Industrial collaborative agglomeration, Scientific and technological innovation, Economic growth

1. Introduction

The current wave of technological revolution and industrial transformation is rapidly advancing, intensifying global competition across industrial and supply chains. Corporate competition has shifted from isolated battles over specific technologies, products, or processes to a broader competition involving entire industrial and supply chains. The report of the 20th National Congress of the Communist Party of China proposes the establishment of a modernized industrial system and the creation of a regional economic layout characterized by complementary strengths and high-quality development. This vision specifically includes advancing the development of the Yangtze River Economic Belt and the integration of the Yangtze River Delta, as well as promoting coordinated development among cities of different sizes through urban agglomerations and metropolitan areas, with the goal of stimulating domestic circulation and advancing the development strategy for the Yangtze River Economic Belt. The central Yangtze River urban agglomeration, with its vast economic hinterland, complete industrial categories, and a strong foundation for industrial collaborative development, is a crucial node in facilitating the economic circulation of the Yangtze River Economic Belt. Advancing the development of this urban agglomeration has become an inevitable trend in the formation of China's fourth growth pole. However, compared to regions such as the Yangtze River Delta, the level of industrial collaboration remains relatively low. This is evidenced by issues such as a lack of market integration, rigid administrative boundaries, the relatively weak strength of market participants, and the homogeneity of industrial structures within urban agglomerations (Xu, 2021). Overcoming these development challenges hinges on the joint promotion of industrial collaboration and technological innovation. To this end, the State Council has successively approved the "Development Plan for the Central Yangtze River Urban Agglomeration" and the "14th Five-Year Implementation Plan for the Development of the Central Yangtze River Urban Agglomeration," aimed at advancing the coordinated development of the region. This strategy envisions a collaborative development model led by provincial capitals such as Wuhan, Changsha, and Nanchang. The urban agglomeration in the middle reaches of the Yangtze River, with its extensive economic hinterland, comprehensive industrial categories, and pivotal role in facilitating economic circulation along the Yangtze River Economic Belt, has become an essential driver of China's fourth economic growth pole. In the new era and under evolving conditions, Industrial Development of the Central Yangtze River Urban Agglomeration is intrinsically linked to increasing levels of intelligence and automation. Manufacturing, as a pillar industry, directly reflects the nation's productivity levels. Meanwhile, producer services, as a key area of the service industry, are characterized by high technological content and intensive knowledge (Liu Xiao et al., 2021). Industrial clusters represent the most effective organizational form for the survival and growth of contemporary industries. Technological innovation

serves as a critical support mechanism driving the “dual engines” of producer services and manufacturing, and the coupling and coordination between these two sectors are fundamental sources of economic growth. This aligns with the requirements for high-quality economic development in the new era.

This paper aims to make contributions in the following three areas: First, it focuses on the Central Yangtze River urban agglomeration, with a particular emphasis on the coupling of industrial collaboration and technological innovation. This approach distinguishes itself from general studies on industrial collaboration, thereby broadening the scope of research on industrial synergy within the Central Yangtze River urban agglomeration. Second, from the perspective of the economic effects of industrial collaboration within urban agglomerations, it evaluates the coupling coordination development level of the Central Yangtze River urban agglomeration and its components, based on the measurement of the coupling degree between industrial collaboration and technological innovation. Third, from the perspective of the threshold model, it discusses the temporal changes in the impact of industrial coordination-agglomeration and technological innovation coupling on economic growth, providing more precise policy recommendations for promoting the high-quality development of the Central Yangtze River urban agglomeration.

2. Literature Review

Research on industrial synergistic agglomeration and economic growth. New economic geography suggests that industrial agglomeration is driven by circular cumulative causation effects. Porter (1990) argues that industrial agglomeration not only refers to the concentration of industrial sectors in a given space, but also includes the concentration of related supporting industries in the same space. Industrial agglomeration and its externalities serve as a foundation for urban economic development (Zheng Jie et al., 2021). Through in-depth discussion on industrial synergy and economic growth, domestic and foreign scholars believe that industrial synergy can improve the “quality” and “quantity” of economic development and achieve sustainable economic development. With the deepening of economic globalization, the synergistic agglomeration between producer services and manufacturing industries has formed a pattern of interactive development in space under the role of industrial correlation (Chen Guoliang et al., 2012). Ciccone (2000) studied the relationship between industrial agglomeration and economic growth, and confirmed that industrial agglomeration is an important booster of economic growth in five European countries. Kolko (2010) believed that the synergistic agglomeration of producer service industry and manufacturing industry would produce obvious knowledge spillover effect. Ji Yahui et al. (2014) explained that producer service industry and manufacturing industry have synergistic agglomeration from the perspective of new economic geography, and the two promote each other. However, there are certain differences in the synergistic positioning of producer services. The agglomeration of producer services in the center of big cities will further reduce transaction costs and consolidate its agglomeration trend (Chen Jianjun et al., 2011). Endogenous growth theory further indicates that agglomeration of similar industries, diverse or complementary industries is conducive to

promoting regional economic growth, and complementary diversified industry agglomeration is an important vitality to enhance economic growth (He Xionglang et al., 2021). Dou Jianmin et al. (2016) found that when the city size is within a certain range, producer services and manufacturing industries will play a complementary effect. Due to the geographical proximity, collaborative agglomeration with industrial enterprises can reduce production costs such as factor input and labor, and healthy competition among enterprises will accelerate technology and information spillover, thus improving labor productivity (Zhang Hui et al., 2007; Zhao Boyu, 2021; Luo Liangwen et al., 2021) and promoting economic development (Chen Xiaofeng et al., 2014).

Research on scientific and technological innovation and economic growth. Economic growth theory holds that economic growth benefits from scientific and technological innovation (Paul M. Romer, 1996). The endogenous growth theory of Aghion and Festre (2017) points out that technological innovation is the fundamental driving force of economic growth and an endogenous factor of economic system, and promotes economic growth with its positive externality of knowledge spillover (Romer, 1990). Science and technology are the primary productive forces, and realizing innovation-led economic growth is an important content of the new pattern of economic development (Zhang Haijun et al., 2021). Science and technology competitiveness is the core engine of regional economic development level (Zhang Haijun et al., 2019), which determines the development direction of regional economy. Jin Bei (2018), from the perspective of economic theory, believes that only an innovation-driven economy can sustain high-quality development, and scientific discovery, technological invention and industrial innovation are the key drivers for achieving high-quality development. The gap in scientific and technological development is an important reason for the difference in economic growth, and the difference in the conversion rate of scientific and technological input and scientific and technological achievements is the concrete embodiment of the gap in scientific and technological development (Huajian et al., 2019). Based on the research perspective of intermediary variables, Li Feng et al. (2021) empirically analyzed the transmission effect of scientific and technological innovation on promoting economic development by taking industrial structure upgrading as the intermediary variable and based on panel data of 30 provinces in China. However, Wang Zhiyong et al. (2021) realized that human capital status determines the type of technological progress and the use efficiency of advanced technology, and the accumulation of human capital affects technological progress and indirectly affects economic development (Wang Shihong, 2017).

Research on industrial synergistic agglomeration and technological innovation. Producer services and manufacturing synergistic agglomeration, as the general starting point for industrial modernization development, is an important platform for innovation-driven development (Zhang Hu et al., 2017). Giving full play to the bonding role of producer services in industrial integration is the key to the synergistic and interactive development of industries (Ji Xiangyu et al., 2020), and fully participating producer services in every link of manufacturing to the maximum extent, which is conducive to the transformation of knowledge-intensive and technology-intensive industries and improving the value of

the entire production chain. Some scholars have found that industrial collaborative agglomeration can significantly promote local technological innovation and has the advantage of innovation-driven development (Qiu Zhiping et al., 2021). Further, based on the perspective of spatial correlation, it is found that industrial collaborative agglomeration can not only promote the local innovation efficiency, but also produce positive spillover effects on the innovation efficiency of the surrounding areas (former Yi Jun, 2020). From the perspective of spatial layout, Chen Jianjun et al. (2016) believe that the adjustment of spatial layout by industrial collaborative agglomeration is of great significance to promote the development drive from factor driven and investment driven to innovation driven under the new normal, and promote industrial integration and integrated innovation.

In summary, most studies have explored the role of industrial synergy agglomeration or scientific and technological innovation on economic growth, or confirmed the effects of industrial synergy agglomeration and scientific and technological innovation on economic growth with human capital (Wang Liming et al., 2021), industrial structure (Xie Zholiang et al., 2021), education (Su Lifeng et al., 2021) and government input (Huang Lei et al., 2016) as intermediary variables. Starting from the collaborative agglomeration of producer service industry and manufacturing industry, this paper explores the internal mechanism of the complementary effect, scale economy effect, knowledge spillover effect and industrial structure upgrading effect of the coupling of industrial collaborative agglomeration and scientific and technological innovation to promote economic development. On this basis, the panel data of 28 cities in the middle reaches of the Yangtze River from 2010 to 2019 were used to construct relevant indicators of industrial collaborative agglomeration and scientific and technological innovation. The coupling coordination degree model was used to calculate and analyze the coupling coordination degree of 28 prefecture-level cities. Secondly, the GMM model was used to explore the internal relationship between the obstetrical coupling degree and economic development. Finally, a threshold model is established to further analyze whether there is a nonlinear relationship between the obstetrical coupling degree and economic development. Through theoretical analysis and empirical test, the economic growth effect of industrial synergy agglomeration and scientific and technological innovation coupling in the middle reaches of the Yangtze River urban agglomeration is verified.

3. Action Mechanism

Industrial collaborative agglomeration is the advanced stage of industrial agglomeration, and the agglomeration effect of industrial collaborative agglomeration and the externalities brought by industrial interaction will have an impact on scientific and technological innovation (Meng Weijun et al., 2021). The two are interdependent and form an organic whole. On the one hand, industrial agglomeration influences regional innovation through technological spillovers and economies of scale. Porter's theory of industrial competitiveness posits that knowledge spillovers during economic agglomeration foster regional innovation, with agglomeration promoting competition—innovation is driven by competition rather than monopoly. Marshall's theory of externalities highlights the role of economies of scale and

various externalities in promoting regional innovation. Industrial agglomeration accelerates innovation through sharing, matching, and learning. In concentrated factor markets, spatial concentration of economic activities facilitates firms in reaping economies of scale. Additionally, spatial concentration of innovation elements not only yields scale benefits but also enhances innovation efficiency. The economies of scale associated with industrial agglomeration promote technological cooperation across different industries, enabling complementary advantages to emerge in the innovation process, and fostering the efficient spatial allocation of innovation resources (Zhang Ke & Mao Jinxiang, 2018). On the other hand, regional technological innovation influences industrial agglomeration through the growth pole effect and knowledge spillover effect. According to Kumpiet's innovation theory, innovation is a process of reconfiguring various elements, with firms' innovative behaviors exhibiting a strong element integration function. Various elements continuously converge and reconfigure in space, forming new growth poles. This process leads to the reconstruction of regional spatial economic structures, causing changes in the population and industry distribution density across different geographic units, ultimately resulting in changes in industrial agglomeration. This, in turn, attracts the spatial agglomeration of population, technology, industries, and public service resources, thus enhancing regional economic agglomeration. From the perspective of the center-periphery theory, firms continuously approach the center of innovation elements in the market to capture local market effects and price index effects, thereby increasing the overall industrial agglomeration level of the region. The innovation activities of high-tech industries simultaneously enhance the industrial specialization of the region, further promoting spatial agglomeration of industries. Overall, The collaborative agglomeration subsystem of producer service industry and manufacturing industry and the scientific and technological innovation subsystem are two important subsystems of economic and social development, and the rational collaborative distribution of producer service industry and manufacturing industry is the key to scientific and technological innovation and technological progress. The coupling and coordination of the two promote economic development through various effect mechanisms such as complementarity effect, economies of scale effect, knowledge spillover effect and industrial structure upgrading effect.

(1) Complementarity effect. Producer services and manufacturing industries converge to catalyze the transformation of scientific and technological achievements, while scientific and technological innovation forces producer services and manufacturing industries to upgrade, and the two mutually promote and stimulate complementary effects. With the rapid development of global innovation, industrial synergy is conducive to reducing production costs, especially in terms of cooperative research and development, but also reduces research and development risks, and speeds up the cycle of scientific and technological research and development to the transformation of results. Scientific and technological innovation forces enterprises to continuously improve service quality and specialization, ensure product quality and improve the competitiveness of enterprises.

(2) Economies of scale effect. Industrial synergy agglomeration is coupled with scientific and technological innovation, so that enterprises can share R&D infrastructure and reduce innovation input

costs in scientific and technological R&D, application and service, etc. Moreover, the proximity of industrial distribution can reduce the problem of information asymmetry, form a good contractual environment in the agglomeration area, reduce transaction costs and improve transaction efficiency, and stimulate economies of scale effect. It is possible to realize economies of scale and scope. When enterprises develop products that meet the market demand, the research and development results in the region can be transformed on a large scale, thus improving the innovation efficiency in the cluster area. At the same time, industrial collaborative agglomeration, accompanied by a higher degree of marketization, can effectively reduce the threshold of capital investment (Ning et al., 2016) and promote regional economic development.

(3) Knowledge spillover effect. Endogenous growth theory emphasizes the importance of knowledge capital to production. The integration of producer services and manufacturing industries relies more on knowledge, information and technology to form a complete knowledge chain (Zhang Xin, 2021). Industrial synergy agglomeration can enable many homogeneous or heterogeneous enterprises to carry out economic and technological exchanges, especially in the process of cooperative innovation to strengthen dialogue with each other and stimulate knowledge spillover effect. Both advanced management ideas and organizational behavior patterns integrate and penetrate each other during the process, which enhances knowledge complementarity and knowledge spillover effect.

(4) Industrial structure upgrading effect. The most obvious positive impact of the coupling of industrial synergy agglomeration and scientific and technological innovation is the optimization and upgrading of industrial structure. Upgrading the industrial structure promotes high-quality economic development by optimizing resource allocation. Industrial agglomeration also gathers talent, technology, capital, equipment, etc. The free flow of these elements between regions will attract high-quality or potential industries to gather here and inject “fresh blood” into the agglomeration area. The technological innovation can induce the technological upgrading of enterprises through the multiplier effect, so as to improve the added value of enterprises’ products and realize the optimization and upgrading of industrial structure.

4. Measure the Coupling Level of Industrial Collaborative Agglomeration and Scientific and Technological Innovation

4.1 Industrial Collaborative Agglomeration and Scientific and Technological Innovation Level Index Selection

Coupling refers to the phenomenon that two or more systems or two forms of movement affect each other and even unite through various interactions. According to the connotation and characteristics of coupling coordination, and based on the objective reality of China’s industrial collaborative agglomeration and scientific and technological innovation, a comprehensive level measurement index system of industrial collaborative agglomeration subsystem and scientific and technological innovation subsystem is established respectively (Table 1). The level of industrial collaborative agglomeration is mainly

measured from three dimensions: agglomeration level, agglomeration scale and agglomeration benefit. In the dimension of agglomeration level, the industrial collaborative agglomeration index is used to describe the agglomeration and coordination degree among industries. The agglomeration scale is measured by the number of employment in producer service industry and manufacturing industry and the number of industrial enterprises above designated size. The total output value of industry and the average salary of employees reflect the level of agglomeration benefit. The scientific and technological innovation is mainly explained from three dimensions: innovation resources, innovation achievements and innovation environment. Innovation resources include capital and talents; Innovation results are represented by the number of patents granted; The innovation environment includes the total number of telecommunications services and the number of Internet broadband access users.

Table 1. Index System of Coupling Coordination between Industrial Collaborative Agglomeration and Scientific and Technological Innovation.

Target Layer	Guideline layer	Guideline layer	Units
Industrial collaborative agglomeration	Agglomeration level	Industrial collaborative agglomeration index	-
	Agglomeration size	Employment in producer services and manufacturing	Thousands of people
		Number of industrial enterprises above designated size	a
	Agglomeration benefit	Total output value of industries above designated size	Yuan Yuan
		Average wages of employees	yuan
Scientific and technological innovation	Innovation resources	Spending on science and technology	Yuan Yuan
		Number of students in regular institutions of higher learning	Ten thousand people
		Regional practitioners Personnel engaged in scientific and technological activities	
	Innovation results	Number of patents granted	a
	Innovation environment	Total telecom business	Yuan Yuan
		Number of broadband Internet users	households

4.2 Industrial Collaborative Agglomeration Level Measurement

There are 31 categories of manufacturing industry studied in this paper, including the classification of national economic industries and the 13-43 categories divided in the code. Production services are represented by eight categories: transportation, warehousing and postal services, information transmission computer services and software industry, scientific research and technical services and geological exploration industry, financial services industry, rental commodity services, public facilities management industry, wholesale and retail industry and real estate industry. The location entropy index is used to measure the agglomeration degree of producer service industry and manufacturing industry.

$$\text{Magglo} = \frac{e_{iM}/e_i}{E_M/E} \quad (1)$$

$$\text{Psagglo} = \frac{e_{iP}/e_i}{E_P/E} \quad (2)$$

Where, Magglo and Psagglo represent the agglomeration index of manufacturing industry and producer service industry respectively; e_{iM} e_{iP} And refers to the number of employees of manufacturing industry and producer service industry in the prefecture-level city i ; e_i Is the number of employees in all industries of city i ; E_M E_P And the number of employees in the national manufacturing and producer services industries, respectively; E represents the total number of employees in the country.

The level of industrial collaborative agglomeration is measured by the difference degree of agglomeration level between two industries, and the calculation formula of industrial collaborative agglomeration index (ica) is

$$ica = (1 - \frac{|\text{Magglo} - \text{Psagglo}|}{|\text{Magglo} + \text{Psagglo}|}) + |\text{Magglo} + \text{Psagglo}| \quad (3)$$

Where, ica represents the synergistic agglomeration index of producer service industry and manufacturing industry. The greater the ica value, the higher the agglomeration degree of the two industries and the smaller the difference between the industries.

4.3 Measurement of the Coupling Level between Industrial Collaborative Agglomeration and Scientific and Technological Innovation

The entropy method is used to determine the weights of each index of the two subsystems of industrial collaborative agglomeration and scientific and technological innovation. Entropy method is a mathematical method used to judge the degree of dispersion of an index. The advantage of entropy method is that it avoids the randomness of subjective assignment and can assign an objective value to the index system. The greater the degree of dispersion, the greater the influence of the index on the comprehensive evaluation. Since the units of measurement of each index are not uniform, they should be standardized before using them to calculate the comprehensive index, that is, the absolute value of the index is converted into relative value, and let $X_{ij} = |X_{ij}|$, $i=1,2,\dots,n$; $j=1,2,\dots,m$. The proportion of the

i sample in the j index is; $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}}$; Secondly, the entropy of the JTH index is calculated as: $e_j =$

$-k \sum_{i=1}^n p_{ij} \ln(p_{ij})$, where $k=1/\ln(n)$, so that $e_j \geq 0$; Then calculate the redundancy of information entropy: where $k=1/\ln(n)$, so that $e_j \geq 0$; Then calculate the redundancy of information entropy: $d_j = 1 - e_j$; Calculate the weights of each index; $p_{ij} = \frac{d_j}{\sum_{j=1}^m d_j}$; Finally, calculate the comprehensive score of each index: $s_i = \sum_{j=1}^m w_j \cdot p_{ij}$.

After determining the weights, the coupling coordination model of industrial collaborative agglomeration and scientific and technological innovation is established.

$$C = \left[\frac{A \cdot B}{(A+B)^2} \right]^{\frac{1}{2}} \quad (4)$$

$$T = \alpha \cdot A + \beta \cdot B \quad (5)$$

$$D = (C \cdot T)^{\frac{1}{2}} \quad (6)$$

Where, C stands for coupling degree, A and B stand for industrial agglomeration and scientific and technological innovation respectively. The value of C is [0,1], and the closer C is to 1, the higher the coupling degree of the two subsystems. D is the degree of coordinated development, and the value of D is [0,1], the larger the value of D, indicating that the two subsystems have a good coordinated development trend. T is the comprehensive coordination index, α and β are contribution coefficients and $\alpha + \beta = 1$. Since industrial synergy is as important to regional development as scientific and technological innovation, $\alpha = \beta = 0.5$ is set. With reference to the existing research results, the coupling degree and coordination degree are divided into several levels, and the specific classification types and standards are shown in Table 2.

4.4 Analysis of Coupling Level between Industrial Collaborative Agglomeration and Scientific and Technological Innovation

The coupled coordination degree model is used to calculate the coupled coordination degree of 28 prefecture-level cities in the middle reaches of the Yangtze River. The specific results are shown in Table 3. It can be observed from the table that the coupling coordination degree of 28 prefecture-level cities shows a fluctuating and rising trend, and the calculation results of each region are quite different. The urban agglomeration in the middle reaches of the Yangtze River is in the stage of low coupling degree and high imbalance as a whole. The coupling coordination degree of capital cities in the middle reaches of the Yangtze River urban agglomerations is generally higher than that of other prefecture-level cities, among which Wuhan City > Changsha City > Nanchang City, and Wuhan City is far ahead in the coupling coordination level among 28 prefecture-level cities. The coupling coordination level of other prefecture-level cities is generally low, basically in the stage of low coupling and serious imbalance, with little fluctuation and little growth trend in the past 10 years.

The reasons for this phenomenon are as follows: (1) Provincial capital cities rely on good infrastructure construction and supporting services, policy advantages, economic advantages and resource advantages, and have a mature industrial division of labor system, high-quality education system, talent attraction and innovation ability compared with other prefecture-level cities. The profound industrial base and

perfect urban functions promote and strengthen each other, and promote the provincial capital to a higher level of coupling and coordination stage. (2) As a new first-tier city, Wuhan is the main engine of the urban agglomeration in the middle reaches of the Yangtze River. Wuhan has obvious competitive advantages in industries such as computer, automobile manufacturing and metal smelting, as well as core industrial clusters of independent innovation demonstration zones and economic and technological development zones. Moreover, its outstanding educational advantages and extensive connections between universities, research institutes and enterprises are conducive to the implementation and operation of innovative technologies. On the other hand, Changsha and Nanchang are still in the middle and late stages of industrialization, with a large proportion of industry in their industrial structure, slow development of service industry, weak urban influence and radiation power, and lack of enterprises and industrial clusters with national influence. (3) The low level of coupling coordination of other prefecture-level cities is mainly due to the competitive disadvantage of infrastructure, transportation and innovation capabilities, and the low demand for high-tech producer services, resulting in a low level of industrial collaborative agglomeration. At the same time, the central city of the middle reaches of the Yangtze River City cluster has weak radiation belt power, which has little impact on the development of other prefecture-level cities, so that the coupling mechanism between the level of industrial collaborative agglomeration and scientific and technological innovation has not yet been formed. (4) The main reason for the low coupling degree between industrial collaborative agglomeration and scientific and technological innovation in the whole middle reaches of the Yangtze River is the convergence of industrial structure, which is an important factor that weakens the division of labor and cooperation in the construction of urban agglomerations. Regional homogenization is a double-edged sword. A certain degree of regional homogenization is conducive to enhancing the competitiveness of regional leading industries. To jointly build industrial clusters, the key is to prevent internal vicious competition and encroachment. Therefore, the city clusters in the middle reaches of the Yangtze River should develop their strengths and strengthen the flow of production factors, so as to break down barriers and establish reasonable industrial division of labor. At the same time, the leading industries should be enlarged and strengthened, the whole industrial chain should be arranged around the leading industries, and the advantageous industrial clusters should be formed to carry the strategic task of the new dual-cycle development pattern. (5) The industrial structure of Hubei, Jiangxi and Hunan focuses on heavy industries such as automobile, metallurgy and coal, and the cooperation mechanism is not yet mature. Moreover, the three provinces of Hubei, Jiangxi and Hunan broke out separately and did not play a joint role. Hubei tried to form a strategic fulcrum for the “rise of the Central Region”, Hunan developed its own industry with the advantage of the development of the Pearl River Delta, and Jiangxi positioned itself as the “back garden” of the Yangtze River Delta. The inconsistency between strategic positioning and development thinking leads to more competition than cooperation among urban agglomerations in the middle reaches of the Yangtze River, and the division of labor and cooperation mechanism lags far behind that of other urban agglomerations.

Table 2. Coupling Coordination Levels and Types of Industrial Collaborative Agglomeration and Scientific and Technological Innovation

COUPLING INTERVAL	COUPLING LEVEL	COUPLING INTERVAL	COUPLING LEVEL
[0,0.2)	Low level coupling	[0.2, 0.4)	Run-in coupling
[0.4, 0.7)	Antagonistic coupling	[0.7, 1)	High level coupling
COORDINATING INTERVAL	Coordination level	Coordination Level	Coordination level
[0.00, 0.10)	Extreme Disorder (I)	[0.10, 0.20)	Severe disorder (II)
[0.20, 0.30)	Moderate disorder (III)	[0.30, 0.40)	Mild disorder (IV)
[0.40, 0.50)	Verge Dissonance (V)	[0.50, 0.60)	Barely coordinated (VI)
[0.60, 0.70)	Primary Coordination (VII)	[0.70, 0.80)	Intermediate Coordination (VIII)
[0.80, 0.90)	Good coordination (IX)	[0.90, 1.00)	Quality Coordination (X)

Table 3. Calculation Results of the Coupling Coordination of Industrial Synergy Agglomeration and Scientific and Technological Innovation in the Middle Reaches of the Yangtze River from 2010 to 2019

		2010	2011	2012	2013	2014	2015	2017	2018	2019	Mean	Coupling type	Coordination type
Jiangxi Province	Nanchang	0.286	0.282	0.285	0.292	0.294	0.287	0.308	0.296	0.302	0.292	Run-in coupling	Moderate coordination
	Jingdezhen	0.143	0.132	0.134	0.129	0.130	0.127	0.124	0.117	0.119	0.128	Low level coupling	Severe misalignment
	Pingxiang	0.140	0.124	0.125	0.134	0.139	0.136	0.135	0.147	0.136	0.135	Low level coupling	Severe misalignment
	Jiujiang	0.177	0.173	0.182	0.194	0.206	0.204	0.205	0.215	0.218	0.198	Low level coupling	Severe misalignment
	Xinyu	0.142	0.109	0.137	0.137	0.143	0.145	0.133	0.150	0.170	0.141	Low level coupling	Severe misalignment
	Yingtian	0.111	0.105	0.109	0.118	0.128	0.141	0.127	0.142	0.143	0.126	Low level coupling	Severe misalignment
	Ji 'an	0.154	0.138	0.148	0.168	0.176	0.176	0.181	0.192	0.191	0.170	Low level	Severe

												coupling	misalignment
	Yichun	0.142	0.131	0.144	0.162	0.169	0.174	0.176	0.186	0.189	0.165	Low level coupling	Severe misalignment
	Fuzhou	0.141	0.130	0.145	0.164	0.171	0.172	0.172	0.178	0.186	0.163	Low level coupling	Severe misalignment
	Shangrao	0.134	0.112	0.130	0.147	0.154	0.152	0.150	0.145	0.150	0.142	Low level coupling	Severe misalignment
Hubei Province	Wuhan	0.420	0.411	0.415	0.413	0.415	0.414	0.415	0.413	0.419	0.414	Antagonisti c coupling	Verge misalignment
	Huangshi	0.181	0.151	0.155	0.157	0.157	0.147	0.139	0.152	0.145	0.153	Low level coupling	Severe misalignment
	Yichang	0.190	0.139	0.164	0.172	0.179	0.169	0.175	0.180	0.175	0.171	Low level coupling	Severe misalignment
	Xiangyang	0.218	0.216	0.236	0.249	0.261	0.257	0.240	0.245	0.239	0.242	Run-in coupling	Moderate misalignment
	Ezhou	0.207	0.190	0.210	0.220	0.233	0.234	0.240	0.242	0.250	0.226	Run-in coupling	Moderate misalignment
	Jingmen	0.133	0.120	0.128	0.124	0.124	0.127	0.123	0.137	0.132	0.128	Low level coupling	Severe misalignment
	Xiaogan	0.178	0.154	0.164	0.165	0.167	0.169	0.162	0.173	0.169	0.167	Low level coupling	Severe misalignment
	Jingzhou	0.178	0.170	0.183	0.191	0.198	0.185	0.183	0.186	0.188	0.185	Low level coupling	Severe disorder
	Huanggang	0.172	0.133	0.136	0.143	0.156	0.166	0.171	0.167	0.167	0.158	Low level coupling	Severe misalignment
	Xianning	0.151	0.116	0.117	0.119	0.135	0.115	0.114	0.130	0.133	0.125	Low level coupling	Severe misalignment
Hunan Province	Changsha	0.354	0.357	0.366	0.365	0.362	0.355	0.361	0.359	0.366	0.360	Run-in coupling	Mild misalignment
	Zhuzhou	0.216	0.245	0.216	0.214	0.216	0.217	0.202	0.214	0.214	0.216	Run-in coupling	Moderate misalignment
	Xiangtan	0.196	0.194	0.180	0.179	0.206	0.199	0.175	0.178	0.178	0.188	Low level coupling	Severe misalignment
	Hengyang	0.212	0.198	0.180	0.176	0.177	0.172	0.174	0.181	0.188	0.183	Low level coupling	Severe misalignment
	Yueyang	0.207	0.197	0.193	0.199	0.199	0.200	0.188	0.185	0.197	0.195	Low level	Severe

											coupling	misalignment
Changde	0.169	0.164	0.169	0.173	0.177	0.172	0.183	0.190	0.195	0.177	Low level	Severe
											coupling	misalignment
Yiyang	0.153	0.146	0.150	0.148	0.150	0.146	0.153	0.161	0.161	0.152	Low level	Severe
											coupling	misalignment
Loudi	0.131	0.136	0.140	0.145	0.139	0.123	0.146	0.149	0.148	0.138	Low level	Severe
											coupling	misalignment

5. Empirical Analysis of the Economic Effect of Coupling Industrial Synergy Agglomeration and Scientific and Technological Innovation

5.1 Model Construction and Data Source

Data in this paper are collected from China City Statistical Yearbook, China Statistical Yearbook, China Science and Technology Statistical Yearbook and statistical bulletins of various provinces from 2011 to 2021, and logarithmic processing is carried out (cities with serious data missing are excluded), and mean interpolation method is used to supplement a few missing values.

(1) Explained variables

Level of economic development ($\ln\text{pergdp}$) : logarithm of GDP per capita is used.

(2) Explanatory variables

The coupling coordination degree ($\ln d$) of industrial collaborative agglomeration and scientific and technological innovation: the logarithm of the coupling coordination degree calculated above is used to express it.

(3) Control variables

The control variables consist of four main variables: The financial development level ($\ln fin$) is expressed as the logarithm of the deposit balance of financial institutions at the end of the year, the foreign investment level ($\ln fdi$) is expressed as the logarithm of the actual amount of foreign investment used in the year, the government role intensity ($\ln gov$) is measured as the logarithm of the public budget expenditure, and the infrastructure level ($\ln road$) is measured as the actual urban road area at the end of the year It is measured by number.

In order to weaken the endogenous nature, this paper adopts the GMM method to explore the relationship between the coupling coordination degree of industrial collaborative agglomeration and scientific and technological innovation and economic development. At the same time, the quadratic term of the coupling coordination degree is added to investigate whether there is a nonlinear relationship between the coupling coordination degree and economic growth. The specific model is as follows: $(\ln d)^2$

$$\ln\text{pergdp}_{it} = \alpha_0 + \alpha_1 \ln d_{it} + \alpha_2 (\ln d_{it})^2 + \alpha_3 \ln fin_{it} + \alpha_4 \ln fdi_{it} + \alpha_5 \ln gov_{it} + \alpha_6 \ln road_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (6)$$

In the formula, i stands for prefecture-level city, t stands for year, individual effect, time effect and random disturbance term. $\mu_i \delta_t \varepsilon_{it}$

5.2 Analysis of Empirical Results

(1) Descriptive Analysis

In order to eliminate the influence of index dimension and eliminate heteroscedasticity to a large extent, all variables were logarithmically processed. The descriptive statistical results of relevant variables are shown in Table 4. The coupling coordination degree, financial development level, government role and infrastructure level of industrial synergy agglomeration and scientific and technological innovation vary greatly among different regions, while the difference of economic development level among different regions is relatively small, with the maximum value being 11.888, the minimum value 9.505 and the average value 10.670. However, there are still some gaps.

Table 4. Descriptive Statistics of Each Variable

	Name of variable	Variable symbol	Sample size	Mean	Standard deviation	Minimum	Maximum
Explained variable	Level of economic development	lnpergdp	280	10.670	0.512	9.505	11.888
Explanatory variables	Degree of coupling coordination	lncl	280	1.729	0.307	2.251	0.868
Control variables	Level of financial development	lnfin	280	16.658	0.856	14.758	19.450
	Foreign investment	lnfdi	280	2.813	0.052	2.692	2.970
	Strength of government role	lngov	280	10.685	1.184	7.744	14.023
	Infrastructure level	lnroad	280	13.907	0.959	11.154	16.923

(2) Correlation Analysis

To preliminarily determine the correlation between the coupling coordination degree of industrial collaborative agglomeration and technological innovation and the level of economic development, scatter plots and fitting curves were generated using Stata to reflect the linear relationship between the two, as

shown in Figure 1. A significant positive correlation is observed, with a Pearson correlation coefficient of 0.526, which is statistically significant at the 1% level.

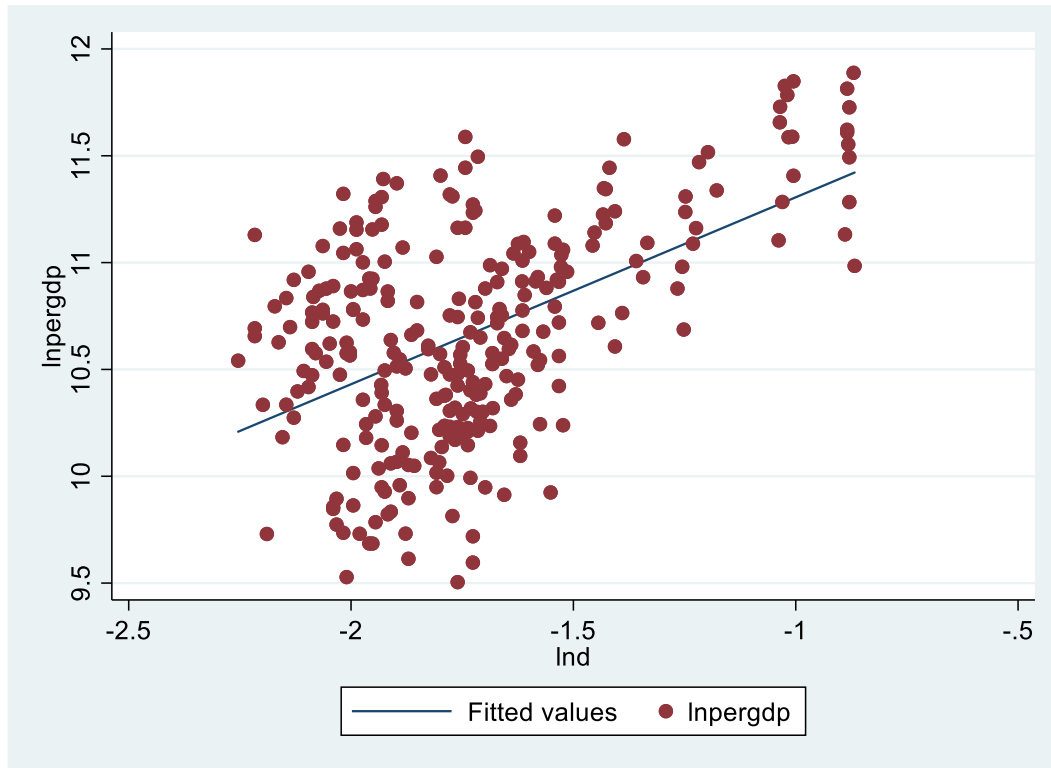


Figure 1. Correlation between the Coupling Coordination Degree of Industrial Collaborative Agglomeration and Technological Innovation and the Level of Economic Development

(3) Baseline Regression Analysis

This study employs the Generalized Method of Moments (GMM) to estimate the model sequentially by adding control variables. Additionally, the first- and second-order lagged terms of the dependent variable are incorporated into the model, which helps mitigate issues related to omitted variable bias, multicollinearity, and other endogeneity concerns to some extent. In Table 5, Model (1) -- Model (5) is the linear regression result of the coupling coordination degree of productive service, manufacturing synergistic agglomeration and scientific and technological innovation on economic growth after control variables are successively added by GMM method. It can be found that the significance of core explanatory variables and each control variable basically does not occur, indicating that the model has stability. In addition, the coefficient of the core explanatory variable *Ind* is always positive and significant at 1% level, indicating that the coupling coordination of industrial collaborative agglomeration and scientific and technological innovation has a promoting effect on economic growth. Moreover, the estimated coefficient of the coupling coordination degree is always greater than that of the control variable, which indicates that the economic effect of the core explanatory variable in this paper is more significant than that of the control variable in promoting economic development. The infrastructure level

in model (5) -- Model (6), with Inroad as the representative index, has an obvious pulling effect on economic development, and it is significant at the 1% level. This shows that infrastructure construction plays a key, leading and supporting role in economic and social development, and is an important symbol of social and economic modernization. Perfect infrastructure lays a solid foundation for industrial synergy and scientific and technological innovation, is an effective way to stimulate economic growth, and thus plays an indirect positive effect on economic development. Model (4) -- Model (6) With lngov as the representative indicator, the government role strength coefficient is negative and significant at the 1% level. (Ind)² This shows that in order to give full play to the role of the market and better play the role of the government, excessive government investment will cause overcapacity, but weaken the market mechanism, have a weak negative effect on economic development, and is not conducive to sustainable economic development. More and more administrative measures of the government have weakened the enthusiasm of enterprises in production. Therefore, the government should transform its functions, further turn to service and guidance, and build a service-oriented government. In model (6), the square term of coupling coordination degree is added, the coefficient of which is negative and significant at the level of 1%, verifying that there is a nonlinear relationship between industrial collaborative agglomeration and the coupling coordination of scientific and technological innovation and economic growth, showing an inverted “U” nonlinear feature. (Ind)² This indicates that the coupling coordination degree of industrial collaborative agglomeration and scientific and technological innovation should maintain a similar development speed and establish a corresponding matching mechanism, in order to exert the optimal economic effect.

Table 5. GMM Estimates

	Model (1)	Model (2)	Model (3)	Models (4)	Models (5)	Models (6)
	lnpergdp	lnpergdp	lnpergdp	lnpergdp	lnpergdp	lnpergdp
L.lnpergdp	0.713 * * *	0.712 * * *	0.702 * * *	0.697 * * *	0.495 * * *	0.512 * * *
	(106.12)	(92.87)	(99.78)	(37.63)	(23.55)	(31.53)
L2.lnpergdp	0.199 * * *	0.195 * * *	0.199 * * *	0.215 * * *	0.357 * * *	0.346 * * *
	(50.66)	(31.21)	(33.73)	(29.70)	(32.13)	(16.10)
Ind	0.0516 * * *	0.0628 * * *	0.0662 * *	0.131 * * *	0.0911 * * *	1.432 * * *
	(12.57)	(8.16)	(7.08)	(7.03)	(3.78)	(5.79)
lnfin		0.00422 *	0.00453 *	0.00428	0.00181	0.0000905
		(2.56)	(2.57)	(1.89)	(0.65)	(0.04)
lnfdi			0.0340	0.102	0.264	0.225

			(0.31)	(0.51)	(1.28)	(0.71)
Ingov				0.0352 * * *	0.0294 * *	0.00565
				(4.57)	(3.02)	(0.65)
lnroad					0.0637 * * *	0.0727 * * *
					(15.62)	(14.52)
(ln²)						0.485 * * *
						(6.21)
_cons	1.141 * * *	1.142 * * *	1.113 * * *	1.299 * * *	0.500	0.320
	(22.87)	(31.71)	(4.63)	(3.92)	(1.62)	(0.44)
N	224	224	224	224	224	224
AR(3)	0.845	0.839	0.872	0.872	0.991	0.427
Sargan test	0.948	0.948	0.957	0.948	0.971	0.981

Note. ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively. AR (3) results of all models were greater than 0.05, indicating that there was no third-order correlation. Sargan test rejected the null hypothesis of overrecognition of instrumental variables, verified the validity of instrumental variables, and set the model reasonably.

(4) Heterogeneity Analysis

The urban agglomerations in the middle reaches of the Yangtze River can be divided at the provincial level into the Wuhan Urban Agglomeration, the Chang-Zhu-Tan Urban Agglomeration, and the Poyang Lake Urban Agglomeration. Thus, the GMM method was used to conduct a heterogeneity test for these three urban agglomerations, as well as a robustness test for the baseline model. The regression results are presented in Table 6. Models (7), (9), and (11) show the heterogeneity estimation results for the three urban agglomerations, all of which indicate that the coupling and coordination degree of industrial collaborative agglomeration and technological innovation has a positive impact on local economic growth. Among these, the impact coefficient for the Wuhan Urban Agglomeration is the highest, while the coefficient for the Poyang Lake Urban Agglomeration is the lowest. Models (8), (10), and (12) include the squared term of the coupling coordination degree $(\ln d)^2$, and the results show that there is an inverted “U” relationship between the industrial collaborative agglomeration-technological innovation coupling coordination degree and economic growth in all three urban agglomerations.

Table 6. Heterogeneity Test Results

	Wuhan Urban Agglomeration		Poyang Lake Urban Agglomeration		Chang-Zhu-Tan Urban Agglomeration	
	Model (7)	Model (8)	Model (9)	Model (10)	Model (11)	Model (12)
L.Inpergdp	0.465* (1.68)	0.0341 (0.21)	-1.129** (-2.10)	-1.275* (-1.74)	-1.498* (-1.67)	-1.276 (-1.41)
Ind	1.602* (1.73)	-13.39*** (-3.07)	0.152** (2.06)	-5.612** (-2.51)	0.853* (1.79)	-10.97*** (-3.40)
(Ind) ²		-3.862*** (-3.14)		-1.401*** (-3.19)		-4.704*** (-2.99)
Control	Control	Control	Control	Control	Control	Control
N	80	80	90	80	64	64
AR (2)	0.9009	0.2557	0.2305	0.4804	0.6722	0.5352
Sargan Test	0.9762	0.9789	0.9974	0.9993	0.9951	0.9443

5.3 Test and Discussion of Threshold Effect

It is concluded from the above analysis that there is a nonlinear relationship between industrial collaborative agglomeration, coupled coordination of scientific and technological innovation and economic growth. In order to further confirm, this paper constructs a panel threshold model to verify whether there is a threshold effect and nonlinear relationship between related variables, and constructs a threshold model with the coupling coordination degree of industrial collaborative agglomeration, industrial collaborative aggregation and scientific and technological innovation as the threshold variables.

The model is as follows:

$$y_{it} = c_{it} + \beta_1 x_{it} I(q_{it} \leq \gamma_1) + \beta_2 x_{it} I(\gamma_1 q_{it} \leq \gamma_2) + \beta_3 x_{it} I(q_{it} \geq \gamma_2) + \beta_4 \ln gov_{it} + \beta_5 \ln fin_{it} + \beta_6 \ln fdi_{it} + \beta_6 \ln road_{it} + \varepsilon_{it} \quad (7)$$

In the formula, i represents the prefecture-level city, t represents the year, represents the regression coefficient, is the threshold variable, is the calculated threshold value; β_1 、 β_2 、 $\beta_3 q_{it} \gamma I()$ is indicative function, when the conditions are met, the value of the indicative function is 1, otherwise it is 0. $q_{it} \leq \gamma$ ε_{it} Is a random interference term.

stata16 was used to process the data, and the significance test of threshold effect was carried out to verify whether the threshold model was reasonable, and the threshold value and threshold number were calculated. Meanwhile, regression estimation was performed. The results are shown in Table 7 and Table 8. In Table 7, the effects of industrial collaborative agglomeration on scientific and technological innovation, industrial collaborative agglomeration on economic growth, and scientific and technological innovation on economic growth all pass the single threshold and double threshold significance test, but fail the three-threshold test. It can be seen that industrial synergistic agglomeration has a double threshold effect on scientific and technological innovation, industrial synergistic agglomeration on economic

growth, and scientific and technological innovation on economic growth. Table 8 shows the regression results of the threshold model Table. In model (7), the two thresholds of industrial collaborative agglomeration are 5.717 and 7.131, respectively. When $\ln inc < 5.717$ and $5.717 < \ln inc < 7.131$, their regression coefficients are both significant at 1% level. When $\ln inc$ exceeds the critical value of 7.131, its regression coefficient is positive though not significant. This indicates that the influence of industrial collaborative agglomeration on technological innovation will have different impacts in different regions. Industrial collaborative agglomeration and scientific and technological innovation need to be continuously run in a specific threshold interval, and a negative value in this interval indicates that the research and development of scientific and technological innovation results may take a long time, cannot be applied in time to industrial development, and it is difficult to transform productivity. The reason for the low transformation efficiency of scientific and technological achievements lies in the system mechanism of separating R&D from production, research and development first, then transformation, and then application and promotion. In addition, enterprises pass through the government, industrial management and other departments to convey the demand to the scientific research department, and the enterprises have no direct contact with the scientific research department, so it is difficult to accurately match and docking in the multi-link communication process. When $\ln inc$ exceeds the critical value of 7.131, the regression coefficient changes from negative to positive, indicating that scientific and technological achievements and enterprises have gradually integrated through running-in, breaking through the bottleneck of scientific and technological achievements, and developing in a good direction. In model (8), the threshold variable is the coupling degree of industrial collaborative agglomeration and scientific and technological innovation, and the threshold values are 0.006 and 0.076 respectively. When $\ln d < -1.943$, $-1.943 < \ln d < -1.516$ and $\ln d > -1.516$, the regression coefficients are 0.262, 0.029 and 0.162, respectively. The promoting effect of industrial coordinated agglomeration on economic growth shows a “strong-weak-strong” trend, indicating that industrial coordinated agglomeration initially has a significant promoting effect on economic development through complementarity effect, scale economy effect, knowledge spillover effect, industrial structure upgrading effect, etc. However, with the further improvement of industrial collaborative agglomeration level, the scale of enterprises continues to expand. There may be a shift from economies of scale to diseconomies of scale, and the average cost of enterprises will gradually increase, which will bring negative effects on regional economic development. If the production scale can be properly adjusted and a good cooperative division of labor system established, the effect of scale economy will continue to be brought into play. In model (9), the threshold variable is the coupling degree of industrial collaborative agglomeration and scientific and technological innovation, and the two threshold values are -1.995 and -0.890, respectively. When $\ln d < -1.995$, $-1.995 < \ln d < -0.890$ and $\ln d > -0.890$, the regression coefficients are 0.020, 0.009 and 0.028, respectively. The promotion effect of scientific and technological innovation on economic growth also presents a “strong-weak-strong” trend, indicating that when the coupling degree of industrial collaborative agglomeration and scientific and technological innovation is at a certain threshold range, the threshold of scientific and technological

achievements transformation is getting higher and higher, and the application cost of scientific and technological innovation is too high, resulting in scientific and technological innovation has a certain hindering effect on regional economic development within a specific threshold value. Scientific and technological innovation requires enterprises to break the traditional thinking, combine their own actual situation, explore practice, establish innovation results suitable for enterprise development, and promote enterprise development.

Table 7. Threshold Effect Test, Estimated Value and Critical Value

Explained variables	Explanatory variables	Threshold variable	Type of test	F-value	P value	Threshold d estimates	Threshold		
							1%	5%	10%
Scientific and technological innovation (Intec)	Industrial collaborative agglomeration	Industrial collaborative agglomeration	Single threshold	18.29***	0.000	7.131	27.883	18.462	16.625
	(lninc)	(lninc)	Double sill	23.12**	0.013	5.717	27.957	17.490	15.067
			Three sill	7.31	0.650	7.763	45.208	37.701	35.030
Economic growth (lnpergdp)	Coordinated industrial agglomeration	Obstetrical coupling (lninc)	Single sill	40.76***	0.006	1.943	30.147	22.028	18.976
			Double threshold	18.21*	0.076	1.516	30.228	19.963	16.818
			Three sill	21.99	0.122	1.005	37.066	28.419	23.762
Economic growth (lnpergdp)	Scientific and technological innovation	Obstetrical coupling degree (lninc)	Single threshold	21.05***	0.01	1.995	20.539	14.464	11.926
	(Intec)	(lninc)	Double sill	14.72*	0.06	0.890	17.495	14.729	13.813
			Three sill	12.58	0.13	2.004	22.079	17.672	13.764

Table 8. Regression Results of Threshold Model

Model (7)		Model (8)		Model (9)	
lninc × I	1.155	lninc × I	0.262***	lninc × I	0.020*
(lninc < 5.717)	(0.207)	(lninc < 1.943)	(0.056)	(lninc < 1.995)	(0.011)
lninc × I	0.580	lninc × I	0.029	lninc × I	0.009
(< lninc < 5.717)	(0.177)	(1.943 < LND) <	(0.043)	(-1.995 < lninc < -	(0.011)

7.131)		−1.516		0.890)	
lninc× I	0.206	lninc × I	0.162***	lninc× I	0.028***
(lninc > 7.131)	(0.191)	(LND > 1.516)	(0.045)	(LND > 0.890)	(0.010)
lnfdi	19.390***	lnfdi	11.57	lnfdi	0.889
	(1.356)		(0.287)		(0.900)
lnroad	0.048	lnroad	0.0392***	lnroad	0.030***
	(0.038)		(0.010)		(0.008)
lngov	0.039	lngov	0.016	lngov	0.033
	(0.049)		(0.0123)		(0.010)
lnfin	0.018	lnfin	0.000	lnfin	0.000
	(0.023)		(0.006)		(0.005)
_cons	44.65	_cons	22.31	_cons	0.583
	(3.695)		(0.685)		(1.912)
R²	0.861	R²	0.940	R²	0.950
F Statistics	33.23***	F Statistics	130.41***	F statistic	2.520***

6. Conclusions and Recommendations

6.1 Conclusions

By analyzing the mechanism of the coupling of industrial collaborative agglomeration and scientific and technological innovation on economic growth, and using the panel data of 28 prefecture-level cities in the middle reaches of the Yangtze River from 2010 to 2019, this paper uses the GMM model to prove whether the coupling and coordination of industrial collaborative agglomeration and scientific and technological innovation can promote economic growth. $(\ln d)^2$ term is also added to verify whether the coupling coordination of industrial collaborative agglomeration and scientific and technological innovation has a nonlinear relationship with economic growth. This study built a threshold effect model, and took the coupling coordination degree of industrial collaborative agglomeration, industrial collaborative agglomeration and scientific and technological innovation as the threshold variable, to verify whether there is a threshold effect and nonlinear relationship between the related variables. The following conclusions are drawn:

(1) From 2010 to 2019, the coupling coordination degree of 28 prefecture-level cities in the middle reaches of the Yangtze River showed a fluctuating upward trend, and there were significant-differences in the coupling coordination degree of various prefecture-level cities. As a whole, the coupling degree of

the middle reaches of the Yangtze River was in the stage of low coupling degree and high imbalance. Among them, the coupling coordination degree of provincial capital cities is generally higher than that of other prefecture-level cities, and Wuhan ranks first among the 28 prefecture-level cities. The coupling coordination level of other prefecture-level cities is generally low, in the stage of low level coupling and serious imbalance, with little fluctuation and little growth trend in the past ten years.

(2) The GMM method is adopted to add control variables. The linear regression results of the coupling coordination degree of productive service agglomeration and manufacturing industry and scientific and technological innovation on economic growth show that the coupling coordination of industrial synergy agglomeration and scientific and technological innovation has a significant promoting effect on economic growth; is significant at the 1% level. $[(\ln d)]^2$ Then, the square term of the coupled coordination degree is added, and the coefficient is negative and significant at the 1% level, indicating that there is a nonlinear relationship between the industrial collaborative agglomeration and the coupled coordination of scientific and technological innovation and economic growth, showing an inverted “U” nonlinear feature. $[(\ln d)]^2$

(3) The infrastructure level has an obvious indirect driving effect on economic development, laying a solid foundation for industrial collaborative agglomeration and scientific and technological innovation. Thus, it is necessary to pay attention to the basic role of infrastructure. Also, full play should be given to the role of the market, the role of the government should be better leveraged, and a service-oriented government needs to be built. Too much government intervention will lead to overcapacity, weaken the market mechanism, and have a slight negative effect on economic development.

(4) Construct a threshold model with the coupling coordination degree of industrial synergy agglomeration, industrial synergy agglomeration and scientific and technological innovation as threshold variables. After a while, industrial collaborative agglomeration and scientific and technological innovation show a good trend of coupling and coordination; The promoting effect of industrial coordinated agglomeration and scientific and technological innovation on economic growth presents the characteristics of “strong-weak-strong”; When the level of industrial coordinated agglomeration exceeds a certain threshold, there may be a shift from scale economy to scale diseconomy; When the obstetrical coupling degree is at a certain threshold interval, scientific and technological innovation has a negative effect on regional economic development.

6.2 Recommendations

(1) The obstetrical coupling degree of provincial capitals is relatively high, so it is necessary to maintain a high level of industrial collaborative agglomeration, and guide the exploration of the industrial collaborative development pattern of urban agglomerations such as “core city R & D design + collaborative manufacturing in surrounding cities” and “core city platform economy + industrial ecosystem in surrounding cities”. There is also a need to simultaneously strengthen the application and transformation of core city innovation in urban agglomerations as well as, build an innovation network system with reasonable structure, gradient distribution, division of labor and cooperation. We will

support urban agglomerations in accelerating the establishment of a modern industrial system and strengthening industrial support for regional cooperation and development. We will conduct trials of a long-term mechanism for expanding domestic demand in Wuhan, Changsha and Nanchang, allocate more factors to the national domestic demand market in these three cities, and guide and support the three cities in carrying out trials in finance, taxation and land administration. We will prioritize urban clusters in the middle reaches of the Yangtze River in the layout of major industrial projects.

(2) We will increase regional trials and demonstrations of emerging industries and speed up the cultivation of emerging industries. Based on Wuhan's original innovation advantages in electronic information, equipment manufacturing, biomedicines and other high-tech industries, we will promote the industrial chain links corresponding to these innovation chains and related enterprises to establish corresponding pilot, incubation and production bases in Changsha and Nanchang. We will give full play to the main role of the three provinces in the coordinated development of the urban agglomeration in the middle reaches of the Yangtze River, build an academic research community, make full use of rich university resources, and encourage major universities and enterprises to cooperate with enterprises. We will also, effectively improve regional innovation capacity, and provide intellectual support for promoting the coordinated development of provinces and cities in the Yangtze River basin.

(3) The government should guide and optimize industrial development in light of the situation, formulate reasonable industrial policies, and avoid the development of enterprises into diseconomies of scale as much as it can, as this will negatively impact economic development. All enterprises should strengthen the economy of scope and joint production, to enhance the correlation between industries within the region. At the same time, it is necessary to strengthen infrastructure construction, increase support for infrastructure construction in urban agglomerations, and promote the integration of regional transportation. Also, we should optimize the orderly distribution of industrial structure and jointly promote the accumulation of factor endowments, while giving full play to the role of the "invisible hand" to optimize resource allocation and avoid excessive regional homogenization.

(4) It is important to strengthen cooperation among governments, banks, and enterprises, build a unified credit information platform, integrate all kinds of resources, strengthen economic and technological cooperation, and build an integrated regional cooperation network and public service platform. Relying on universities and research institutes in the three provinces, we will build a science and technology education information network; as well as a technical support platform for key industries in the middle reaches of the Yangtze River city cluster in areas such as electronic information, automobiles and equipment manufacturing. We will give full play to the potential of social organizations, actively innovate ways of cooperation, create platforms for cross-province cooperation, define the roles of government and social organizations, and promote complementarity, integration, cooperation and exchanges.

7. Future Outlook

Based on the above research, there are still some shortcomings in this paper. In the future, on this basis, industrial synergy agglomeration, scientific and technological innovation and economic development will be included in the analysis framework of spatial spillover for discussion, and the mechanism of spatial spillover effect of industrial synergy agglomeration and scientific and technological innovation will be clarified at the theoretical level, so as to make up for the traditional research methods underestimating the real impact of industrial synergy agglomeration and scientific and technological innovation coupling on urban economic development due to the failure to consider spatial factors. The heterogeneity of industrial synergy agglomeration and scientific and technological innovation coupling on urban economic development will be deeply discussed by segment, industry and region, so as to provide necessary theoretical support and decision-making reference for differentiated customization of high-quality economic development policies in various regions.

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