ISSN 2616-5902 Vol. 3, Issue 6: 27-43, DOI: 10.25236/AJBM.2021.030605

How Does Synergistic Agglomeration of Productive Service Industry and Manufacturing Industry Promote Regional Innovation

Yixin Dai[1,*]

[1] *School of Business,Nanjing University, Nanjing 210009, China*
[*] *Corresponding Author*

Abstract: *Based on the theoretical analytical framework of new economic geography, this paper measures the degree of synergistic agglomeration of productive service industry and manufacturing industry by using provincial panel data from 2006 to 2016 in Central and East China, and adopts SYS-GMM to study the impact of synergistic agglomeration of productive service industry and manufacturing industry on regional innovation. The results indicate that the synergistic agglomeration of productive service industry and manufacturing industry can promote regional innovation, but the degree of synergistic agglomeration shows a significant difference in spatial distribution. Further analysis shows inconsistencies in the impact of industrial synergistic agglomeration on regional innovation. For the regions at the early and middle stages of industrialization, industrial synergistic agglomeration of productive service industry and manufacturing industry can promote innovation, while for the regions at the later stage of industrialization, industrial synergistic agglomeration of productive service industry and manufacturing industry will restrain innovation. The industrial synergistic agglomeration of productive service industry and manufacturing industry mainly acts on regional innovation through three channels, including information sharing effect, infrastructure scale economy effect and knowledge spillover effect. The above findings provide enlightenment for industrial development and adjustment in different regions.*

Keywords: *synergistic agglomeration; productive service industry, regional innovation, manufacturing industry*

1. Introduction

China has put forward the "Made in China 2025" strategy, which is aimed at making China's manufacturing industry lead the world by the middle of the 21st century, thus achieving sustainable and stable economic growth. After a certain stage of industrialization and marketization, as a typical spatial organization phenomenon of economic activities, industrial agglomeration has become an important driving force and form for improving industrial competitiveness and promoting sustainable economic growth. Therefore, industrial agglomeration is an important direction of China's future industrial competition and integration. With the continuous refinement and deepening of industrial division, the interrelation between productive service industry and manufacturing industry is getting closer, and more and more scholars at home and abroad have begun to pay attention to the interaction and agglomeration form between them. From the historical experience of developed countries and regions, it is a typical path of economic development and transformation to promote industrial agglomeration and effectively realize the synergistic drive of modern service industry and manufacturing industry. The continuous introduction of new technologies and their achievements industrialization have made technical innovation become an important source of enterprise competitiveness. In order to be invincible in international competition, industrial agglomeration in advantaged regions must strengthen technical innovation and improve the innovation capacity, thus forming and maintaining strong international competitiveness. "Forming a innovative situation with multi-agent cooperation and promotion in an all-round manner" has been clearly put forward in the 2018 Government Work Report of the State Council. Therefore, it is of great practical significance to study the impact of the synergistic agglomeration of productive service industry and manufacturing industry on regional innovation.

Due to the fact that the productive service industries are born in the manufacturing industry and have a relatively short history of division and differentiation with the manufacturing industry, there is little research on the synergistic agglomeration of the productive service industries and the

ISSN 2616-5902 Vol. 3, Issue 6: 27-43, DOI: 10.25236/AJBM.2021.030605

manufacturing industry at home and abroad. In general, the current academic research on this issue mainly focuses on three main aspects: research on the existence of synergistic agglomeration, research on the measurement level and differentiation of synergistic agglomeration, and research on the impact of synergistic agglomeration on productivity and innovation.

The first is the research on the existence of synergistic agglomeration. The theoretical framework of agglomeration could be traced back to Marshall's (1890) Externality Theory. Later, Krugman (1991) demonstrated the production mechanism of agglomeration economies from the perspective of the new economic geography. The "vertical correlation model" proposed by Venables (1996) provided a useful analytical framework for the study of industrial synergistic agglomeration by incorporating inter-industry links into the analytical framework of synergistic agglomeration. While on this basis, Ellison and Glaeser (1997) conceptualized industrial synergistic agglomeration and shifted the research focus to the intrinsic connection between industrial agglomerations. There were many studies based on synergistic agglomeration among manufacturing industries (Henderson, 1998; Amiti, 2005; Forslid and Midelfart, 2005), while there were fewer studies focusing on the synergistic agglomeration of service industry and manufacturing industry, especially productive service industry and manufacturing industry: Andersson (2004) discussed the interaction between productive service industry and manufacturing industry in agglomeration and location selection based on the relation between supply and demand, while Gao and Liu (2008) put forward the theory of industrial synergistic agglomeration to promote industrial agglomeration and industrial upgrading, and pointed out that improving the synergistic agglomeration of manufacturing and service industries was an effective way to realize the virtuous agglomeration and upgrading of manufacturing industry. Zhang Yifeng and Li Meiling (2011) carried out an empirical study on the data of China's provinces by using location quotient and concluded that there was a strong positive correlation between the agglomeration of productive service industry and the agglomeration of advanced manufacturing industry.

Regarding the measurement of the level of industrial synergistic agglomeration, more measurement methods have been derived according to different research perspectives, mainly including: the E-G index (Ellison and Glaeser, 1997), the D-O index (Duranton and Overman, 2005; 2008), the Colocalization index (Stephen and Erik, 2016), the γ index and the Θ index (Chen and Chen Jianjun, 2012; Chen Jianjun, 2016). In terms of differential research on synergistic agglomeration, Desmet and Fafchamps (2005) investigated differences in the agglomeration status and spatial distribution of manufacturing and productive service industries at the county level in the United States. There also exists differences of synergistic agglomeration model of productive service industry and manufacturing industry at the city level. Large cities first focused on productive service industry in order to cause the agglomeration of manufacturing industry, while small cities first supported the agglomeration of service industry through the agglomeration of manufacturing industry (Chen Jianjun and Chen Jingjing, 2011; Wang Shuo, 2013). At the same time, there are differences in the synergistic agglomeration between different productive service industries and manufacturing industry. Jiang Manqi and Xi Qiangmin (2014) found that the productive service industries that are highly synergistic with the manufacturing industry are those with high input-output intensity and high added value.

There are different research conclusions on the impact of synergistic agglomeration of productive service industry and manufacturing industry on productivity and innovation. Some studies supposed that there was a positive effect on regional economic growth (Chen and Chen Zhaofeng, 2014; Hu Yan and Zhu Wenxia, 2015), but Yan Fengzhu and Qiao Juan (2010) concluded that industrial agglomeration had a negative effect on industry growth in general. At the same time, there might be a non-linear inverted "U-shaped" relationship between industrial synergistic agglomeration and TFP, and there were both scale and crowding effect in industrial agglomeration(Zhou Shengqiang and Zhu Weiping, 2013). It was also found that when the synergistic agglomeration was at a low level, industrial synergistic agglomeration could promote the upgrading of manufacturing industry. On the contrary, when the level of synergistic agglomeration of the two industries exceeded a certain scale, it would have a reverse effect on the upgrading of the manufacturing industry (Guo Qingbin et al., 2018).

Most of the literature focuses on the impact of agglomeration on regional and industrial productivity and investigates the impact of agglomeration in a single industry on regional innovation while there is little literature studying on the relationship between agglomeration and innovation. Du Chuanzhong and Qi Xiaofu (2009) created a dynamic game model for technical innovation of cluster enterprises and concluded that the degree of product differentiation of cluster enterprises had a significant impact on technical innovation. Gu Naihua (2011) believed that the agglomeration of urban productive service industry could significantly improve the TFP of local industry. Chen Xiaofeng and Chen Zhaofeng(2014) pointed out that the synergistic agglomeration of productive service industry and

ISSN 2616-5902 Vol. 3, Issue 6: 27-43, DOI: 10.25236/AJBM.2021.030605

manufacturing industry was beneficial to improving the efficiency and competitiveness of regional industries. Chen Jianjun et al. (2016) argued that industrial synergistic agglomeration could create innovation and improve urban production efficiency through division of labor and technological externalities. Zhang Caijiang et al. (2017) hold that high-tech industrial agglomeration had obvious differences in regional innovative technology development in different types of regions.

Compared with the existing literature, the possible contributions of this paper are as follows: First, little literature has investigated the impact of the phenomenon of industrial synergistic agglomeration on regional innovation from the perspective of the increasing returns to scale of industrial synergistic agglomeration. It can be noted that existing domestic and foreign research has paid more attention to the impact of synergistic agglomeration on the productivity and economic growth of manufacturing industry, while there are few studies on the impact of innovation that are critical to regional economic development. Second, there is little literature on the theoretical mechanism of the synergistic agglomeration of productive service industry and manufacturing industry on regional innovation. Although scholars have noted that the synergistic agglomeration of productive service industry and manufacturing industry has the potential to affect innovation, they have not deeply analyzed and explored the underlying mechanism, so as to analyze the influence path of synergistic agglomeration on regional innovation from the theoretical and empirical perspectives. In order to make up for the deficiency of the existing literature, this paper first constructs a simple theoretical model and analyzes the mechanism of the synergistic agglomeration of productive service industry and manufacturing industry on regional innovation. On this basis, this paper will attempt to construct a synergistic agglomeration index of productive service industry and manufacturing industry to further study and analyze the impact of synergistic agglomeration of productive service industry and manufacturing industry on regional innovation. Based on the different levels of regional industrialization development, 18 selected provinces and cities in the Central and East China are divided into two regions at the early and middle stage of industrialization and at the later stage of industrialization, and the empirical test is conducted for samples.

2. Theoretical model

The high level of synergistic agglomeration between productive service industry and manufacturing industry essentially reflects the fact that both of them are at a relatively reasonable level of agglomeration and have a synergistic effect. As the demand sector of productive service industry, the development and agglomeration of manufacturing industry creates market demands for productive service industry. As a specialized manufacturing service sector, productive service industry can improve the specialization level of manufacturing industry, while reducing the production cost of manufacturing industry and expanding capital and knowledge-intensive production, thus improving productivity and innovation of enterprises. Therefore, the "demand correlation" effect between productive service industry and manufacturing industry would deepen their mutual dependence (Chen Jianjun and Chen Jingjing, 2011), that was, productive service industry tended to be located in manufacturing cluster districts and vice versa. Thus, increasing the degree of synergistic agglomeration would be more conducive to giving play to the agglomeration effect of the respective industry, while promoting the spatial relation between the productive service industry and manufacturing industry and driving the effective interaction and integration of two types of industries (Zhang Hu et al., 2017).

At the same time, the synergistic agglomeration of productive service industry and manufacturing industry may also have some negative effects, which are related to the heterogeneity of regional industrialization development. Regions with a lower degree of industrialization are more conducive to exerting the returns to scale effect of synergistic agglomeration. In the regions with high degree of industrialization, excessive agglomeration may have a "congestion effect". On the one hand, enterprises in the same or similar industries will have vicious competition for capturing markets and resources. On the other hand, because the productive service industry is attached to upstream and downstream industries of the manufacturing industry, so homogeneous or similar specialized demand for labor forces will lead to an increase in labor costs, which will increase the production cost and inhibit the innovative impetus of enterprises. If factors such as competition in the product market and costs in the factor market were taken into account, the negative spillover effect due to excessive agglomeration of enterprises would hinder profit enhancement, thus restraining enterprise innovation (Ye Ninghua et al., 2014). In addition, Wu Xianfu(2018) found that productive service enterprises in industrial synergistic cluster districts especially manufacturing enterprises could not easily exit a region, so that enterprises with relatively low productivity stayed in industrial cluster districts for a long time or even became "zombie enterprises", which would reduce the production and innovation capacity of the relevant

ISSN 2616-5902 Vol. 3, Issue 6: 27-43, DOI: 10.25236/AJBM.2021.030605

enterprises.

Before carrying out the empirical analysis, this paper will construct a simple mathematical model for explanation. It is assumed that the typical manufacturer in the market determines whether the enterprise seeks for industrial agglomeration at phase 0 and its production function is the Cobb-Douglas production function as follows:

$$y_0 = AK_0^{\alpha} L_0^{\beta}$$

Among them, y_0 represents the output of typical manufacturer, and A represents the technical level of innovation capability. K_0 refers to capital input, and L_0 represents labor input. It is assumed that the growth rates of capital and labor are r and n, respectively($r \geq 0$, $n \geq 0$). At this time, the manufacturer is in the constant returns to scale, that is, $\alpha+\beta=1$. When the typical manufacturer does not seek for the economies of scale brought by industrial agglomeration, its technical level at phase 1 is:

$$A=\frac{y_1}{\left[(1+r)K_0\right]^{\alpha}\left[(1+n)L_0\right]^{\beta}}$$

In order to simplify the derivation and calculation, this paper assumes that the relocation cost of the enterprise is zero in the case of seeking for industrial agglomeration. Due to the scale effect of industrial agglomeration, the production elasticity of capital and labor force in the production function changes, that is, changes of α and β indexes in the formula, among which the change of production elasticity α of capital is ε, and the change of production elasticity β of labor force is θ. $\varepsilon+\theta>1$.

However, due to the lagged effect of industrial synergistic agglomeration on technical progress, that is, industrial agglomeration does not have an immediate effect on technical progress, but only has an effect on the production elasticity of capital and labor force, which transforms the production function of a typical manufacturer at phase 0 when the industrial agglomeration occurs into:

$$y_0 = AK_0^{\varepsilon} L_0^{\theta}$$

Therefore, the increase in output brought by scale economies effect of industrial agglomeration is:

$$\Delta y = A*(K_0^{\varepsilon} L_0^{\theta} - K_0^{\alpha} L_0^{\beta})$$

Assuming that the typical enterprise will invests all of its increase in output or profit in technology development, which causes the technical change, the technical level will change from A to B. At the beginning of phase 1, the production function of typical manufacturing is as follows:

$$y_1 = B\left[(1+r)K_0\right]^{\varepsilon}\left[(1+n)L_0\right]^{\theta}$$

At this time, the technical progress is:

$$B=\frac{y_1}{\left[(1+r)K_0\right]^{\varepsilon}\left[(1+n)L_0\right]^{\theta}}$$

Assuming that the total output of manufacturer at phase 1 is consistent under the condition of no industrial agglomeration and industrial agglomeration, the relative change in technology due to industrial agglomeration can be expressed as follows.

$$\frac{B}{A}=\frac{\left[(1+r)K_0\right]^{\alpha}\left[(1+n)L_0\right]^{\beta}}{\left[(1+r)K_0\right]^{\varepsilon}\left[(1+n)L_0\right]^{\theta}}$$

It is obvious from the above equation that ε and θ are decreasing. If $\varepsilon+\theta=\mu$ (μ is a

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constant greater than 1), $\frac{B}{A}=1$. It can be obtained that:

$$\varepsilon^{*}=\frac{\alpha\ln\left[(1+r)K_0\right]+\beta\ln\left[(1+n)L_0\right]-\mu\ln\left[(1+n)L_0\right]}{\ln\left[(1+r)K_0\right]-\ln\left[(1+n)L_0\right]}$$

$$\theta^{*}=\frac{\alpha\ln\left[(1+r)K_0\right]+\beta\ln\left[(1+n)L_0\right]-\mu\ln\left[(1+r)K_0\right]}{\ln\left[(1+n)L_0\right]-\ln\left[(1+r)K_0\right]}$$

It can be found that two conditions will occur in solving the equation at this time. The specific analysis is as follows:

If $(1+n)L_0=(1+r)K_0$, it means that $\frac{B}{A}=1$ has no solution, that is, $\frac{B}{A}\neq 1$. Its economic implication is that industrial synergistic agglomeration can have an effect on technical progress. $(1+n)L_0=(1+r)K_0$ is substituted to obtain $\frac{B}{A}=\left[(1+r)K_0\right]^{1-(\varepsilon+\theta)}$.

① When $(1+r)K_0>1$, due to $1-(\varepsilon+\theta)<0$, $\frac{B}{A}<1$ is established constantly. The economic conclusion that can be drawn from the above equation is that the technical progress is only affected by initial capital and capital growth rate, and has no relation with the returns to scale of industrial agglomeration.

② When $(1+r)K_0=1$, $\frac{B}{A}=1$ (contradictory to the presupposition, so it is rejected).

③ When $(1+r)K_0<1$, due to $1-(\varepsilon+\theta)<0$, $\frac{B}{A}>1$ is established constantly. The conclusion that can be drawn is that the technical progress is only affected by initial labor force and labor force growth rate, and has no relation with the returns to scale of industrial agglomeration.

However, if the two conclusions above conflict with the previous presuppositions, the situation that $\frac{B}{A}=1$ has no solution does not exist.

If $(1+n)L_0\neq(1+r)K_0$, it means that $\frac{B}{A}=1$ has solutions, which are ε^{*} and θ^{*}.

① When $\varepsilon<\varepsilon^{*}$ and $\theta<\theta^{*}$, it means that returns to scale brought by industrial synergistic agglomeration will promote technical progress;

②When $\varepsilon=\varepsilon^{*}$, $\theta=\theta^{*}$ and $\varepsilon^{*}+\theta^{*}>1$, it means that returns to scale brought by industrial synergistic agglomeration has no effect on technical progress;

③When $\varepsilon>\varepsilon^{*}$ and $\theta>\theta^{*}$, it means that returns to scale brought by industrial synergistic agglomeration will hinder technical progress instead of promoting it.

From the above analysis, it can be seen that the returns to scale from industrial synergistic agglomeration will promote technical progress, but as the scale of agglomeration continuously increases, it may hinder the technical progress, thus restraining the level of regional innovation. This paper believes that this is related to the heterogeneity of regional industrialization development. Regions with low degree of industrialization are more conducive to exert the returns to scale effect of synergistic agglomeration, while in the regions with high degree of industrialization, excessive agglomeration may have a "congestion effect", that is, industrial synergistic agglomeration has a negative spillover effect.

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Based on the above analysis, the synergistic agglomeration of productive service industry and manufacturing industry leads to both positive and negative effects, and empirical evidence has been provided in the literature. This paper also considers that there is a conflict between the synergistic agglomeration effect and the congestion effect. However, this paper more emphasizes on the synergistic development of productive service industry and manufacturing industry agglomeration, i.e. the degree of structural optimization between them. Therefore, in terms of overall impact, this paper holds that the positive effect of synergistic agglomeration between productive service industry and manufacturing industry will be greater than the negative effect, while there has heterogeneous characteristics in regional impact. Based on this, this paper proposes the following two basic hypotheses:

H1: Industrial synergistic agglomeration of productive service industry and manufacturing industry can promote regional innovation.

H2: The positive effect of synergistic agglomeration on innovation decreases with the increase of the industrialization level of the region, i.e. in the regions with high degree of industrialization, the synergistic agglomeration will have a smaller innovative effect and even create a negative effect. In the regions with low degree of industrialization, the synergistic agglomeration will have a significantly positive effect on innovation.

Although the core hypothesis of this paper, that is, improving the industrial synergistic agglomeration of productive service industry and manufacturing industry can promote regional innovation, has been highlighted in the preceding part of the text, the internal mechanism of this issue has not been deeply analyzed. Therefore, this paper will further discuss the channels through which the synergistic agglomeration of productive service industry and manufacturing industry influences regional innovation.

First, the synergistic agglomeration of manufacturing industry and productive service industry expands external economies of scale, facilitates the sharing of the same production factors, and stimulates the construction scale and quality of innovation infrastructure. A certain level of agglomeration scale is an initial condition for synergistic agglomeration, so the cost reduction effect of economies of scale still remains, with the emphasis on infrastructure elements. On the one hand, enterprises can directly benefit from the reduction of production and innovation costs, thus introducing more high-quality and sufficient resources into innovation activities, so as to improve innovation efficiency and output. On the other hand, economies of scale can improve the scale and quality of infrastructure in cluster districts, and enterprises can share quality infrastructure at a lower cost. For example, the adjacency of enterprises and the information infrastructure make the information seeking and acquisition for innovation and research and development faster, while the logistics and warehousing infrastructure reduces the communication cost between enterprises, transportation cost, and so on. Therefore, complete infrastructure construction will be an important support for synergistic agglomeration to promote regional innovation.

Secondly, the synergistic agglomeration of manufacturing industry and productive service industry enhances the inter-industry correlation effect, thus further promoting knowledge spillover and learning effects, which is conducive to improving regional research and development impetus and capability. Industrial agglomeration is a concentrated layout of a large number of industries in accordance with the deepening and extension of the division of labor, and the enterprises in industrial synergistic agglomeration are all vertically and horizontally correlated, or produce similar products, or are in the upstream and downstream of production and have correlations. Productive service activities are dependent on manufacturing enterprises. Due to the spatial proximity and agglomeration with the manufacturing industry, specialized factors such as human capital and intellectual capital will bring about technological externalities and knowledge spillover effect through the deepening of the division of labour and cooperation, thus promoting exchanges between enterprises, enhancing mutual learning, imitation and innovation between manufacturing and productive service enterprises, and improving the technical content of the whole industry products.

Finally, industrial agglomeration strengthens business contacts between enterprises, provides more information and channels for product innovation, enhances information exchange between similar enterprises and between upstream and downstream enterprises, and provides a better platform for new product development and innovation. With the enhancement of inter-regional industrial agglomeration, the information exchange and cooperation among enterprises can be strengthened, which will further promote the R&D innovation capacity of enterprises, thus improving the innovation capacity of the region.

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Based on the above analysis, this paper proposes hypothesis 3 for the influence mechanism of synergistic agglomeration of productive service industry and manufacturing industry on regional innovation:

H3: The industrial synergistic agglomeration of productive service industry and manufacturing industry mainly acts on regional innovation through three channels, including external scale effect, knowledge spillover effect and information sharing effect.

3. Variable selection and Econometric Analysis

3.1 Model setting

In order to maximize their own interests, productive services and manufacturing industries will gather production activities in specific regions and interrelate with each other.When the industrial agglomeration effect is brought into play, the industrial agglomeration of productive services and manufacturing industry will produce a certain synergistic effect, thus realizing the interaction and integration of productive services and manufacturing industry.Since industrial synergistic agglomeration is a process of dynamic change, that is, industrial agglomeration in the current period will have an impact on regional innovation in the next period, according to the theoretical model, we establish the following econometric model:

$$lnRI_{it}=a+\theta lnRI_{it-1}+\beta_1 lnCA_{it}+\beta_2 lnX_{it}+\varepsilon_{it}$$

Where, RIit represents the level of regional innovation, RIit-1 represents the regional innovation in T-1 year , and θ represents the coefficient.CAit represents the industrial synergistic aggregation index .In this paper, the location quotient proposed by Haggett (1996) is used to construct the synergistic agglomeration index of productive services and manufacturing industries.location quotient reflects the degree of industrial spatial distribution or professional agglomeration of industrial distribution, and its basic calculation formula is as follows:

$$r_{ij}=\frac{g_{ij}/G_i}{g_j/G}$$

Where, j represents region and i represents industry, which in this paper specifically refers to productive services and manufacturing. g_{ij} represents the gross product , G_i represents the gross product of industry i in the whole country, represented by the added value of industry i in the current year, g_j represents the gross product of all industries in region j , and G is represented by the gross domestic product of the whole country.

If the location quotient value is greater than 1, it can be considered that the industry is a specialized sector with relatively agglomeration advantage in the region.The higher the value, the higher the level of specialization.On the basis of location quotient, the calculation formula of synergistic agglomeration index is as follows:

$$R_j=1-\frac{\left|r_{mj}-r_{sj}\right|}{(r_{mj}+r_{sj})}$$

r_{sj} and r_{mj} represent the location quotient of productive services and manufacturing in region j , respectively.It can be seen from the above formula that the larger R_j value is, the closer the agglomeration level of m industry (manufacturing) and s industry (productive services) in region j is, and the higher the agglomeration and coordination level of the two industries is.It should be noted that to measure regional industrial synergistic agglomeration, it is necessary to study the location quotient and synergistic agglomeration index of productive services and manufacturing industries at the same time, so as to get a more real conclusion.Otherwise, if the location quotient of productive services and manufacturing industries is very small, the value of synergistic agglomeration index is very high, which is untrue.

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X represents the control variables, including: scientific and technological personnel input (PIN), proportion of government fiscal expenditure in GDP (G), degree of opening to the outside world (FDI), level of informatization (ML) and level of economic development (PGDP).

In view of the late release of China's Statistical Yearbook and the Statistical Yearbook of all provinces, and the adjustment of statistical calibre for many times, Our paper, in combination with the needs of this research, refers to the practice of Li Ziye et al. (2015), classifying the 7 industries of the service industry in the Statistical Yearbook as productive services.The data are mainly from the official website of the National Bureau of Statistics, China Statistical Yearbook, China Industrial Enterprise Database, as well as the statistical Yearbook of 18 provinces (municipalities) in central and eastern China from 2006 to 2017 and their statistical bulletins from 2006 to 2017.

3.2 Variable description

1) Regional innovation (RI).The annual growth rate of the number of patent grants in each region is chosen to represent it.

2) Industrial Synergistic Aggregation Index(CA).It is calculated by location quotient method.As a common method to measure industrial agglomeration from the perspective of region, location quotient can better reflect the regional characteristics of industrial agglomeration areas and the respective characteristics of industries.

3) Number of technical personnel (PIN).Generally speaking, the more the number of scientific and technological personnel invested, the more can promote regional innovation. In this paper, the input of scientific and technological personnel is measured by the number of scientific and technological activities.

4) Science and Technology Investment (EIN).Science and technology expenditure is a direct factor affecting regional innovation. It is expressed by the total internal expenditure of science and technology activity expenditure in each region.

5) Government fiscal expenditure (G).Government fiscal expenditure is an important factor affecting regional innovation, which is represented by the proportion of government fiscal expenditure budget to GDP in this paper.

6) Openness (FDI).Whether capital flow and foreign capital inflow can promote inter-regional technological progress has become an important indicator in the research of regional innovation in recent years.Relevant literature shows that FDI technology spillover effect plays an important role in promoting the technological progress of the host country.Therefore, this paper takes the proportion of the actual transaction volume of foreign direct investment in the regional economy as the index to measure the degree of openness of each region.

7) Informatization level (ML).The development of modern industries cannot be separated from the exchange of information, especially among related industries, and the main means of modern communication is telephone. Therefore, this paper uses the penetration rate of mobile phones in each province (city) to measure.

8) Infrastructure level (IFS).In a region with industrial agglomeration, relevant industries will share local infrastructure. Therefore, this paper adopts per capita urban paved road area of each province to represent the level of local infrastructure.

9) Network level (IN).Network is playing an increasingly important role in the process of modern enterprise communication. Therefore, the ratio between local network penetration rate and national network penetration rate is adopted in this paper to represent the regional network level.

10) Regional economic development level (PGDP).There is no doubt that the level of regional economic development will affect regional innovation. Therefore, this paper chooses the per capita GDP of each region to represent the level of economic development.

Table 1 shows the statistical characteristics of the relevant variables.In the region at the late stage of industrialization, the mean value of the sample of industrial synergistic agglomeration is 0.80, the minimum value is 0.35, and the maximum value is 1.00.The mean value of the innovation sample is 78890.25, the minimum value is 3045, and the maximum value is 269944.In the region in the middle period of pre-industrialization, the mean value of the sample of industrial synergistic agglomeration is 0.78, the minimum value is 0.51, and the maximum value is 1.00.The mean value of the innovation

ISSN 2616-5902 Vol. 3, Issue 6: 27-43, DOI: 10.25236/AJBM.2021.030605

sample is 18233.39, the minimum value is 1361, and the maximum value is 74240.It can be seen that the industrial synergistic agglomeration and innovation in different regions have regional differentiation.This shows from the side that China's regional economic development level is significantly different, but also further shows that the paper divides regions into regions of different stages according to their economic development level, which is reasonable.Jiangsu, Guangdong, Zhejiang, Shandong and other provinces are the most obvious regions of industrial synergistic agglomeration, and the number of patent applications also ranks the top in the country. The number of patent applications granted in Jiangsu, Zhejiang and Guangdong all account for more than 10% of the total number of patent applications granted in the country.

Table 1 Descriptive statistics

Variable name	Mean	standard deviation	minimum	maximum
RI	41591.88	54645.95	1536	26944
CA	0.80	0.16	0.35	1.00
EIN	450.07	394.50	22	1801.23
PIN	435660	321610.9	41141	1210337
FDI	0.03	0.02	0.00	0.08
G	3319.431	2001.073	543.12	12827.8
ML	77.0456	31.6908	19.9133	189.46
IFS	13.4361	4.6709	4.04	25.82
IN	41.5370	17.2502	9.6	76.5
PGDP	37.247	24316.37	43.4	105231.4

3.3 Basic regression results

Table 2 Industrial synergistic agglomeration and regional innovation

	lnRIt					
	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)
	(1)	(2)	(3)	(4)	(5)	(6)
$lnCA_t$	0.151* (1.94)	0.158* (1.76)	0.143* (1.73)	0.182* (1.85)	0.104* (1.91)	0.153* (1.73)
$lnRI_{t-1}$	0.984*** (32.27)	0.984*** (32.14)	0.982*** (31.95)	0.913*** (31.28)	0.981*** (30.94)	0.994*** (30.87)
$lnPIN_t$		0.001* (1.85)	0.001* (1.83)	0.001* (1.91)	0.001* (1.88)	0.001* (1.82)
$lnML_t$			0.211* (1.82)	0.284 (0.56)	0.381 (0.74)	0.976* (1.71)
$lnPGDP_t$				-0.092 (-1.31)	-0.116 (-1.58)	-0.247 (-0.78)
lnG_t					-0.975** (-2.19)	-1.368 (-1.53)
$lnFDI_t$						-0.467** (2.03)
AR(1)P	0.029	0.032	0.140	0.065	0.078	0.032
AR(2)P	0.257	0.254	0.250	0.235	0.220	0.197
Sargan	0.135	0.254	0.304	0.357	0.322	0.357

Table 2 reports the benchmark test results of the econometric model. The coefficient of industrial synergistic agglomeration index in column (1) is 0.151, and it is significant at 10% confidence level.This shows that industrial synergistic agglomeration has a positive effect on regional innovation.This is because the industrial cluster under the synergistic agglomeration will appear a cluster effect, the positive externalities formed within the industrial cluster stimulate the technological innovation activities of individual enterprises within the industrial cluster, the industrial synergistic agglomeration is conducive to the improvement of the technical level of the mutually synergistic industries, thus contributing to the improvement of innovation ability and efficiency. Although SYS-GMM allows the existence of first-order sequence correlation, SYS-GMM requires that the

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residual terms of the model do not have second-order sequence correlation. In addition, SYS-GMM requires that the residual term of the model meet the over-recognition constraint of the moment condition.The first-order sequence correlation, second-order sequence correlation and the test results of the over-recognition constraint on the moment condition of the residuals are all presented in Table 2.AR (2) test results in the model show that there is no second-order sequence correlation of residuals.The results of Sargan test show that the model satisfies the over-recognition constraint of the moment condition.

However, the regression in column (1) may miss other important variables. Studies have shown that the input of scientific and technological personnel, government financial expenditure, degree of opening to the outside world, level of informatization and level of economic development (Shi Xiusong et al., 2009) may also have an impact on regional innovation, and the omission of these variables may lead to errors of omission variables.In order to reduce this estimation error as much as possible, we introduce five control variables, namely, the input of scientific and technological personnel, the level of informatization, the level of economic development, the government financial expenditure and the degree of opening to the outside world.

After adding the control variables of researchers' input, the coefficient of industrial synergistic agglomeration index slightly increases by 0.158, and the coefficient is still significant at the level of 10%, which indicates that the increase of researchers will have a positive effect on regional innovation. The reason is that the increase of researchers will expand the depth and breadth of research on new technologies, which will make the generation of new technologies and new knowledge more intensive. Column (3) introduces informatization level, and the results show that the influence coefficient of informatization level is significantly positive, indicating that informatization level has a positive effect on regional innovation. This is intuitive because the improvement of enterprise informatization level will reduce the management cost and organizational innovation ability of enterprises, thus promoting the research and development of new products and innovation of enterprises, and promoting the technological progress of the whole region.In Table2 column(4), the coefficient of economic development level is not significant after the introduction of economic development level. This is because the theoretical analysis shows that under different levels of economic development, industrial synergistic agglomeration will have different influences on regional innovation. After adding the control variable of government fiscal expenditure, the coefficient of government fiscal expenditure is -0.975, which is significant at the level of 5%, indicating that government fiscal expenditure has a negative effect on regional innovation. One possible reason is that government financial expenditure includes government subsidies to enterprises.When enterprises successfully obtain high intensity government subsidies through rent-seeking activities, this may greatly weaken the motivation of enterprises to obtain excess profits through research and development and innovation to improve production efficiency. Column (6) introduces foreign direct investment, and the results show that the coefficient of FDI is -0.093 and significant at the level of 5%.This shows that foreign direct investment has a negative impact on regional innovation. It is not difficult to find that foreign direct investment is mostly dominated by multinational corporations, which usually transfer the parts of production sectors with lower technical level, such as labor and resource-intensive production sectors, to developing countries, while leaving the technology-intensive production sectors in their home countries. This is conducive to the technological progress of the host country when the technological level of the two countries is greatly different. However, the speed of such technological progress will become slow with the narrowing of the technological gap between the two countries. After reaching a certain degree, FDI will inhibit the technological progress of the host country.

3.4 Endogeneity test

Endogeneity is a common problem among most economic variables. Serious endogeneity in model will lead to biased and inconsistent estimation results. For this paper, the main problem of endogeneity comes from the interaction between explanatory variables and explained variables. On one hand, industrial synergistic agglomeration has an impact on regional innovation;On the other hand, regional innovation counteracts industrial synergistic agglomeration. There are two main methods to overcome this endogeneity problem. One is to find the instrumental variable that affects the constraint conditions without affecting the synergistic agglomeration of productive services and manufacturing. However, in reality, it is difficult to find the appropriate instrumental variable. The other method, which has been widely used in existing studies, is to use the lag period of the variable as the instrumental variable.Therefore, this paper adopts the latter method to solve the endogeneity problem that may exist between variables.

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Table 3 Endogeneity test between industrial synergistic agglomeration and regional innovation

	$lnRI_t$					
	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)
	(1)	(2)	(3)	(4)	(5)	(6)
$lnCA_{t-1}$	0.195** (2.73)	0.016* (1.76)	0.018* (1.73)	0.016* (1.87)	0.038* (1.75)	0.047* (1.83)
$lnRI_{t-1}$		0.949*** (81.46)	0.950*** (78.7)	0.957*** (64.67)	0.943*** (58.70)	0.949*** (58.28)
$lnPIN_t$			0.025 (1.48)	0.025 (1.53)	0.017 (1.00)	0.022 (1.28)
$lnML_t$				0.014 (0.77)	0.032 (0.53)	0.036 (0.50)
$lnPGDP_t$				-0.035 (-0.89)	0.008 (0.85)	-0.028 (-0.60)
lnG_t					-0.134** (-2.24)	-0.112* (-1.85)
$lnFDI_t$						0.052** (2.21)
AR(1)P	0.098	0.047	0.021	0.111	0.033	0.001
AR(2)P	0.115	0.247	0.446	0.750	0.342	0.772
Sargan	0.325	0.240	0.321	0.307	0.350	0.302

Industrial synergistic agglomeration index is treated with a lag of one period, and the results are shown in Table 3. The estimation results show that although the coefficient of industrial synergistic agglomeration index decreases, the significance level does not change significantly. This indicates that the above basic regression results still support the conclusion of this paper after considering endogeneity, that is, the synergistic agglomeration of productive services and manufacturing can significantly promote regional innovation.

3.5 Further analysis

3.5.1 Sample test based on the level of industrialization

The synergistic agglomeration of productive services and manufacturing industries plays the role of production correlation effect, sharing of production factors and knowledge spillover through increasing returns to scale, and thus has a positive impact on innovation. However, as returns to scale increase, this positive effect turns into a inhibiting effect. At the end of the empirical analysis, we will divide 18 provinces and cities in central and eastern China into two areas according to the level of economic development, and conduct empirical tests respectively.

According to the theoretical analysis and current situation description, it can be found that the industrial synergistic agglomeration will have different performances in different economic development stages of regions, and will have different impacts on innovation. Due to China's vast territory, regional economic development levels vary.Therefore, according to the level of economic development, we divide the regions into two categories: Pre-industrial period and Mid-pro industrial period, and conducts sub-sample tests respectively. The regression results are shown in Table 4.

Column (1) reports that the coefficient is 0.562 for the regions in the Pre-industrial period, which is significant at the level of 5%, indicating that industrial synergistic agglomeration will promote regional innovation. As the local economic development level is backward, the people's living standard is low, and the skills and knowledge are lacking, it is urgent to increase employment and develop low-technology industries in this region.In this case, the agglomeration of manufacturing industry can not only promote the increase of local employment and economic development. Moreover, the manufacturing industry will have a certain attraction to productive services.productive services, in order to maximize their own interests, will also actively participate in industrial agglomeration and division of labor, so as to have a positive impact on the improvement of manufacturing productivity. Under the interaction of the two, the positive effect of industrial synergistic agglomeration will be highlighted, which can greatly promote the innovation capacity of the region.

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Column (2) of Table 4 reports that the coefficient of synergistic agglomeration index is significantly negative for the regions in the Mid-pro industrial stage, indicating that for the regions in the Mid-pro industrial stage, the synergistic agglomeration of productive services and manufacturing industry will inhibit the innovation of such regions to some extent. The reason may be that the regions Mid-pro industrial stage are striving to develop service industry, especially productive service industry. However, some manufacturing industries with high energy consumption and low technology content are moved to other relatively backward regions, which virtually leads to the relatively low synergistic agglomeration level of productive services and manufacturing industries in economically developed regions.If we blindly pursue the synergistic agglomeration of productive services and manufacturing, the crowding effect of synergistic agglomeration is bound to be amplified, resulting in the low efficiency of resource allocation, the reduction of R&D investment, and the inhibition of technological progress.

Table 4 The results of dynamic regression of subregional samples in industrialization stage

	$lnRI_t$	
	GMM (SYS)	GMM (SYS)
	(1)	(2)
$lnCA_t$	0.562**(1.87)	-0.510**(-2.05)
$lnRI_{t-1}$	0.891***(18.84)	0.820***(11.37)
$lnEIN_t$	0.331***(3.21)	-0.531***(-2.87)
$lnPIN_t$	-0.003***(-2.94)	0.038**(2.08)
$lnML_t$	-0.504(-1.09)	0.280*(1.75)
$lnFDI_t$	-0.685***(-4.03)	0.252***(3.82)
lnG_t	0.132(1.52)	-0.193(-1.06)
$lnIN_t$	0.420(0.54)	0.974**(2.41)
$lnIFS_t$	-0.139(-1.09)	-0.321(-0.75)
AR(1)	0.039	0.098
AR(1)	0.266	0.826
Sargan	0.199	0.153

According to the synergy of productive service and manufacturing agglomeration empirically and results analysis of the regional innovation, can verify the hypothesis of this article: in the different stages of economic development, synergistic effect of productive services and manufacturing agglomeration on regional innovation performance is different: in the Mid-pro industrial stage, the synergy of productive services and manufacturing agglomeration suppresses regional innovation. In the pre-industrial region, the synergistic agglomeration of productive services and manufacturing industries will promote regional innovation.

3.5.2 The mechanism by which industrial synergistic agglomeration influences innovation

Because of the productive services and manufacturing agglomeration phenomenon occurring on the space, and under the condition of synergy in industry cluster, industrial agglomeration can pass three path as an influence on the regional innovation, namely the synergy of productive services and manufacturing industry agglomeration mainly through three channels: information sharing effect, scale external effect and knowledge spillover effect and then apply to regional innovation.Therefore, after examining the direct effect of industrial synergistic agglomeration on innovation, we will examine whether industrial synergistic agglomeration has an impact on regional innovation through these three mechanisms.In this paper, the level of information networking, the construction of infrastructure and the investment in scientific research are taken as proxy variables to investigate whether the externality of scale, the knowledge spillover effect and the informationization sharing effect are mediating variables.Based on the research of Baron and Kenny (1986), we set the model as follows:

$$lnM_{it}=a+\theta lnM_{it-1}+\beta_1 lnCA_{it}+\beta_2 lnX_{it}+\varepsilon_{it}$$

$$lnRI_{it}=a+\theta lnRI_{it-1}+\beta_1 lnCA_{it}+\beta_2 lnM_{it}+\beta_3 lnX_{it}+\varepsilon_{it}$$

Where, RIit represents the regional innovation in province i in t year, RIit-1 represents the regional innovation in province I in t years, and θ represents the coefficient corresponding to the regional innovation in province i in t year.CAit represents the industrial synergistic aggregation index of

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productive services and manufacturing industries in province i in year t, and X represents the control variables.Among them, the control variables X are: the input of scientific and technological personnel (PIN), the proportion of government fiscal expenditure in GDP (G), the degree of opening to the outside world (FDI), the level of informatization (ML), and the level of economic development (PGDP).M represents the mediating variable, which respectively includes: information networking level (IN), infrastructure construction level (IFS) and science and technology investment (EIN).

Table 5 reports the regression results .The regression results in column (1) show that the influence coefficient of industrial synergistic agglomeration on information sharing effect is significantly positive, indicating that industrial synergistic agglomeration has a significantly positive impact on information sharing.Generally speaking, industrial agglomeration in a specific region will make information transfer faster and more efficient.According to the regression results in column (2), the influence coefficient of industrial synergistic agglomeration on infrastructure is 0.373, which is significantly positive at the level of 1%, indicating that industrial synergistic agglomeration has a promoting effect on infrastructure construction.This is because industrial agglomeration of enterprises in a specific region will make the use efficiency of infrastructure become higher and resources get more reasonable allocation, that is, there is scale externality.The regression results in column (3) show that the influence coefficient of industrial synergistic agglomeration on knowledge spillover is 0.103, which indicates that industrial synergistic agglomeration has a significant positive impact on knowledge spillover.Because the enterprises of industrial synergistic agglomeration will get some extra income due to industrial synergistic agglomeration, the enterprises will add part of the extra income to the research and development. This will make the enterprise scientific research funds in the industrial synergistic agglomeration region get a certain increase.

Table 5 The mechanism 1

	$lnIN_t$	$lnIFS_t$	$lnEIN_t$
	GMM (SYS)	GMM (SYS)	GMM (SYS)
	(1)	(2)	3
$lnCA_t$	0.250*** (5.94)	0.373*** (10.65)	0.103* (1.75)
$lnRI_{t-1}$	0.125*** (3.48)	0.093*** (4.27)	0.890*** (21.81)
$lnPGDP_t$	0.722*** (11.53)	0.504*** (12.50)	-0.072** (-1.95)
lnG_t	0.420*** (7.93)	-0.833*** (-21.08)	-0.181*** (-2.41)
$lnML_t$	0.170*** (4.21)	-1.033*** (-32.89)	-0.042 (-0.70)
$lnPIN_t$	0.003 (0.30)	0.028*** (2.91)	0.056*** (3.00)
$lnFDI_t$	-0.147*** (-11.17)	-0.140*** (-11.32)	0.028 (1.17)
AR(1)P	0.032	0.042	0.059
AR(2)P	0.307	0.374	0.264
Sargan	0.252	0.243	0.155

On this basis, this paper tests whether information sharing, infrastructure scale effect and knowledge spillover play a mediating effect in the process of industrial synergistic agglomeration affecting regional innovation. The regression results are shown in Table 6.The first column (2) compared with the first column (1), after joining the network level (IN), the influence of industrial agglomeration together coefficient reduced and no longer significantly, and information transfer coefficient significantly positive, suggests that information sharing in the process of industry agglomeration affecting the regional innovation together plays an intermediary role completely. Column (3) investigates whether infrastructure construction is the mediating variable of industrial synergistic agglomeration affecting regional innovation. The results show that the impact coefficient of infrastructure construction is significantly positive, indicating that infrastructure construction has a significant positive effect on regional innovation. However, compared with column (1), the influence coefficient of industrial synergistic agglomeration is no longer significant, indicating that infrastructure construction plays a complete intermediary role in the process of industrial synergistic agglomeration's

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influence on regional innovation. Column (4) investigates whether knowledge spillover is the mediating variable of industrial synergistic agglomeration affecting regional innovation. The results show that the influence coefficient of industrial synergistic agglomeration index on regional innovation is 0.011 and not significant, while the influence coefficient of knowledge spillover on regional innovation is 0.088 and significant at the level of 10%.Compared with column (1), the influence coefficient of industrial synergistic agglomeration decreases to a certain extent and is not significant, while the influence coefficient of knowledge spillover is significantly positive, indicating that information transfer plays a complete intermediary role in the process of industrial synergistic agglomeration's influence on regional innovation. The industrial synergistic agglomeration of productive services and manufacturing promotes the improvement of regional innovation level through three ways: information sharing effect, external effect of infrastructure scale and knowledge spillover.

Table 6 The mechanism 2

	$lnRI_t$			
	GMM (SYS)	GMM (SYS)	GMM (SYS)	GMM (SYS)
	(1)	(2)	(3)	(4)
$lnCA_t$	0.153* (1.73)	0.076 (1.25)	0.195 (1.54)	0.011 (0.87)
$lnRI_{t-1}$	0.994*** (30.87)	0.938*** (39.16)	0.944*** (43.46)	0.918*** (26.53)
$lnIN_t$		0.133* (1.83)		
$lnIFS_t$			0.087* (1.74)	
$lnEIN_t$				0.088* (1.85)
$lnPGDP_t$	-0.247*** (-2.78)	-0.121* (-1.69)	-0.043 (-0.78)	-0.099* (-1.93)
lnG_t	-1.368 (-1.53)	-0.168** (-2.40)	-0.062 (-0.88)	-0.048 (-0.75)
$lnML_t$	-0.976* (-1.71)	-0.058 (-1.06)	0.044* (1.73)	0.008 (0.88)
$lnPIN_t$	0.001* (1.82)	0.020 (1.16)	0.021* (1.84)	0.008 (0.48)
$lnFDI_t$	-0.467** (2.03)	0.066*** (2.66)	0.063** (2.56)	0.031 (1.13)
AR(1)P	0.032	0.001	0.012	0.001
AR(2)P	0.197	0.109	0.357	0.687
Sargan	0.357	0.378	0.417	0.257

4. Conclusion and policy suggestion

Productive service industry is an industry that provides goods or services for the manufacturing industry. In the process of pursuing the benefit maximization, in order to reduce transaction cost, the productive service industry will consciously or unconsciously move closer to the manufacturing industry. The manufacturing industry will be concentrated in specific regions in order to obtain quality services and gain the benefits that come from returns to scale. Through modern information transfer, both of them share production factors and knowledge spillover is generated in the production process, thus having a mutual effect and finally realizing the regional innovation progress. However, with the continuous increase of returns to scale, it will bring a negative effect on innovation. According to the study on the agglomeration of productive service industry and manufacturing industry and its influence on regions, the following conclusions can be drawn: First of all, as a whole, the synergistic innovation of productive service industry and manufacturing industry has a promoting effect on regional innovation. The industrial synergistic agglomeration of productive service industry and manufacturing industry mainly acts on regional innovation through three channels, including external scale effect, knowledge spillover effect and information sharing effect. Second, for regions at different stages of industrialization, the synergetic agglomeration of productive serivce industry and manufacturing

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industry has different effects on innovation. Among them, for regions at the later stage of industrialization, the synergetic agglomeration of productive service industry and manufacturing industry has an inhibiting effect on regional innovation. For regions at the early and middle stages of industrialization, the synergetic agglomeration of productive service industry and manufacturing industry has a positive promoting effect on innovation.

Based on these findings, this paper makes the following three policy suggestions. Firstly, the cross-regional economic and industrial cooperation should be actively promoted. Regions with relative backward economic development and at the early stage of industrialization should enhance the synergistic agglomeration of productive service industry and manufacturing industry, improve the mechanism of industrial synergistic agglomeration, and promote the cluster district construction of productive service industry and manufacturing industry with high quality. Developed regions should strengthen information sharing and transfer with surrounding regions, expand the scale of infrastructure construction, and give play to the external effect of economies of scale. For example, in the Yangtze River Delta region, Shanghai, as a region with developed productive service industry, should strengthen its driving and radiating role in the development of the manufacturing industry in the regions of Jiangsu and Zhejiang and promote the industrial synergistic agglomeration of the whole Yangtze River Delta region.

Secondly, each region should formulate suitable development policies appropriate. Each region has different economic development levels and should formulate development policies according to circumstances. In the regions with relatively backward economic development, manufacturing enterprises should try to be adjacent to some related productive service industry cluster districts in terms of site selection. Regions with developed economic development can gradually explore the new model of synergistic agglomeration of "productive service industry center- manufacturing periphery", increase the supply of high-quality productive service industry, effectively alleviate the demand for productive service industry in the agglomeration process of manufacturing industry, and effectively promote the balanced development and effective interaction between both of them. At the same time, relevant departments should also formulate and implement supporting policies and systems to reduce resource misallocation and improve the synergistic matching degree between productive service industry and manufacturing industry.

Finally, the market should play a decisive role in the allocation of resources. Competition is an effective means of stimulating enterprise innovation and improving market efficiency, and it is necessary to make active use of fiscal, tax, financial and other economic means to eliminate enterprises with low production efficiency and concentrate limited resources on enterprises with high efficiency in order to stimulate enterprise innovation. At the same time, it is necessary to liberalize the conditions for investment access and allow various types of market entities to enter "unprohibited" areas, so as to allow the free flow of production factors among various sectors and play a decisive role of market in the allocation of resources. The development of the non-public sectors of the economy should be encouraged, supported and guided to stimulate its vitality and creativity. In addition, we need to strengthen the regulatory function of the government, tighten up the legal system and restrain vicious competition to ensure fair competition and maintain market order.

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