Earthline Journal of Mathematical Sciences
E-ISSN: 2581-8147
Volume 10, Number 2, 2022, Pages 317-340
https://doi.org/10.34198/ejms.10222.317340

The Impact of Industrial Agglomeration on Urban Innovation: An Empirical Analysis in China

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Abstract

Based on the theory of industrial agglomeration affecting urban innovation, the panel data of 269 prefecture-level cities and above in China from 2011 to 2017 was used to empirically analyze the internal relationship between industrial agglomeration and urban innovation. The study found that overall industrial agglomeration and tertiary industry agglomeration have a significant promotion effect on urban innovation, while the secondary industry agglomeration does not significantly affect urban innovation; The overall industrial agglomeration and tertiary industrial agglomeration of eastern cities, large and medium-sized cities, and high-tech cities have a significant role in promoting urban innovation, while the promotion effects of mid-western cities, small-scale cities, low-tech, and medium-tech cities are not obvious; The secondary industry agglomeration has no significant impact on the innovation of all regional cities, large-scale cities, and cities with medium and high-tech levels, and the secondary industry agglomeration of low-tech cities also hinders urban innovation. However, with the improvement of the city's technological level, the effect of the concentration of secondary industries on urban innovation has gradually increased; Further analysis found that after using the PSM model to eliminate urban system differences, the basic conclusion that industrial agglomeration affects urban innovation is still valid. The secondary industry agglomeration has a threshold effect on urban innovation, and the effect of the secondary industry agglomeration on urban innovation will gradually increase with the increase of the degree of secondary industry agglomeration. It can be seen that China's high-quality secondary industry agglomeration effect has not yet formed. The above findings provide

Received: June 21, 2022; Accepted: July 20, 2022

2020 Mathematics Subject Classification: 91B74.

Keywords and phrases: industrial agglomeration, urban innovation, threshold effect, urban heterogeneity.

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a theoretical basis for the rational formulation of industrial policies to promote urban innovation.

1. Introduction

Jinping Xi pointed out at the World Public Scientific Literacy Promotion Conference that science and technology are the primary productive forces and innovation is the primary driving force for development. It can be seen from this that under the policy of shifting China's economy from rapid development to high-quality development, innovation-driven high-quality economic development is a major strategic decision implemented by the country. As the mainstay of implementation of innovation, cities have gathered the human, financial, and other innovation elements and innovation resources needed for innovation. Urban innovation has a pivotal position in China's implementation of innovation strategies. Therefore, discussing urban innovation and how to promote urban innovation has important practical significance. Marceau [10] argues that urban innovation is determined by the city's innovation elements and resources, but from the perspective of industrial structure, industrial agglomeration is the main influencing factor of urban innovation. Liu et al. [9] argue that industrial agglomeration can accelerate knowledge spillover and promote urban innovation. The academic circle widely agrees that industrial agglomeration is beneficial to promoting innovation, however, there are certain disputes about the influence of each industrial agglomeration effect on innovation. However, China is stepping up its pace to adjust and upgrade the industrial structure. The industrial structure has changed from the original "two, three, one" to a "three, two, one" pattern. This change affects the degree of agglomeration of various industries to a certain extent. And the degree of industrial agglomeration has changed significantly in some cities. To identify the impact of industrial agglomeration types on urban innovation, this paper considers the overall industrial agglomeration and the effects of industrial agglomeration on urban innovation. Therefore, discussing the agglomeration of various industries and the overall industrial agglomeration play an important role in the development of urban innovation.

In conclusion, considering the importance of urban innovation and the practical significance of the impact of industrial agglomeration on urban innovation, this paper focuses on solving the relationship between industrial agglomeration, overall industrial agglomeration, and urban innovation. This paper mainly addresses the following questions: Can the agglomeration of various industries and the overall industrial agglomeration improve the level of urban innovation? Are there differences in the impact of industrial agglomeration on urban innovation? What are the different factors that influence the agglomeration of various industries on urban innovation? Answering the above questions can provide ideas and policy evidence for China's industrial agglomeration to improve the efficiency of urban innovation.

The inner link between industrial agglomeration and innovation has received widespread attention. On the one hand, the industrial agglomeration has a significant role in promoting innovation. Many kinds of literature have proved that manufacturing agglomeration has a significant role in promoting technological innovation (Andersson et al. [1], Peng and Jiang [11], Zhang [16]). Manufacturing agglomeration can shorten geographic distances, bring advantages of the industrial division of labor, reduce transaction costs through agglomeration effects, and promote knowledge and technology spillovers in the region. The specialized division of labor in cities caused by the agglomeration effect of the manufacturing industry and the inflow and agglomeration of labor from other places provide favorable resources for regional innovation. Secondly, the agglomeration effect is conducive to the information exchange and communication between innovation subjects and is conducive to the generation of innovative knowledge and new technology. Due to the spillover effect of industrial agglomeration of knowledge and technology, it provides knowledge and technology supply for innovation subjects, thus promoting regional innovation. The concentration of manufacturing and related industries in a certain area has led to fierce competition in the regional market. In order not to be eliminated by the market, it is necessary to increase product R&D and innovation, so as to further stimulate regional innovation. At the same time, many studies have shown that the overall agglomeration of the production service industry also has a significant role in promoting innovation (Sheng [12], Yu et al. [14]). These scholars found that the industrial agglomeration of the production service industry promotes the upgrading of the service industry by playing an intermediary role, thereby promoting regional innovation. The production service industry and the manufacturing industry agglomeration also have resource elements and knowledge spillovers caused by the agglomeration effect. However, the production service industry agglomeration can improve the production efficiency of the manufacturing industry, promote the upgrading of the manufacturing industry, and promote regional innovation. In summary, the agglomeration of the manufacturing industry and production service industry is conducive to promoting urban innovation.

On the other hand, the spillover effects of knowledge and technology brought about by industrial agglomeration may not be conducive to urban regional innovation. Due to the large differences between Chinese cities and their attitudes towards innovation, regions will adopt different attitudes towards intellectual property rights according to their own conditions and resources. In cities with weak knowledge and protection of intellectual property rights, the knowledge, technology spillovers, and personnel mobility of cities with higher industrial agglomeration provide conditions for other cities to imitate innovation. These cities can obtain substantial economic benefits in the short term, but gradually lose the power of independent innovation. Similarly, in cities with strong knowledge and protection of intellectual property rights, due to the adoption of stricter protection measures for innovation achievements, it is not conducive to the spillover of knowledge and technology. Consequently, excessive protection measures also hinder the flow of technical personnel, which is not conducive to the imitation and re-innovation of other cities, making innovation more passive. Therefore, the industrial agglomeration has uncertainty for urban innovation. The effect of industrial agglomeration can not only bring about the spillover of knowledge and technology and promote urban innovation but also bring negative effects due to the intellectual property rights and innovation imitation of other cities. At the same time, at the current stage of the adjustment and upgrading of China's industrial structure, industrial agglomeration in some cities is still in its infancy, and the degree of industrial agglomeration is relatively low, and it is still based on the extensive horizontal and vertical division of labor. This has not formed deep cooperation and division of labor between upstream and downstream industries. These industries still focus on cost control and do not have continuous innovation motivation, which is not conducive to improving innovation efficiency and forming a collaborative innovation network. Under this theory, with the actual situation in China, Xie [13] believes that industrial agglomeration has a threshold effect on innovation, and there is a nonlinear relationship between industrial agglomeration and innovation.

Based on the above theoretical analysis, it can be seen that in general, the industrial agglomeration has a promoting effect on urban innovation, but considering the asymmetry of urban knowledge and technology spillovers, and China's industrial agglomeration is at a relatively low level, the impact of industrial agglomeration on urban innovation may not be a linear relationship, but a non-linear relationship may exist.

For this reason, different from the previous literature, this article combines China's secondary and tertiary industries in the adjustment and upgrading stage, uses the macroscopic secondary and tertiary industry agglomeration levels to explore the impact of industrial agglomeration on urban innovation, and adopts the overall industrial agglomeration to analyze the internal relationship between industrial agglomeration and urban innovation. Thus, this paper systematically solves the influence of various industrial agglomeration and overall industrial agglomeration on urban innovation, and on this basis, discusses whether the influence of various industrial agglomeration and overall industrial agglomeration has a nonlinear relationship on urban innovation.

2. Model, Variables, and Data

2.1. *Model setting*

Is industrial agglomeration conducive to urban innovation? To explore the impact of industrial agglomeration on urban innovation, we specify a model as follows:

$$lnInno_{i,t} = \alpha_0 + \alpha_1 Aggl_{i,t} + \alpha_2 X_{i,t} + \mu_i + year_t + \varepsilon_{i,t} \tag{1}$$

where i is the city individual, t is the time, $lnInno$ is the city innovation, $Aggl$ is the industrial agglomeration, X is the control variable, and ε is the random error term. μ_i is an individual dummy variable of the city, and $year_t$ is a dummy variable reflecting the characteristics of the year. These dummy variables are added to the regression equation to control the individual effect of the city and time effect.

2.2. *Variable selection*

(1) Explained variable

The Explained variable in this paper is $lnInno$. The number of urban patents have been used to measure urban innovation (Griliches [6], Chi and Qian [3]). Therefore, we use the logarithm of urban patents to measure urban innovation.

(2) Core explanatory variables

The level of urban industrial agglomeration ($Aggl$), the literature's measurement of the degree of industrial agglomeration mainly includes the average regional industrial concentration rate, location entropy, EG index, etc., taking into account the availability of city data and location entropy can clearly describe the spatial distribution of geographic elements and to a large extent reduce the heterogeneity effect of urban scale. Therefore, based on the practice of Duranton and Puga [4], we select location entropy to measure the level of urban industrial agglomeration. The specific expression is:

$$Aggl_{i,t} = \left(E_{i,m}/E_i\right)/\left(E_{k,m}/E_k\right), \tag{2}$$

where $E_{i,m}$ is the added value of m industry in city i, E_i is the added value of all industries in the city; $E_{k,m}$ is the added value of m industry in all cities, and E_k is the added value of all industries in the city. Considering the availability of urban data, we mainly use the second industry agglomeration degree ($Aggl1$) and the tertiary industry agglomeration degree ($Aggl2$) to measure the urban industry agglomeration level. Meanwhile, we further use the entropy method to obtain a comprehensive index of the level of agglomeration of the tertiary industries to construct the overall degree of industrial agglomeration ($TotalAggl$) of the city.

(3) Control variables

According to the literature, this paper selects the following variables as the control variables: foreign investment level (*FDI*), which is measured by the proportion of foreign investment in GDP converted into RMB by the average exchange rate of that year; economic development level (*lnPgdp*), measured by the logarithm of per capita GDP; the level of financial development (fin) is measured by the proportion of the total deposits of urban financial institutions to GDP; urban population size (*lnPop*), measured by the logarithm of the city's end-of-year registered population; urban green development level (Green), refer to the research methods of Zhang et al. [15], Lin and Du [8], this paper uses the total factor non-radial distance function (TNDDF) to measure the urban green development efficiency, and takes the global environment DEA method to estimate the green development level of each decision unit in different years; the scale of urban industrial enterprises ($lnNum$) is measured by the logarithm of the number of industrial enterprises above designated size in the city; the level of scientific development ($Science$) is measured by the proportion of urban science and technology expenditures in GDP.

2.3. *Data*

This paper selects 2011-2017 panel data from 269 prefecture-level and above cities as empirical samples. The selected data comes from the "China City Statistical Yearbook", "China Regional Economic Statistical Yearbook" and the regional economic research sub-database of CSMAR. Since some urban variables have a small number of missing values, we use interpolation methods to fill them. To reduce the influence of outliers on the regression results, continuous variables are bilaterally tailed at the 0.5% level. Through the above processing, parallel panel data of 1883 observations in 269 cities in 2011-2017 are obtained. The basic statistics of the variables are shown in Table 1.

Table 1: Summary statistics for main variables.

VarName	Obs	Mean	SD	Min	Median	Max
lnInno	1883	7.309	1.559	3.178	7.150	11.870
TotalAggl	1883	0.299	0.058	0.068	0.307	0.782
Aggl1	1883	0.212	0.054	0.000	0.221	1.000
Aggl2	1883	0.398	0.101	0.000	0.403	1.000
FDI	1883	0.030	0.028	0.000	0.022	0.142
lnPgdp	1883	5.017	3.728	0.692	3.956	54.854
Fin	1883	0.917	0.567	0.116	0.751	7.450
lnPop	1883	5.937	0.633	3.992	5.953	8.129
Green	1883	0.475	0.137	0.169	0.457	1.000
lnNum	1883	6.665	1.012	3.912	6.644	9.285
Science	1883	0.003	0.003	0.000	0.002	0.063

Note: The degree of agglomeration of the secondary industry (*Aggl1*) and the degree of agglomeration of the tertiary industry (*Aggl2*) are basic statistics obtained by non-dimensional processing using the entropy method.

3. Empirical Analysis

3.1. *Analysis of benchmark regression results*

The benchmark regression results of industrial agglomeration on urban innovation are shown in Table 2. From the estimated results in Table 2, we can see that the estimated coefficient of the overall industrial agglomeration level (*TotalAggl*) of the cities in column (1) is significantly positive at the 1% level, indicating that the overall industrial agglomeration level of the city is conducive to the improvement of the city's innovation level; the estimated coefficient of the secondary industry agglomeration level (*Aggl1*) in column (2) is not significant and negative, implies that secondary industry agglomeration has a certain hindering effect on urban innovation, but the effect is not significant; the estimated coefficient of the tertiary industry agglomeration level (*Aggl2*) in column (3) is significantly positive at the 1% level, shows that tertiary industry agglomeration can effectively improve the level of urban innovation. Column (4) is the regression result of adding the agglomeration levels of the secondary and tertiary industries into the model at the same time. The estimated coefficient of *Aggl1* is not significant, and the estimated coefficient of *Aggl2* is significantly positive, which is similar to columns (2) and (3). The estimated results are consistent. To sum up, the level of urban overall industrial agglomeration and tertiary industry agglomeration significantly promotes urban innovation, while the level of secondary industry agglomeration does not significantly affect urban innovation.

From the other control variables, the regression coefficients of foreign investment level (*FDI*) and urban population size (*lnPop*) are both significantly negative at the 1% level. This shows that the improvement of the level of foreign investment is not conducive to the improvement of urban innovation. Foreign investment may open up more markets without bringing advanced production technology, which has a limited effect on improving the innovation level of cities. However, the size of the urban population actually hinders urban innovation. The possible reason is that the urban population size selected in this paper is the total population, and the population is considered population size, is not the quality of the urban population. The level of economic development (*lnPgdp*), the level of financial development (Fin), and the scale of urban industrial enterprises (*lnNum*) have a significant role in promoting urban innovation, while the promotion of urban green development level (*Green*) is not obvious, and the positive impact of science on urban innovation is not fully apparent.

Table 2: Benchmark regression results.

Variable	(1)	(2)	(3)	(4)
TotalAggl	1.220***			
	(4.03)			
Aggl1		-0.401		-0.302
		(-1.62)		(-1.23)
Aggl2			1.128***	1.114***
			(6.42)	(6.33)
FDI	-7.688***	-8.176***	-7.565***	-7.636***
	(-8.25)	(-8.78)	(-8.20)	(-8.26)

lnPgdp	0.024***	0.030***	0.019**	0.019**
	(2.93)	(3.82)	(2.32)	(2.37)
Fin	0.468***	0.452***	0.450***	0.444***
	(9.27)	(8.87)	(8.97)	(8.81)
lnPop	-1.242***	-1.127***	-1.218***	-1.192***
	(-3.65)	(-3.29)	(-3.61)	(-3.53)
Green	0.334*	0.482**	0.066	0.049
	(1.67)	(2.44)	(0.32)	(0.24)
lnNum	0.494***	0.745***	0.383***	0.411***
	(5.23)	(9.31)	(4.14)	(4.32)
Science	4.347	4.568	3.734	3.674
	(0.61)	(0.63)	(0.52)	(0.52)
_cons	10.537***	8.549***	11.217***	10.961***
	(5.19)	(4.27)	(5.59)	(5.44)
Time dummies	Yes	Yes	Yes	Yes
N*obs*	1883	1883	1883	1883
Within-R^2	0.185	0.178	0.198	0.198
F	45.614	43.545	49.415	44.107

t statistics in parentheses,* p<0.1, ** p<0.05, *** p<0.01,the same as the table below.

3.2. *The impact of industrial agglomeration on urban innovation in different regions*

Taking into account the large regional differences in China's economic development, the level of industrial agglomeration and innovation in each city is relatively unbalanced. In response to this problem, this paper is divided into eastern cities and mid-western cities to discuss. The regression results are shown in Table 3.

Table 3: Regression results by region.

Variable	Eastern cities		mid-western cities	
TotalAggl	2.109***		0.140	
	(3.46)		(0.43)	
Aggl1		0.296		-0.291
		(0.70)		(-1.02)
Aggl2		1.762***		0.260
		(4.64)		(1.34)
FDI	-5.481***	-5.297***	-5.038***	-5.070***
	(-3.35)	(-3.26)	(-4.40)	(-4.43)
lnPgdp	0.005	0.003	0.184***	0.173***
	(0.49)	(0.35)	(8.24)	(7.38)
Fin	1.056***	1.012***	0.206***	0.205***
	(6.52)	(6.26)	(4.15)	(4.13)
lnPop	-1.379	-1.914	-1.281***	-1.263***
	(-1.10)	(-1.53)	(-4.00)	(-3.94)
Green	-0.495	-0.800*	0.388*	0.301
	(-1.13)	(-1.79)	(1.87)	(1.41)
lnNum	0.088	-0.049	1.017***	0.994***
	(0.51)	(-0.28)	(8.81)	(8.55)
Science	11.659	11.724	-4.053	-4.122
	(0.80)	(0.81)	(-0.53)	(-0.54)
_cons	14.600*	18.921**	6.924***	7.053***
	(1.95)	(2.50)	(3.71)	(3.77)
Time dummies	Yes	Yes	Yes	Yes
N *obs*	700	700	1183	1183
Within-R^2	0.170	0.183	0.314	0.315
F	15.182	14.730	57.468	51.460

Note: The cities in the 11 provinces and cities of Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, Shandong, Fujian, Hebei, Guangdong, Liaoning, and Hainan are eastern cities, and the remaining cities are mid-western cities. After the division, there are 100 cities in the east and 169 cities in the mid-western regions.

According to the estimation results, the regression coefficient of the overall industrial agglomeration level of eastern cities is significantly positive at the level of 1%, while the regression coefficient of the overall industrial agglomeration level of mid-western cities is not significant, indicating that the overall industrial agglomeration level of eastern cities has a significant role in promoting urban innovation, but the promotion effect of the overall industrial agglomeration level of the mid-western cities on urban innovation has not been exerted. The main reason for this is that most of the eastern cities are developed cities, which are concentrated areas of technology- and knowledge-intensive enterprises. They also have more universities and scientific research institutes to carry out innovation, which is conducive to urban innovation. Secondly, compared with the mid-western cities, the eastern cities have a higher level of industrial agglomeration and more mature industries. Under the policy of high-quality development of the national economy, they are more willing to pursue high-quality industries through industrial technological innovation, forming a virtuous circle of industrial-technological innovation, which is conducive to the improvement of the overall innovation level of the city.

In terms of specific industrial agglomeration, the agglomeration level of the secondary industry in eastern cities and mid-western cities does not significantly affect urban innovation, and even the estimated coefficient of the secondary industry agglomeration level in mid-western cities is negative. The reason for this result is that China is undergoing industrial upgrading, heavy industry and other secondary industries are undergoing industrial restructuring, the agglomeration effect of technology and knowledge-intensive secondary industries has not been completed, and the agglomeration level of high-quality secondary industries is low. The impact on urban innovation is relatively weak.

The level of agglomeration of tertiary industries in the eastern region has a significant role in promoting urban innovation, while the effect of the mid-western regions is not obvious. It is because the eastern cities have a relatively high level of financial development, which is conducive to the rapid development of tertiary industries such as blockchain and logistics, forming an industrial agglomeration effect, which is beneficial to urban innovation. Compared with the eastern region, the development of the tertiary industry in the mid-western cities is relatively lagging, and the agglomeration effect of the tertiary industry has not formed. Therefore, mid-western cities should combine their own industrial characteristics and resource advantages to accelerate the agglomeration of tertiary industries to promote regional innovation and development.

3.3. *The impact of industrial agglomeration on innovation in cities of different sizes*

There are big differences in the development of cities of different sizes, and the level of economic development, resources, and talents of cities are asymmetry in the innovation of cities. Thence, by the "Notice on Adjusting the Criteria for City Size Classification" issued by the State Council, this article divides the cities where companies are located into large, medium, and small cities. The regression results are shown in Table 4. From the estimated results in Table 4, it can be seen that the overall industrial agglomeration level of large and medium cities has a significant role in promoting urban innovation, while the overall industrial agglomeration level of small cities has no significant impact on urban innovation. The main reason may be that compared with small cities, large and medium cities have more agglomeration of innovation resources, and it is easier to form an agglomeration of target industries and related industries. The agglomeration effect is more significant, which is more conducive to urban innovation. Regardless of the scale of the city, the level of secondary industry agglomeration has no significant impact on urban innovation, but the level of tertiary industry agglomeration significantly promotes the level of urban innovation.

Table 4: Regression results by city size.

Variable	large cities		medium cities		small cities	
TotalAggl	1.516***		1.520***		-2.753	
	(3.22)		(3.77)		(-1.30)	
Aggl1		0.137		-0.368		0.140
		(0.41)		(-1.04)		(0.07)
Aggl2		1.404***		1.214***		-1.886
		(4.37)		(5.47)		(-1.57)
FDI	-5.159***	-4.953***	-8.556***	-8.496***	-2.841	-2.728
	(-2.71)	(-2.62)	(-7.62)	(-7.63)	(-0.78)	(-0.74)

lnPgdp	0.006	-0.007	0.020**	0.019**	0.226**	0.260**
	(0.34)	(-0.36)	(2.20)	(2.07)	(2.27)	(2.44)
Fin	0.170**	0.153**	0.571***	0.533***	0.172	-0.007
	(2.20)	(1.99)	(8.58)	(8.00)	(0.25)	(-0.01)
lnPop	0.743	0.383	-1.160**	-1.005*	-3.075	-2.183
	(0.99)	(0.51)	(-2.03)	(-1.77)	(-0.78)	(-0.53)
Green	0.779**	0.573	0.128	-0.152	-4.986	-4.442
	(2.23)	(1.62)	(0.51)	(-0.59)	(-1.41)	(-1.23)
lnNum	1.049***	0.919***	0.270**	0.205*	1.596**	1.431*
	(6.09)	(5.20)	(2.29)	(1.74)	(2.12)	(1.84)
Science	23.081	16.106	0.195	-0.030	-1.595	-5.379
	(0.89)	(0.62)	(0.03)	(-0.00)	(-0.01)	(-0.05)
_cons	-5.391	-2.008	10.791***	10.544***	11.911	8.489
	(-1.10)	(-0.40)	(3.32)	(3.27)	(0.66)	(0.46)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
N*Obs*	704	704	1136	1136	43	43
Within-R^2	0.239	0.250	0.198	0.212	0.475	0.490
F	23.239	21.900	29.590	28.712	3.165	2.881

Note: The urban resident population is greater than 1 million as large cities, those with less than 500,000 are small cities, and those in between are medium-sized cities.

3.4. *The impact of industrial agglomeration on the innovation of cities with different technological levels*

The foregoing theoretical analysis shows that the agglomeration of different industries can produce the agglomeration effect of technology and knowledge, and the agglomeration effect depends on the attraction of the city to talents, and its essence can be traced to the support of local finance for technological innovation and attracting talents. To identify the impact of urban technological innovation support, we divided the sample into low-tech cities, medium-tech cities, and high-tech cities based on the level of scientific development.

It can be seen from the estimated results in Table 5 that for low-tech and medium-tech cities, the estimated coefficient of the total industrial agglomeration level (*TotalAggl*) is not significant, indicating that the overall industrial agglomeration level of these cities does not significantly affect urban innovation, while the estimated coefficient of the total industrial agglomeration level (*TotalAggl*) of high-tech cities is significantly positive at the 1% level, indicating that the overall industrial agglomeration level of high-tech cities has significantly promoted the level of urban innovation. Subdivided into the level of secondary industry agglomeration, the level of secondary industry agglomeration in low-tech cities is not conducive to urban innovation. Mid-tech and high-tech cities have no significant impact on urban innovation, but the estimated coefficient gradually changes from negative to positive, which shows that with the improvement of urban science and technology level, the effect of secondary industry agglomeration on urban innovation is gradually improving. For tertiary industry agglomeration, the level of tertiary industry agglomeration in low-tech and medium-tech cities does not significantly affect urban innovation, while the level of tertiary industry agglomeration in high-tech cities has significantly improved the level of urban innovation. It can be seen that China is upgrading its industrial structure, and the upgrading process needs a higher level of science and technology as support. The progress of scientific and technological levels promotes the agglomeration effect of high-quality industries. Therefore, the higher level of science and technology makes industrial agglomeration play a significant role in promoting urban innovation.

Table 5: Regression results of science and technology level by city.

Variable	large cities		medium cities		small cities	
TotalAggl	-0.267		-0.124		1.552***	
	(-0.47)		(-0.19)		(3.09)	
Aggl1		-1.236***		-0.614		0.556
		(-2.64)		(-1.16)		(1.63)
Aggl2		0.408		0.270		1.059***
		(1.30)		(0.70)		(3.01)
FDI	-6.094***	-5.955***	-7.404***	-7.435***	-5.768***	-5.574***
	(-3.19)	(-3.15)	(-3.82)	(-3.84)	(-3.59)	(-3.46)
lnPgdp	0.216***	0.191***	0.127***	0.111***	0.007	0.006
	(4.73)	(4.15)	(3.33)	(2.78)	(0.95)	(0.79)

Fin	0.250***	0.241***	0.367***	0.360***	0.864***	0.804***
	(3.65)	(3.55)	(3.76)	(3.69)	(4.56)	(4.12)
lnPop	-0.957	-0.927	1.231	1.025	-1.709***	-1.683***
	(-1.23)	(-1.21)	(1.09)	(0.90)	(-4.42)	(-4.35)
Green	0.163	-0.177	0.460	0.326	-0.015	-0.116
	(0.42)	(-0.45)	(1.17)	(0.81)	(-0.04)	(-0.33)
lnNum	0.491**	0.459**	0.778***	0.771***	0.490***	0.435**
	(2.50)	(2.35)	(3.68)	(3.65)	(2.79)	(2.41)
Science	221.702*	225.922**	311.457***	307.399***	-10.915	-11.607
	(1.93)	(1.98)	(3.36)	(3.32)	(-1.02)	(-1.09)
_cons	7.919*	8.232*	-6.721	-5.318	13.764***	14.048***
	(1.75)	(1.83)	(-1.02)	(-0.80)	(5.79)	(5.89)
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
N*Obs*	623	623	630	630	630	630
Within-R^2	0.157	0.173	0.259	0.262	0.206	0.209
F	10.815	10.799	18.946	17.089	15.571	14.041

3.5. *Robustness test*

Considering that patents have a long period from research and development, application to final authorization, to further ensure the robustness of the previous estimation results, the measurement indicators of urban innovation are lagging one period (*L.lnInno*) for regression. At the same time, use the city innovation index (*Index*) in the report of Kou and Liu [7] to do a robustness test. This index uses city patents as technology and calculates the city-level innovation index through the patent update model. Since the index is based on city patents, we choose as a substitute index for the robustness test. If the significance and sign of the estimated coefficients of the core explanatory variables are consistent with Table 2 as a whole, it indicates that the previous estimation results are robust and reliable. Table 6 reports the results of the robustness estimation. The results show that no matter whether the lagging urban innovation or the urban innovation index is used, the estimated results of the core explanatory variable industry agglomeration's impact on urban innovation are basically consistent with Table 2, indicating that the results of this paper are robust and credible.

Table 6: Robustness regression results.

Variable	*L.lnInno*	*L.lnInno*	*Index*	*Index*
TotalAggl	0.805**		0.567***	
	(2.57)		(4.68)	
Aggl1		-0.096		0.168
		(-0.41)		(1.45)
Aggl2		0.736***		0.320***
		(3.98)		(4.63)
Control variables	Yes	Yes	Yes	Yes
_cons	6.210***	6.586***	-3.387***	-3.431***
	(3.12)	(3.31)	(-4.51)	(-4.57)
Time dummies	Yes	Yes	Yes	Yes
N*Obs*	1614	1614	1708	1708
Within-R^2	0.140	0.146	0.903	0.903
F	27.172	25.432	961.453	898.067

4. Further analysis

4.1. *The threshold effect test of industrial agglomeration*

The previous analysis shows that the overall industrial agglomeration and the tertiary industry agglomeration have a significant role in promoting urban innovation, but the threshold test results show that the overall industrial agglomeration and the tertiary industry agglomeration do not have a threshold effect, and have a generally linear relationship to urban innovation. However, the previous analysis shows that the secondary industry agglomeration does not have a significant impact on urban innovation. The main reason is that the agglomeration level of secondary industry in different cities is quite different. The industrial structure is in the initial stage of upgrading, and the secondary industry agglomeration level of most cities is low, which leads to the estimated urban average effect not being significant. To identify this factor, we further adapted the panel threshold model (Hansen [5]) to deeply explore the impact of secondary industry agglomeration on urban innovation.

We first use a bootstrap method to determine whether there is a panel threshold and the number of thresholds for the secondary industry agglomeration level (*Aggl1*). Table 7 shows the results of the threshold sampling test. The results sequentially tested the F statistic obtained by the single threshold, double threshold, and triple threshold and the P-value obtained by sampling 300 times. Figure 1 clearly shows the estimated value of the double threshold and the confidence interval. According to the double threshold, the sample is divided into three sub-intervals, namely the first interval: Aggl1≤0.1104, the second interval: 0.1104<Aggl1≤0.2052, and the third interval: Aggl1>0.2052.

Table 7: Threshold test results.

Threshold	RSS	MSE	F-value	P-value	10%	5%	1%
single threshold	472.4236	0.2518	103.51	0.0000***	43.9436	48.8601	56.4136
double threshold	462.1158	0.2463	41.85	0.0433**	32.2768	40.4435	48.6941
triple threshold	456.1630	0.2432	24.48	0.8300	78.3172	88.9732	102.2125

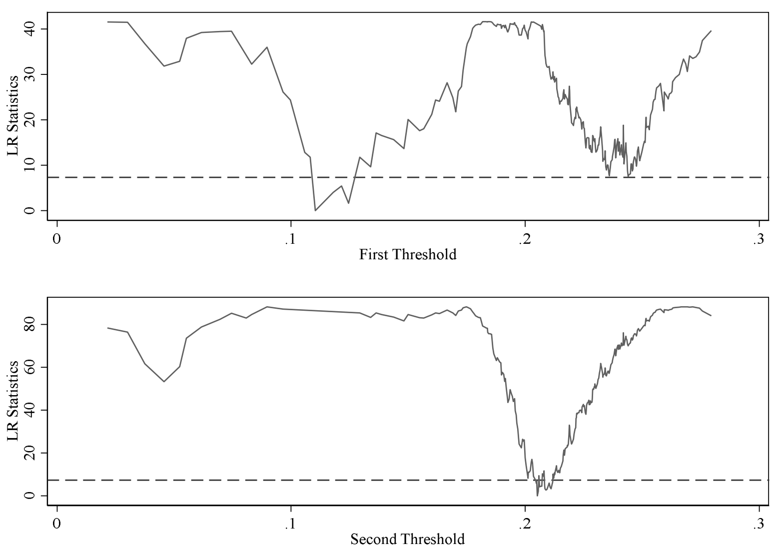

Figure 1: The threshold value and confidence interval.

The threshold estimation results are shown in Table 8. It can be seen from the regression results that when the secondary industry agglomeration level is less than 0.110, its estimated coefficient is significantly negative at the 10% level, indicating that when the urban secondary industry agglomeration level is in the first interval, industrial agglomeration is not conducive to urban innovation; The estimated coefficient of the industrial agglomeration level in the second interval is not significant, indicating that the industrial agglomeration at this level does not affect urban innovation; when the urban secondary industry agglomeration is in the third interval, the regression coefficient is significantly positive at the 5% level, indicating that this level of the agglomeration of secondary industries can effectively promote urban innovation. This shows that with the improvement of the level of secondary industry agglomeration, the impact of secondary industry agglomeration on urban innovation gradually increases. This conclusion further verifies that China is in the critical period of industrial upgrading, the upgrading of the secondary industry in most cities has not been completed completely, and the impact of the agglomeration of secondary industry on urban innovation is not obvious.

Table 8: Threshold regression results.

Variable	Regression coefficient	t-value
the first interval	-3.734*	(-1.88)
the second interval	1.789	(1.10)
the third interval	0.232**	(2.43)
Aggl2	0.830***	(4.81)
FDI	-6.605***	(-7.33)
lnPgdp	0.013	(1.61)
Fin	0.370***	(7.51)
lnPop	-0.931***	(-2.83)
Green	-0.002	(-0.01)
lnNum	0.332***	(3.59)
Science	3.634	(0.53)
_cons	10.183***	(5.21)

Time dummies	Yes
N *Obs*	1883
Within-R^2	0.249
F	48.226

4.2. *Discussion on endogenous issues*

The above analysis of heterogeneity shows that the industrial agglomeration of cities of different regions, scales, and technological levels has significant differences in urban innovation. To control the estimation bias caused by sample selection bias and minimize the potential endogeneity, we adopt the propensity score matching (PSM) explores the impact of industrial agglomeration on urban innovation. The PSM method can better reduce the system deviation between cities, and estimate the ATT based on the potential result difference between the treatment group and the control group, to judge the city's innovation changes. We divide the sample into a treatment group and a control group according to the average value of the industrial agglomeration level. If the city's industrial agglomeration level is greater than the annual average, it is defined as the treatment group, and if it is less than the average, which is defined as the control group. Then the ATT of industrial agglomeration to urban innovation can be expressed as (Becker and Ichino [2]):

$$\begin{aligned} ATT &= E(Y_{1i} - Y_{0i} | D = 1) \\ &= E\{E[Y_{1i} - Y_{0i} | D_i = 1, p(X_i)]\} \\ &= E(Y_{1i} | D_i = 1) - E(Y_{0i} | D_i = 1). \end{aligned} \tag{3}$$

Among them, Y_{1i} and Y_{0i} represent the potential results of the treatment group and the control group, respectively, D_i is whether industrial agglomeration has occurred, 1 means that the city has industrial agglomeration, 0 means that the city does not have industrial agglomeration, X_i is the vector of characteristic variables affecting urban innovation, $P(X_i)$ is the propensity score. To obtain the propensity score value, this paper uses the predicted probability obtained by Logit regression as the estimated value of the propensity score $P(X_i)$, which is defined as follows:

$$P(X_i) = pr[D_i = 1 | X_i] = \frac{exp(\beta X_i)}{1 + exp(\beta X_i)} \tag{4}$$

where β is the coefficient vector. Since $P(X_i)$ is a continuous value, it is impossible to find two samples with the same propensity score, so formula (2) cannot be directly estimated. To this end, this paper uses three methods of nearest neighbor matching, radius matching, and kernel matching to estimate the results (Becker and Ichino [2]). The ATT estimation results are shown in Table 9.

Table 9: ATT analysis.

Variable	TotalAggl		Aggl1		Aggl2	
	ATT	*t*-value	ATT	*t*-value	ATT	*t*-value
Nearest neighbor matching						
lnInno	0.151	1.84*	0.115	0.42	0.109	2.32**
radius matching						
lnInno	0.158	2.13**	0.154	1.11	0.093	1.65*
kernel matching						
lnInno	0.170	2.34**	0.174	1.41	0.102	2.61***

Note: There is a certain difference between this result and the basic regression. The possible reason is that after removing the systematic error, the secondary industry agglomeration still has a certain promotion effect on urban innovation.

The estimation results in Table 9 show that when the overall industrial agglomeration is agglomerated, no matter what matching method is adopted, the ATT before and after the matching of the urban innovation indicator (*lnInno*) is at least significantly positive at the 10% level, indicating that when the overall industrial agglomeration occurs in the city, it is conducive to improving the level of urban innovation. Regardless of whether the secondary industry is agglomerated or not, no matter what matching method is adopted, the ATT before and after the matching of urban innovation indicators is not significant, but all are positive, which indicates that China's current secondary industry agglomeration has a certain promotion effect on cities, but has no significant impact. And this conclusion further supports the previous analysis that the agglomeration of the secondary industry has no significant impact on urban innovation. When the tertiary industry is agglomerated or not, no matter what matching method is adopted, the ATT is significantly positive at least at the 10% level, indicating that when the tertiary industry is agglomerated in the city, it is conducive to urban innovation. All in all, after using PSM to eliminate the factors affecting urban system differences, overall industrial agglomeration and tertiary industry agglomeration are conducive to urban innovation, while secondary industry agglomeration does not significantly affect urban innovation.

5. Conclusion and Discussion

Based on the theoretical foundation that industrial agglomeration affects urban innovation, this paper uses panel data of 269 cities from 2011 to 2017 to empirically explore the impact of industrial agglomeration on urban innovation. The empirical results show that: 1) In general, the overall industrial agglomeration and tertiary industry agglomeration of the city have a significant promotion effect on urban innovation; while the secondary industry agglomeration does not have a significant effect on urban innovation. 2) From the perspective of heterogeneity, the overall industrial agglomeration and tertiary industry agglomeration in eastern cities have a significant role in promoting urban innovation, while mid-western cities have no significant impact, and the secondary industry agglomeration in eastern and mid-western cities does not significantly affect urban innovation; The overall industrial agglomeration and tertiary industry agglomeration of large and medium cities have a significant positive impact on urban innovation, while the overall industrial agglomeration of small cities has no significant impact on urban innovation. For all scale cities, the level of secondary industry agglomeration has no significant impact on urban innovation; The overall industrial agglomeration and tertiary industry agglomeration of cities with low and medium technological levels do not significantly affect urban innovation, while the overall industrial agglomeration and tertiary industry agglomeration of high-tech cities significantly promote urban innovation, while the secondary industry agglomeration level of low-tech cities is not conducive to urban innovation, while cities with medium and high-tech levels have no significant impact on urban innovation. However, with the improvement of urban science and technology level, the effect of secondary industry agglomeration on urban innovation gradually becomes stronger. 3) The agglomeration of the secondary industry has a threshold effect on urban innovation. With the improvement of the level of secondary industry agglomeration, the effect of secondary industry agglomeration on urban innovation is gradually increasing, and a higher level of secondary industry agglomeration has a positive promotion to urban innovation effect.

On the basis of the conclusions of this paper, the policy implications for further promoting industrial agglomeration and promoting urban innovation are as follows: 1) accelerating the upgrading of urban industries, completing the upgrading and optimization of secondary industries such as technology and knowledge intensive industries, transforming into high-quality secondary industries and forming agglomeration effects, so as to give full play to the promoting effect of secondary industries on urban innovation. 2) Eastern cities should focus on the development of high-quality secondary industry agglomeration, and give full play to the impact of secondary industry agglomeration on urban innovation. Mid-western cities should raise the level of industrial agglomeration of target industries and related industries according to their local characteristics, and develop their own industrial agglomeration characteristics to promote urban innovation. 3) Continue to exert the influence of industrial agglomeration in large and medium-sized cities on urban innovation, and use technological innovation to drive high-quality industrial agglomeration, thereby leading urban innovation. Small cities and cities with low technological levels should combine the characteristics of the city to increase investment in regional education, infrastructure, and other fields, strengthen financial support for scientific activities, promote the development and agglomeration of regional human capital, and enhance the level of industrial agglomeration, to stimulate the city's innovation drive.

We only considered the impact of macro-industry agglomeration on urban innovation and did not consider the impact of the agglomeration effect of each sub-industry on urban innovation. Future research will collect data from each micro-industry and analyze the impact of the agglomeration effect of various industries on urban innovation. We use enterprise micro-data as much as possible to explore the impact of industrial agglomeration on urban innovation.

Acknowledgments

This work was supported by the National Science Foundation of China under grant 71761015 and Economic Development Research Center of China under grant AHST2021007.

The authors are very grateful for the comments of the anonymous reviewers. The authors are also grateful to the editor.

References

[1] R. Andersson, J. M. Quigley and M. Wilhelmsson, Agglomeration and the spatial distribution of creativity, *Papers in Regional Science* 84(3) (2005), 445-464. https://doi.org/10.1111/j.1435-5957.2005.00049.x

[2] S. Becker and A. Ichino, Estimation of average treatment effects based on propensity

scores, *The Stata Journal* 2(4) (2002), 358-377. https://doi.org/10.1177/1536867X0200200403

[3] W. Chi and X. Qian, The role of education in regional innovation activities: spatial evidence from China, *Journal of the Asia Pacific Economy* 15(4) (2010), 396-419. https://doi.org/10.1080/13547860.2010.516158

[4] G. Duranton and D. Puga, Micro-foundations of urban agglomeration economies, *Handbook of Regional and Urban Economics* 4 (2004), 2063-2117. https://doi.org/10.1016/S1574-0080(04)80005-1

[5] B. E. Hansen, Threshold effects in non-dynamic panels: estimation, testing, and inference, *Journal of Econometrics* 93(2) (1999), 345-368. https://doi.org/10.1016/S0304-4076(99)00025-1

[6] Z. Griliches, Patent statistics as economic indicators: a survey, *Journal of Economic Literature* 28(4) (1990), 287-343. https://doi.org/10.3386/w3301

[7] Z. Kou and X. Liu, FIND Report on City and Industrial Innovation in China (2017), Fudan Institute of Industrial Development, School of Economics, Fudan University, Shanghai, China, 2017.

[8] B. Lin and K. Du, Energy and CO_2 emissions performance in China's regional economies: Do market-oriented reforms matter?, *Energy Policy* 78 (2015), 113-124. https://doi.org/10.1016/j.enpol.2014.12.025

[9] J. Liu, Z. Cheng and H. Zhang, Does industrial agglomeration promote the increase of energy efficiency in China?, *Journal of Cleaner Production* 164 (2017), 30-37. https://doi.org/10.1016/j.jclepro.2017.06.179

[10] J. Marceau, Introduction: Innovation in the city and innovative cities, *Innovation - The European Journal of Social Science Research* 10 (2008), 136-145. https://doi.org/10.5172/impp.453.10.2-3.136

[11] X. Peng and C. Jiang, Industrial agglomeration, technological spillovers and regional innovation: evidences from china, *China Economic Quarterly* 10(03) (2011), 913-934.

[12] F. Sheng, The spatial agglomeration of producer service industry and the upgrading of manufacturing industry: mechanism and experience —— a spatial econometric analysis based on the data from 230 cities, *Industrial Economics Research* 2 (2014), 32-39+110 (in Chinese).

[13] L. Xie, Do industrial agglomeration and innovation incentives improve regional innovation efficiency? —— An empirical study of urban agglomerations in the Yangtze River Delta, *China Economic Quarterly* 8 (2019), 102-112 (in Chinese).

[14] Y. Yu, D. Liu and Y. Xuan, The spatial spillover effect and regional damping boundary of productive services agglomeration on manufacturing productivity: empirical research based on spatial econometric model, *Journal of Financial Research* 2 (2016), 23-36 (in Chinese).

[15] N. Zhang, F. Kong, Y. Choi, et al., The effect of size-control policy on unified energy and carbon efficiency for Chinese fossil fuel power plants, *Energy Policy* 70 (2014), 193-200. https://doi.org/10.1016/j.enpol.2014.03.031

[16] H. Zhang, How does agglomeration promote the product innovation of Chinese firms?, *China Economic Review* 35 (2015), 105-120. https://doi.org/10.1016/j.chieco.2015.06.003