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Industrial agglomeration, spatial structure and economic growth: Evidence from urban cluster in China

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ABSTRACT

The industrial agglomeration and spatial structure characteristics play important roles in the economic development and improvement of competitiveness for urban cluster. The article constructs a C-D model using panel data of 130 cities in 13 urban clusters in China from 2006 to 2015, then constructs regression equations of the relationship between industrial agglomeration, spatial structure and economic growth through fixed-effects regression models, and finally analyzes the influence of industrial agglomeration and spatial structure on economic growth of urban clusters. The research results indicate that the economic structure of urban clusters is affected by both the level of industrial agglomeration and spatial structure of urban clusters. The higher the level of industrial agglomeration, the more obvious the economic effect of urban clusters. From the perspective of the spatial structure of urban clusters, the impact of monocentric spatial structure of urban clusters on economic growth shows a positive correlation. Human capital, physical capital, economic openness and resident population have significant positive effects on the economic growth of urban clusters, while transportation infrastructure is not significant. At this moment, we should further promote the industrial agglomeration, and continuously optimize the internal spatial structure of urban clusters with the linkage mechanism of land and household registration to improve the comprehensive competitiveness of urban clusters.

1. Introduction

Urban clusters are the main platforms for population and industrial agglomeration. As China's economic entered the new normal, urban clusters have gradually become the core of China's economic development by their regional advantages. Economic development regions with core central cities and urban clusters are important power sources for China's economic development under the new normal. Thus it is clear that urban clusters have gradually evolved into a development model for regional cultivation of key growth poles and a major player in global economic activities, and their development is related to the fate of the economic development pattern of China and the world in future [1]. The nature of urban clusters is to eliminate market barriers and promote the formation of a unified market, which is mainly manifested in the moderate industrial agglomeration and the rational spatial structure of urban clusters [2].

Existing studies on the relationship between industrial agglomeration, spatial structure and economic growth are mainly examined through a single-region perspective such as cities or provinces [3–10], and there is a lack of studies that explore the economic effects of industrial agglomeration and spatial structure at the level of urban clusters or within the framework of urban clusters from a

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large-region perspective, especially the metric analysis of industrial agglomeration and spatial structure of urban clusters and the impact on the economic growth of urban clusters. The conclusions obtained from city-level or provincial-level studies may not be very representative. Therefore, does the existing scale of industrial agglomeration in Chinese urban clusters promote or inhibit economic growth? Does the spatial structure of urban clusters have an impact on economic growth? This paper will focus on the impact of industrial agglomeration as well as spatial structure on economic growth of urban clusters.

The possible marginal contributions of this paper are as follows.

Firstly, from the perspective of city clusters, the use of panel data at the level of cities within city clusters improves the accuracy of industrial agglomeration indicators, which is of great significance to the research of industrial layout and economic effects within city clusters.

Secondly, the level of industrial agglomeration and spatial structure of urban cluster will be put into the model together to study the impact of both on economic growth, and to answer the questions of "which level of industrial agglomeration can better promote the economic development of urban cluster" and "which spatial structure can better promote the economic efficiency of urban cluster" initially.

2. Literature review and research hypothesis

2.1. Industrial agglomeration and economic growth in urban agglomeration

Modern inter-industrial factor flows can determine the size of the market in the region through their own competitive advantages, thus alleviating the factor tensions caused by industrial agglomeration and promoting the agglomeration of modern industries, which leads to strong economic growth. At the theoretical level, Baldwin and Forslid (2000) [11] argue that agglomeration is an important factor in economic growth, assuming free mobility of labor and vertical linkages of firms. Ottaviano and Martin (2001) [12] introduced the theory of endogenous economic growth based on Krugman's theory of new economic geography to show that industrial agglomeration contributes to economic growth and obtained similar conclusions to those of Baldwin and Forslid. Fujita and Thisse (2002) [13] argue that aggregation can also be obtained to contribute to economic growth using endogenous growth theory under the assumption that technology and labor mobility are free. Vernon (2000) [14] argues that high concentrations of industry and population in cities can increase the efficiency of knowledge spillovers from firms and service companies, thus making the labor market more efficient and contributing to the overall regional economy.

From an empirical perspective, Crozet and Koenig (2005) [15] have examined relevant information from the European Union from 1980 to 2000, and illustrates that the spatial clustering of industries has contributed to regional economic development, especially in areas with uneven spatial distribution across production activities, and this effect is more significant. The empirical analysis of Wu and Shen (2013) [16] on 16 central cities in the Yangtze River Delta indicates that the agglomeration of dominant factors in the Yangtze River Delta is an important factor in promoting the economic development and industrial structure upgrading in the Yangtze River Delta. Xie and He (2014) [17] find that industrial agglomeration can promote regional economic development to some extent through spatial analysis of panel data of each province in China from 1985 to 2011. Zhang and Liu (2008) [18] also adopt an instrumental variable approach based on data of Chinese cities and conclude that industrial agglomeration has a positive impact on China's economic development. In addition, most scholars have confirmed through their studies that manufacturing agglomeration has a positive impact on economic growth [19–23]. Based on the above study, the following assumptions are made in this paper.

H1. Industrial agglomeration in urban clusters can promote economic growth.

H2. There are differences in the role of industrial agglomeration on economic growth among urban clusters in different geographical locations.

2.2. Spatial structure of urban clusters and economic growth

From the point of view of urban economy, a good urban form can promote the flow of factors and further productivity growth, while the view of economies of scale points directly that the formation of urban centers is the main reason, and multiple centers can effectively solve the problem of diseconomies brought by a single center. Hence, it can be inferred that the development and evolution of the spatial structure of urban clusters is also a dynamic process of their economic development. E. Meijers (2008) [24] and E. J. Meijers and Burger (2010) [25] discover that the level of labor productivity is relatively high within the U.S. metropolitan area after taking into account the role of other factors. In recent years, several scholars have conducted investigation on metropolitan clusters of different sizes and conclude that the effect of metropolitan clusters of different sizes varies depending on the size of the object. The effect of a single center on economic performance is greatest when the size is small, while the effect of multiple centers is better when the size is large [26–28]. Veneri and Burgalassi (2012) [29] find that the spatial structure of polycentric centers is detrimental to labor productivity; Zhang and Yi (2012) [30] analyze the spatial structure and economic growth of urban clusters, and it is found that the spatial layout of a single center is conducive to improving total factor productivity. Sun and Li (2016) [31] selected prefecture-level cities in China as a basis and found that a monocentric urban spatial structure can promote regional economic efficiency. Based on the above study, the following assumptions are made in this paper.

H3. The spatial structure of urban clusters with a single center exerts a positive influence on economic growth.

H4. The spatial structure of urban clusters in different geographical areas has different effects on economic growth.

3. Research design

3.1. Selection of sample city clusters

The data used in this paper come from the statistical yearbooks of provinces, municipalities and autonomous regions, the statistical bulletins of municipalities, and the China Urban Statistical Yearbook from 2006 to 2015, due to the accuracy and availability of the data. Due to the administrative adjustment or survey statistics, the data of individual cities may be missing in some years, and this paper adopts the interpolation method to make up for it.

According to the relevant development plans, existing classification of urban clusters and the effective evaluation of urban cluster policies, the urban clusters containing less than 5 cities are deleted, and the final research object of this paper is determined to be the 13 urban clusters in China, and these major urban clusters are relatively developed well. Since these 13 urban clusters cover various regions and different levels of development in China, the research findings are representative by taking these 13 urban clusters as the research samples. Their specific scope is shown in Table 1 below.

3.2. Variable selection

3.2.1. Explanatory variables

This paper uses the GDP per capita of urban clusters as an indicator to measure the economic growth of urban clusters.

3.2.2. Core explanatory variables

The core explanatory variables of this paper are the degree of industrial agglomeration and spatial structure of urban clusters. This paper draws on Fan (2006) [32] employment density index to represent industrial agglomeration, which is measured by the density of non-agricultural industry employees in the administrative regions of urban clusters. The specific measurement results are shown in Table 2.

According to Tables 2 and it can be seen that the employment density level of each urban agglomeration shows an upward trend during the period 2005–2016, with most of them showing a significantly higher increase in employment density level around 2010 and almost reaching a peak around 2013 and 2014 years. Among them, for example, based 2006, the Chengdu-Chongqing urban agglomeration, the Hefei urban agglomeration, and the Nanchang urban agglomeration have higher growth rates, with 43.4%, 38.3%, and 30.0%, respectively. In addition, the Yangtze River Delta city cluster and the Pearl River Delta city cluster, as developed city clusters in China, also reached their peak growth rates in 2014 and 2013, with growth rates of 24.2% and 24.4%, respectively. What's more, the city cluster ranked fourth in terms of growth rate is Zhengzhou city cluster, suggesting that the dominance of traditional city clusters is no longer a monopoly, and emerging city clusters have been slowly rising. The industrial agglomeration level of other urban agglomerations mostly increased by 5%–20% from 2006 to 2015, with the city clusters at the bottom of the list being Qingdao and Taiyuan, at 5.5% and 9.8% respectively, existing lots of improvement space compared with others. The rest of urban clusters like Beijing-Tianjin-Hebei, Wuhan and Shijiazhuang reach the highest value of growth in 2014, with 10.5%, 19.8% and 19.9% respectively, and Xi'an and Jinan reach a peak score of 19.1% and 13.5% in 2013, respectively.

The Herfindahl index of resident population of urban clusters is used to measure the spatial structure of urban clusters, and the Herfindahl index is calculated as follows.

$$HHI_{it} = \sum_{i=t}^{n} \left[\frac{p_{it}}{P}\right]^2 = \sum_{i=1}^{n} S_{it}^{\ 2} \tag{1}$$

Table 1
Names of Chinese urban clusters and cities included in this paper.

Name of Urban Clusters	Cities Included in Urban Clusters
Yangtze River Delta Urban Cluster	Shanghai, Nanjing, Hangzhou, Ningbo, Suzhou, Huzhou, Changzhou, Chuzhou, Huai'an, Jiaxing, Jinhua, Maanshan, Nantong, Shaoxing, Taizhou, Taizhou, Wuxi, Wuhu, Xuancheng, Yangzhou, Zhenjiang, Zhoushan
Pearl River Delta Urban Cluster	Guangzhou, Shenzhen, Jiangmen, Zhaoqing, Dongguan, Zhongshan, Zhuhai, Foshan, Huizhou
Beijing Tianjin Hebei Urban Cluster	Beijing, Tianjin, Zhangjiakou, Baoding, Langfang, Tangshan
Hefei Urban Cluster	Hefei, Lu'an, Anqing, Bengbu, Tongling, Chuzhou, Huainan, Ma'anshan, Wuhu, Suzhou
Qingdao Urban Cluster	Qingdao, Weihai, Weifang, Yantai, Rizhao
Chengdu Chongqing Urban Cluster	Chengdu, Chongqing, Deyang, Meishan, Mianyang, Ya'an, Ziyang, Leshan, Neijiang, Suining, Zigong, Guang'an
Xi'an Urban Cluster	Xi'an, Baoji, Shangluo, Tongchuan, Weinan, Xianyang
Zhengzhou Urban Cluster	Zhengzhou, Kaifeng, Xinxiang, Xuchang, Jiaozuo, Hebi, Luoyang, Jincheng, Pingdingshan
Jinan Urban Cluster	Jinan, Binzhou, Dezhou, Laiwu, Liaocheng, Tai'an, Zibo
Wuhan Urban Cluster	Wuhan, Ezhou, Huanggang, Huangshi, Xianning, Xiaogan
Shijiazhuang Urban Cluster	Shijiazhuang, Hengshui, Xingtai, Baoding, Yangquan
Taiyuan Urban Cluster	Taiyuan, Jinzhong, Yangquan, Luliang, Xinzhou
Nanchang Urban Cluster	Nanchang, Xinyu, Fuzhou, Jiujiang, Yichun

Source: "China Metropolitan Area Development Report 2018"

Table 2
Employment density of urban clusters from 2006 to 2015.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Yangtze River Delta Urban Cluster	3.76	3.87	3.94	4.00	4.09	4.24	4.33	4.62	4.67	4.63
Pearl River Delta Urban Cluster	4.18	4.24	4.23	4.31	4.35	4.49	4.54	5.20	5.17	5.14
Beijing Tianjin Hebei Urban Cluster	3.31	3.31	3.29	3.31	3.36	3.59	3.68	3.65	3.66	3.58
Hefei Urban Cluster	2.27	2.31	2.29	2.39	2.47	2.73	2.85	3.12	3.04	3.14
Qingdao Urban Cluster	3.62	3.64	3.59	3.58	3.60	3.72	3.77	3.82	3.79	3.77
Chengdu Chongqing Urban Cluster	2.53	2.58	2.62	2.65	2.66	2.85	3.36	3.60	3.52	3.63
Xi'an Urban Cluster	2.51	2.51	2.51	2.52	2.51	2.63	2.70	2.99	2.96	2.93
Zhengzhou urban Cluster	2.92	2.94	2.93	2.96	3.01	3.24	3.37	3.76	3.78	3.77
Jinan Urban Cluster	3.40	3.45	3.45	3.45	3.50	3.62	3.68	3.86	3.82	3.76
Wuhan Urban Cluster	3.17	3.34	3.40	3.45	3.56	3.58	3.61	3.70	3.80	3.78
Shijiazhuang Urban Cluster	2.46	2.44	2.42	2.39	2.40	2.57	2.87	2.88	2.95	2.91
Taiyuan Urban Cluster	1.92	1.98	1.95	1.94	1.98	1.97	2.21	2.11	2.08	2.04
Nanchang Urban Cluster	2.35	2.41	2.29	2.20	2.24	2.65	2.77	3.02	3.07	3.08

Source: Author's own conception, based on excel software

in the equation, p_i is the number of urban clusters, p is the total population, and S_i is the number of urban clusters. The Herfindahl index (HHI) is between [1/n, 1], and the closer the index is to 0, the more inclined the polycentric urban structure is. Otherwise, it tends to be a monocentric urban structure. The specific measurement results are shown in Table 3.

From Table 3, we can find that the Herfindahl index of each city cluster is below 0.3, and only the Herfindahl index of Yangtze River Delta city cluster is below 0.1, while the other city clusters are between 0.1 and 0.3, among which the Herfindahl index of capital city cluster, Qingdao city cluster, Shijiazhuang city cluster and Nanchang city cluster are above 0.2. Furthermore, the Herfindahl index of each city cluster has a large gap from the Herfindahl index of each city cluster while there is a little change from the variation of Herfindahl index of each city cluster, and they all show a monocentric trend, basically representing a slow rise or unaltered trend.

3.2.3. Control variables

(1) Human capital

The accumulation of human capital plays a significant role in the transformation of regional economic development from "population" to "talent" dividend, and the key to human capital is education. Therefore, this paper refers to Cai and Liu (2014) [33] and Qian et al. (2014) [34] to define the human capital of urban clusters as the education expenditure per 10,000 resident population of urban clusters, i.e., the annual government education expenditure of each urban cluster/average annual population of urban clusters.

(2) Physical capital

Physical capital investment and human capital investment are the "two carriages" for rapid regional economic development. In this paper, we refer to Chao and Shen (2014) [35] and Guo and Cao (2008) [36] who define physical capital as the amount of investment in fixed assets/real GDP.

(3) Economic openness

Foreign direct investment can reflect the level of economic openness of a region, and it can push for economic growth by attracting

Table 3
Herfindahl index of urban clusters from 2006 to 2015.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Yangtze River Delta Urban Cluster	0.067	0.069	0.070	0.071	0.072	0.071	0.071	0.072	0.072	0.071
Pearl River Delta Urban Cluster	0.140	0.141	0.142	0.144	0.145	0.145	0.145	0.145	0.145	0.147
Beijing Tianjin Hebei Urban Cluster	0.204	0.207	0.210	0.213	0.214	0.216	0.218	0.221	0.222	0.222
Hefei Urban Cluster	0.126	0.126	0.126	0.126	0.125	0.123	0.123	0.123	0.123	0.117
Qingdao Urban Cluster	0.240	0.240	0.241	0.241	0.242	0.242	0.242	0.242	0.242	0.243
Chengdu Chongqing Urban Cluster	0.198	0.194	0.195	0.196	0.206	0.207	0.209	0.210	0.210	0.211
Xi'an Urban Cluster	0.217	0.218	0.218	0.220	0.220	0.220	0.221	0.221	0.221	0.221
Zhengzhou urban Cluster	0.124	0.124	0.124	0.124	0.126	0.127	0.127	0.128	0.129	0.129
Jinan Urban Cluster	0.160	0.160	0.160	0.160	0.161	0.161	0.161	0.161	0.161	0.161
Wuhan Urban Cluster	0.230	0.231	0.232	0.233	0.238	0.240	0.241	0.242	0.243	0.245
Shijiazhuang Urban Cluster	0.256	0.256	0.256	0.257	0.257	0.257	0.257	0.253	0.254	0.254
Taiyuan Urban Cluster	0.216	0.216	0.216	0.216	0.219	0.219	0.219	0.219	0.219	0.219
Nanchang Urban Cluster	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229

Source: Author's own conception, based on excel software the use of foreign investment to bring advanced production and management. Therefore, this paper refers to Li et al. (2018) [37] and Sun and Zhang (2019) [38] to define the degree of economic openness of urban clusters as the amount of foreign direct investment.

(4) Transportation infrastructure

Regional physical and human capital can make better with the cooperation of good transportation facilities, so the construction of regional transportation infrastructure can effectively accelerate the development of regional economy. In this paper, we refer to the literature of Si (2011) [39] and Su et al. (2012) [40] to define the level of transportation infrastructure as the amount of road passenger traffic in urban clusters.

(5) Resident population and Area of administrative regions

Wang and Li (2009) [41] consider that both urban population and area have a critical impact on per capita public expenditure and regional economy, and Ren and Wang (2003) [42] argue that permanent population has a greater effect on the economic development of cities compared to the migration of the household population, so this paper includes the number of resident population in urban clusters and the area of administrative regions of urban clusters as control variables.

3.3. Model setting

Shi and Zhou (2007) [43] believe that production function is a method to study the impact of a certain factor on regional efficiency. This paper uses C-D (Cobb Douglas) function as the starting point of the theoretical model:

$$Y = AK^{\alpha}L^{\beta} \tag{2}$$

where Y denotes total output (usually in terms of GDP), K represents capital, L represents labor and A represents production efficiency. Our basic hypothesis is that the industrial agglomeration and spatial structure of urban clusters can promote economic growth, and therefore they can be used as part of the production efficiency factor A. Specifically, if the aggregate production function is rewritten in per capita form and taken logarithmically, the above equation can be rewritten as the following representation:

$$\text{Iny} = InA_1 + \beta_1 agg + \beta_2 struc + \alpha Ink + (\alpha + \beta - 1)InL \tag{3}$$

where y and k represent the per capita form of GDP and capital in a certain region, agg and struc are the degree of industrial agglomeration and spatial structure of the urban cluster, and A_1 is the other factors affecting economic growth of the urban agglomeration except industrial agglomeration and spatial structure. β_1 and β_2 are the coefficients we are pay attention to. If β_1 is significantly greater than 0, then it indicates that the higher the degree of industrial agglomeration, the more obvious the economic effect of the urban cluster. If β_2 is significantly greater than 0, then it indicates that the single center of urban cluster spatial structure has a positive correlation with economic growth. In order to estimate the effects of industrial agglomeration and spatial structure on economic growth independently, they must be separated from other factors that may affect economic efficiency, so we obtain the following equation:

$$\text{Iny} = \alpha + \beta_1 agg + \beta_2 struc + X + \varepsilon \tag{4}$$

where X represents control variables, including physical capital (pinvest), human capital (edu), economic openness (pfdi), transportation (trans), resident population (pop) and administrative area (area). The specific model is expressed as follows:

$$Iny_{it} = \alpha + \beta_1 \text{agg}_{it} + \beta_2 struc_{it} + \beta_3 pinves_{it} + \beta_4 edu_{it} + +\beta_5 pfdi_{it} + +\beta_6 trans_{it} + \beta_7 pop_{it} + \beta_8 area_{it} + \varepsilon_{it} \tag{5}$$

where i denotes city cluster and t denotes year. represents the economic efficiency of the ith urban cluster in the t year. and iny_{it} are the industrial agglomeration degree and spatial structure of the ith urban cluster in the t year. α is the constant term, and ε_{it} indicates the

Table 4
Descriptive statistics of main variables.

variable name	variable	observations	mean	sd	min	max
Economic growth	PGDP	130	9.569	0.901	7.713	11.738
Industrial agglomeration	agg	130	3.228	0.748	1.924	5.196
Spatial structure	strac	130	0.188	0.055	.067	0.257
Human capital	edu	130	0.004	0.002	.001	0.008
Physical capital	pinvest	130	8.712	0.329	7.884	9.339
Economic openness	pfdi	130	13.167	1.215	10.032	15.683
Transportation infrastructure	trans	130	11.128	0.991	9.026	13.122
Area of administrative region	area	130	11.248	0.407	10.836	12.134
Resident population	pop	130	8.253	0.548	7.276	9.497

Source: Author's own conception, based on stata15.0 software

error term. We use pinvest, the proportion of fixed assets in GDP, to reflect material capital input, and use edu, the education expenditure per 10,000 permanent residents, to reflect human capital per capital. In addition, the economic openness pfdi is measured by foreign direct investment. Except for the spatial structure index, the data of explanatory variables are all from China Statistical Yearbook and China Urban Statistical Yearbook of each year. Descriptive statistics of variables are shown in Table 4 below.

4. Analysis of empirical results

4.1. Relevant checks

1. Panel unit root test

Before regression, since macro data is used in this paper and the time dimension is relatively long, unit root test is needed for each variable. If the variable is not stationary, the result of pseudo-regression will easily appear, which is of no practical significance. Therefore, the unit root test method is to test whether the variable is stationary. The original hypothesis of unit root test is "the variable sequence has unit root and is a non-stationary sequence". If the test results meet the requirements, that is, the P-value of the test statistic is less than 5%, representing there is no unit root. On the other hand, if most of the variables are non-stationary, you have to do a first or second order difference, and then you can do a regression or if their linear combination is co-integration, you can do a regression directly. In this paper, stata15.0 software is used for testing, and the LLC test method is adopted. The test results are shown in Table 5.

The unit root test results show that all variables in the model basically pass the unit root test, which indicates that all variables in the model are stationary series and no co-integration test is needed.

2. Hausman test

Hausman test is a common test for panel data, mainly regression to choose fixed effect or random effect model. Hausman test original hypothesis is: there is no systematic difference between fixed effect model and random effect model, and random effect model should be chosen. Therefore, this paper uses stata15.0 to conduct Hausman test on the regression models of economic growth of urban clusters and industrial agglomeration level, spatial structure variables and other control variables, and the test results are shown in Table 6.

As can be seen from the table above, the Hausman test has a chi-square value of 31.35 and a concomitant probability of 0.0001, which rejects the original hypothesis at the 1% significance level, so the model should be chosen as a fixed effects model.

4.2. Baseline regression analysis

According to the Hausman test structure, the fixed effects model (FE) [44–48] is used for regression analysis in this paper. Table 7 shows the regression results through the fixed effects model. It can be found that reg-1 represents the result of ordinary OLS regression, reg-2 represents the result of general fixed effects regression, and reg-3 represents the result of fixed effects regression of robust standard error. OLS regression results shows that industrial agglomeration variables and spatial structure variables are positively correlated with the economic efficiency of urban cluster. In fixed effect regression, after controlling the influence of other variables, the indicators of industrial agglomeration and spatial structure are still significant, and the R^2 is large, indicating that the regression model fits well.

Specifically, the industrial agglomeration variable is positive at the 1% significance level under all models, showing that industrial agglomeration in urban clusters has a positive effect on the economic growth of urban clusters, which verifies Hypothesis H1; for the spatial structure variable, it is positive at the 10% significance level under the ordinary OLS regression model, but the coefficients in

Table 5
Unit root test results of variable LLC.

variable	Test statistics		
	T value	P value	Significance
TGDP	−4.798	0.0002	***
PGDP	−6.767	0.0000	***
Industrial agglomeration	−3.4263	0.0023	***
Space structure	−5.164	0.0008	***
Human capital	−5.165	0.0410	**
Physical capital	−4.0442	0.0015	***
Economic Openness	−6.870	0.0002	***
Transportation infrastructure	−5.4151	0.0000	***
Resident population	−7.217	0.0000	***
Area of administrative region	−4.613	0.0468	***

Note: *, **, ***are significant at 10%, 5% and 1% significance levels respectively.
Source: Author's own conception, based on stata15.0 software

Table 6
Statistical results of Hausman test.

Test Summary	Chi-sq. Statistic	P值
Cross-section random	31.35	0.0001

Source: Author's own conception, based on stata15.0 software

Table 7
Baseline regression results.

lnPGDP	reg-1	reg-2	reg-3
	OLS	FE	FE r
Industrial agglomeration	0.469***(0.0502)	0.291***(0.0593)	0.291***(0.0725)
Space structure	0.0924*(0.0527)	2.942***(0.7770)	2.942***(0.6490)
Physical capital	0.242***(0.0625)	0.705***(0.0871)	0.705***(0.1240)
Human capital	2.321***(0.1980)	1.440***(0.1830)	1.440***(0.1360)
Economic Openness	0.0767***(0.0261)	0.0658***(0.0199)	0.0658***(0.0142)
Transportation infrastructure	−0.0531*(0.0285)	0.00278 (0.0244)	0.00278 (0.0317)
Area of administrative region	0.124 (0.0844)	1.732**(0.733)	1.732**(0.621)
Resident population	2.921***(0.216)	2.583***(0.440)	2.583***(0.514)
Constant	−6.345***(0.755)	−25.77***(6.383)	−25.77***(5.275)
Observations	130	130	130
R^2	0.971	0.941	0.941

Note: The brackets are standard errors. * * * means significant at the 1% level, * * means significant at the 5% level, and * means significant at the 10% level.
Source: Author's own conception, based on stata15.0 software

the fixed-effects regression, both in the general fixed-effects model and the fixed-effects model controlling for the robust standard errors, are positive at the 1% significance level. That is, the Herfindahl index of resident population has a contributing effect on the GDP of urban clusters, meaning that the monocentricity of urban clusters is more conducive to the centralized utilization of resources, and also verifies the research hypothesis H3.

For the relevant control variables, the coefficients of human capital and physical capital variables of urban cluster are significantly positive, showing that they all play a positive influence on the economic growth of urban cluster; for the economic openness variables, the coefficients pass the significance test at 1% level, meaning that the economic openness plays a role in promoting the economic growth of urban clusters; the coefficients of the transportation infrastructure variables in the fixed regression model, although positive, but the significance is relatively low, which doesn't necessarily mean that they don't have an effect on the economic growth, probably due to the fact that in the framework of the research on urban clusters, the impacts of some of the variables may be different from other scholars on the city level. The coefficients are significantly positive for the two control variables of the size of the administrative area and the resident population of the urban cluster, indicating that the floating population within the urban cluster is crucial to economic growth, in consistent with Chen Yuguang (1982) [49] who argues that economic development is influenced by the size of the population.

Table 8
Heterogeneity test.

ResultslnPGDP	reg-4	reg-5
	non-coastal areas	coastal areas
Industrial agglomeration	0.310***(0.0770)	0.266***(0.0911)
Space structure	2.603***(0.961)	−0.701 (2.006)
Physical capital	0.637***(0.116)	1.096***(0.170)
Human capital	1.463***(0.251)	1.313***(0.222)
Economic Openness	0.0698***(0.0257)	0.0619**(0.0282)
Transportation infrastructure	0.0404 (0.0425)	0.0289 (0.0272)
Area of administrative region	1.098 (0.996)	4.968***(1.357)
Resident population	2.620***(0.679)	3.054***(0.763)
Constant	−19.71**(7.908)	−76.25***(17.04)
Observations	90	40
R^2	0.940	0.968

Note: The brackets are standard errors. * * * means significant at the 1% level, * * means significant at the 5% level, and * means significant at the 10% level.
Source: Author's own conception, based on stata15.0 software

4.3. Heterogeneity test

It has been shown that regional differences are one of the factors affecting industrial agglomeration. In order to justify the hypothesis that there are regional differences in the influence of the industrial agglomeration and spatial structure on the economic growth of urban clusters, the 13 urban clusters studied in this paper are divided into coastal urban clusters and non-coastal urban clusters according to whether they are coastal areas. The specific heterogeneity tests are shown in Table 8.

It may be that with the development of urban agglomerations in different regions, the industrial agglomeration of coastal urban agglomerations has reached a higher level than that of non-coastal urban agglomerations, that is, the industrial agglomeration degree of urban agglomerations is more reasonable. Therefore, the "icing on the cake" effect of industrial agglomeration on coastal urban clusters is significantly less than the "sending charcoal in snow" effect on non-coastal urban agglomerations, which verifies the research hypothesis H2: There are differences in the effect of industrial agglomeration on economic growth in urban clusters of different regions.

Compared with coastal urban agglomerations, the spatial structure of non-coastal urban clusters can significantly promote the economic growth of urban clusters, while the spatial structure of coastal urban clusters has no significant effect on the economic growth of urban clusters, which may be the reason that spatial structure of coastal urban clusters has been perfect, compared with non-coastal urban clusters, the economic effect of industrial agglomeration is more obvious. It also verifies the research hypothesis H4: The spatial structure of urban clusters in different regions has different impacts on economic growth.

4.4. Robustness test

To further test the robustness of the model, this paper switches from the dependent variable GDP per capita to total GDP to test the stability of the above findings. The results are shown in Table 9. It is confirmed that the coefficients of the core explanatory variables are positive at the 1% significance level, whether in the general fixed-effects model or the fixed-effects model controlling for robust standard errors. The coefficients of the industrial agglomeration variable are significantly positive, consistent with the previous section. The economic effect of the Herfindahl index, which reflects the spatial structure of city clusters, is also positive, and the significance and sign of the coefficients of the control variables are mostly consistent with the above, suggesting that the results described in the previous section that industrial agglomeration as well as spatial structure contribute to the economic performance of city clusters are robust.

5. Conclusions and recommendations

This paper uses the density of non-primary industry to measure the industrial agglomeration of urban clusters, and uses the Herfindahl index of resident population to represent the spatial structure of urban clusters, and the total GDP and the GDP per resident population of urban clusters as indicators of economic growth of urban clusters, and analyzes the influence of industrial agglomeration and spatial structure on the economic growth of urban clusters. In addition, we also select 13 urban clusters in China as the research objects, and use the panel data of 13 urban clusters in China from 2006 to 2015 to construct a panel regression model to analyze the effects of industrial agglomeration and spatial structure on the economic growth of urban clusters.

5.1. Main findings

1 Differences in industrial agglomeration and spatial structure of city clusters

Table 9
Robustness test results.

lnTGDP	reg-5	reg-6
	FE	FE-r
Industrial agglomeration	0.452***(0.0636)	0.452***(0.103)
Space structure	2.236***(0.726)	2.236***(0.703)
Physical capital	0.636***(0.0793)	0.636***(0.115)
Human capital	1.365***(0.168)	1.365***(0.130)
Economic openness	0.0552***(0.0181)	0.0552***(0.0112)
Transportation infrastructure	0.0210 (0.0226)	0.0210 (0.0333)
Area of administrative region	1.375**(0.674)	1.375**(0.537)
Resident population	1.305***(0.406)	1.305**(0.499)
Constant	−10.29*(5.982)	−10.29*(5.276)
Observations	130	130
R^2	0.942	0.942

Note: The brackets are standard errors. * * * means significant at the 1% level, * * means significant at the 5% level, and * means significant at the 10% level.
Source: Author's own conception, based on stata15.0 software

For the industrial agglomeration of city clusters, as a whole, during the period of 2006–2015, the level of industrial agglomeration of each city cluster showed a slow rising trend, in which most of the city clusters' industrial agglomeration reached a significant increase in around 2010, and basically reached a peak in around 2013 and 2014. Specifically, the Yangtze River Delta city cluster, the Pearl River Delta city cluster and the Wuhan city cluster have apparently higher levels of industrial agglomeration than the other city clusters, while the Taiyuan city cluster and the Xi'an city cluster have lower levels of industrial agglomeration and still have a gap compared with the other city clusters.

For the spatial structure of urban clusters, in general, the Herfindahl index of each urban cluster is below 0.3, among which only the Herfindahl index of the Yangtze River Delta urban cluster is below 0.1, and the Herfindahl index of other urban clusters is between 0.1 and 0.3, among which the Herfindahl indexes of the Capital City Cluster, the Shijiazhuang City Cluster of Qingdao City Cluster, and the Nanchang City Cluster are all over 0.2, and there is a wide difference in Herfindahl indexes among the city clusters. However, in terms of the variation of the Herfindahl index for each urban cluster, there is little change, and all of them show a monocentric trend, basically showing a slowly increasing or basically unchanged trend.

2 Industrial agglomeration in urban clusters is positively correlated with economic growth

This paper empirically analyzes the impact of industrial agglomeration and spatial structure of urban clusters on economic growth by using the density of non-agricultural workers to measure the degree of industrial agglomeration of urban clusters, and the Herfindahl index of resident population to represent the spatial structure of urban clusters. The results show that after controlling other influencing factors, the positive impact of city cluster industrial agglomeration on economic growth is quite obvious, and the regression results of ordinary OLS regression, general fixed effect model regression, and fixed effect regression controlling the robust standard error all completely reflect the important role of city cluster industrial agglomeration in the process of economic growth.

3 Monocentric spatial structure of urban clusters contributes to economic growth

From the perspective of resident population, the Herfindahl index of resident population is used to calculate the degree of spatial agglomeration of city clusters to measure the impact of spatial structure of city clusters on economic growth. The regression results show that the Herfindahl index of resident population of urban agglomerations passes the 1% significance test, indicating that there is a obvious positive correlation between urban cluster monocentric structure and economic growth, and that urban clusters with a monocentric distribution will show higher economic efficiency.

4 Positive correlation between human capital, physical capital, economic openness and economic growth in urban clusters.

Human capital measured by per capita education expenditure of the resident population and physical capital measured by the ratio of fixed assets to GDP have a significant positive effect on the economic growth of the urban cluster; in addition, the contribution of foreign direct investment to the economy of the urban cluster is significantly positive, which is consistent with the theoretical expectation, indicating that the economic opening of the urban cluster will promote the degree of openness of the cluster to the outside world, and that the economic pull effect of foreign investment has been positive; the coefficient of highway passenger capacity, which is a measure of the transportation infrastructure, is positive but relatively insignificant in the regression model; for the two control variables of administrative area and resident population, the coefficient is also significantly positive, but it is relatively insignificant. The effect on the economic growth of the urban cluster is also significantly positive for the two control variables, administrative area as well as resident population, indicating that the mobile population within the urban cluster is crucial for economic growth.

5.2. Policy recommendations

Based on the above research findings, this paper considers the following recommendations.

1. City governments at all levels within urban clusters should further optimize local government policies and continuously optimize the internal spatial structure of urban clusters with linkage mechanisms in land and household registration to improve the overall competitiveness of urban clusters. In imperfectly developed regions, the gathering and economies of scale of the central cities can be maximized by guiding population and resources, thus forming a pattern with the central cities as the growth poles and the coordinated development of large, medium and small cities.
2. For cities with more mature development and larger scale, the low-end production functions of core cities should be appropriately dispersed, the division of labor between regions should be strengthened, and the overcrowding phenomenon caused by the excessive and disorderly expansion of a single city could be avoided, so that the occurrence of uneconomic aggregation can be reduced effectively.
3. Finally, we should increase investment in transportation and communication, continuously optimize the industrial structure, further expand the opening to the outside world, and strengthen the resources and functions in the region in order to enhance the comprehensive competitiveness of the city cluster.

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Author contribution statement

Guohua Zeng: Conceived and designed the experiments.
Yuelong Hu: Performed the experiments; Analyzed and interpreted the data.
Yongyou Zhong: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

The authors do not have permission to share data.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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