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Industrial efficiency analysis based on the spatial panel model

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Abstract

High-tech industrial agglomeration is conducive to boosting technological progress, promoting industrial structure upgrading and realizing economic transformation, and certainly affects the overall industrial environmental efficiency. However, few recent studies have focused on its impact on industrial environmental efficiency from a green perspective. In the context of promoting the development of green economy, it is of great significance to clarify the links between high-tech industrial agglomeration and industrial environmental efficiency. In this research, we first analyzed the theoretical mechanism of the impact of high-tech industrial agglomeration and its spatial spillover effects on industrial environmental efficiency and then made an empirical analysis based on the panel data of 29 provinces and cities in China from 2003 to 2016. During the research, Super-DEA method, ESDA method and spatial Dubin model are used. The result shows that: (1) There is a significant spatial positive correlation between China's industrial environmental efficiency and high-tech industrial agglomeration; (2) high-tech industrial agglomeration has improved the local industrial productivity and industrial technology level through scale effects and technical effects, which has accordingly significantly enhanced the corresponding environmental efficiency; (3) through the association of regional industries, the cross-regional cooperation of enterprises and the formation of innovation networks, high-tech industrial agglomeration promotes the spillover of knowledge and technology among regions, improves the level of industrial technology in neighboring regions, and enhances the industrial environmental efficiency in neighboring regions. All these three is helpful to re-evaluate the development mode of high-tech industry agglomeration and to formulate relevant government policies.

Keywords: High-tech industrial agglomeration, Space spillover, Industrial environmental efficiency, Spatial Dubin model

1 Introduction

High-tech industry is a knowledge-intensive and technology-intensive industry. From 2000 to 2016, China's high-tech industry maintained a growth rate of over 15% at a constant price. It is a strong driving force for regional and national economic growth. Taking the high-tech development park as a carrier, the government works to integrate resources and cultivate industries in batches so as to form a batch of high-tech industrial chains and clusters, which is the main model for the development of high-tech industries in various provinces in China [1]. Agglomeration of high-tech industries can boost local economic growth with the aid of the advantages due to economies of scale. Also, agglomeration can enhance the technological level of the overall industrial chains in the region, and its externalities can improve the technological level of neighboring regions. The improvement of local and neighboring technological levels is conducive to that of industrial environmental efficiency and promotes green economic development. However, at the same time, the crowding effect of agglomeration will increase the plunder of resources. The higher the degree of agglomeration is, the more serious the pollution will be, and that is to say, the agglomeration reduces environmental efficiency [2]. If the agglomeration of high-tech industries reduces the efficiency of the industrial environment, then it is an ineffective way of development. Therefore, clarifying the links and mutual mechanism between high-tech industrial agglomeration and industrial environmental efficiency is conducive to re-evaluating the development mode of high-tech industrial agglomeration and also helps China's high-tech industrial development policy formulation [3, 4].

1.1 Related work

Agglomeration tends to produce agglomeration effect. Marshall (1920) pointed out that MAR spillover caused by specialized agglomeration would affect the efficiency of technological innovation. The agglomeration effect of industrial agglomeration would also have a certain impact on environmental efficiency. For a long time, this issue has been a hot topic in industrial economics, environmental science and some other fields [5]. The research views are highly diverse, which can be mainly divided into two categories. Some scholars believe that industrial agglomeration intensifies environmental pollution and reduces environmental efficiency [6]. For example, Virkanen (1998) used data from Finland to find that industrial clusters would cause environmental pollution [6]. Verhoef and Nijkamp (2002) empirically concluded that industrial agglomeration was positively correlated with air pollution by using data of European cities. Duc (2007) also found that industrial agglomeration is an important cause of river pollution by studying industrial emission data around Vietnamese rivers. Ren et al. (2003) claim that in the process of rapid urbanization in Shanghai, the agglomeration of industries led to the excessive development and utilization of land, resulting in the decline of water quality. Other scholars argue that industrial agglomeration reduces environmental pollution and improves environmental efficiency [7]. For example, Zeng and Zhao (2009) hold the view that manufacturing agglomeration can help reduce the "pollution shelter" effect and improve environmental efficiency by building a spatial economic growth model of the two countries and two sectors. As a manufacturing industry with high knowledge content, the agglomeration of high-tech industry can improve the labor production efficiency. However, there are few studies on the advantages and disadvantages of high-tech industry agglomeration on environmental pollution [8]. In recent years, under the demand of the high-quality development and the transformation and upgrade of the manufacturing sector, China has made great efforts to develop the high-tech industry and achieved good results [9]. The research on the agglomeration of the high-tech industry has also been gradually enriched, mainly focusing on the discussion of three issues. The first is the technological innovation effect of high-tech industry agglomeration. Ding Xuhui discussed the relationship between China's high-tech industry agglomeration and regional innovation efficiency. He pointed out that the former significantly promotes the latter of technology, and this promotion has a continually growing trend but performs quite differently among different regions [10]. Ke Zhang and Zhaohui Xu (2019) claim that there is a significant two-way promotion between high-tech industrial agglomeration and regional innovation by analyzing the interaction between them. The former can promote the latter through technology spillover effects, scale effects and labor productivity effects. The second issue lies in the knowledge spillover effect of high-tech industry agglomeration. Firstly, in terms of industry spillovers, Wu Yonglin and Chen Yu (2012) consider that the high-tech industry clustering has a large technological spillover effect in basic industries, while Qu Wan and Feng Haihong (2016) maintain that it has a significant technological spillover effect on the service industry [11]. Secondly, on space spillovers, Wang Qingxi et al. (2013) hold that there is a clear spatial correlation between the innovation activities of high-tech industries in various provinces of China, and it has a greater role in promoting regional innovation activities than R & D investment and human capital investment. The last issue is the economic growth effect of high-tech industry agglomeration. Chen Jun et al. (2016) evaluated the economic effects of high-tech industrial agglomeration in China and found in it there was a significant spatial difference. The economic effect was significantly higher in the mid-western regions than in the eastern region. Based on a threshold regression model, Huang Baofeng et al. (2019) validated the Williams hypothesis of the impact of high-tech industrial agglomeration on economic growth. The research results indicate that in the early stage high-tech industrial agglomeration significantly promoted economic growth [12, 13]. When it exceeded a certain threshold, its impact on economy will fall sharply. In addition, with the continuous development of China's high-tech industry and the development of high-quality economy, some scholars began to shift their attention to its impact on the efficiency of green economy [14].

In summary, it is not difficult to find that although existing studies have analyzed the impact of high-tech industrial agglomeration on the efficiency of technological innovation, its impact on the green environmental efficiency from a green perspective is rarely addressed. At present, China is promoting high-quality economic development, in which green development is one of the most important contents [15]. In addition, high-tech industries belong to industry and are at the upstream of the industrial chain. From the perspective of industrial development, high-tech industrial agglomeration greatly enhances the level of industrial technology and, as a result, directly affects industrial environmental efficiency. Currently, few studies have been rooted in the field of the high-tech industrial impact on industrial and environmental efficiency. In addition, based on the existing research, we can further draw the conclusion that the development of regional high-tech industries is no longer independent but has a close spatial relationship [16]. Therefore, the spatial spillover effect of high-tech industrial agglomeration will also have an important effect on industrial environmental efficiency. In view of this, based on the cross-provincial panel data of China from 2003 to 2016, we use the spatial panel measurement model as the research method to empirically analyze the linkages between the high-tech industrial agglomeration and the industrial environment after clarifying the links between these two. Hopefully, it will provide a realistic basis for the formulation of China's high-tech industry development policy [17].

1.2 Theoretical hypothesis and research design

Before clarifying the actual linkages between high-tech industrial agglomeration and industrial environmental efficiency, in this article we first analyze the mechanism between these two and propose corresponding research hypotheses. From the existing research, the high-tech industrial agglomeration itself affects industrial environmental efficiency of the local, and its externalities will also affect that of the neighboring areas. This will be explained in detail later [17].

Here we will analyze its impact on local industrial environmental efficiency. In most cases, the high-tech industrial agglomeration produces scale effects and technological effects [18]. The impact of scale effects on industrial environmental efficiency is reflected in that the agglomeration of high-tech industries conditions of using the public resources for enterprises within the agglomeration, utilization efficiency and configuration capabilities of social public industrial resources have been improved, the waste of resources and environmental pollution has been reduced, and thereby industrial environmental efficiency has been improved [19]. The technical effect is reflected in the spillover of knowledge within and between industries and the competitive relationship among enterprises in the cluster. For one thing, the concentration and flow of talents and information in the high-tech industry agglomeration area is relatively large, and social networks and technological networks are perfect [20]. The flow of talents and perfect social networks provide an informal exchange platform for the transmission of tacit knowledge and strengthen the diffusion of technology between industries. The convergence of technology and process, the homology of technology, the division of labor among enterprises in the gathering area and the formation of a technology network together strengthen the diffusion of knowledge, which thus not only strengthens the independent innovation capability of the enterprises, but also increases the introduction and absorption of foreign production technology and management experience, and increases the production efficiency and resource allocation capabilities of the enterprises, thereby improving the efficiency of the industrial environment as a whole. For another, the agglomeration zone has a perfect trading network [21]. In the face of market competition pressure and its own interests, all enterprises will inevitably take the initiative to carry out technological innovation, consequently increasing the economic efficiency of production and the efficiency of the regional industrial environment. Accordingly, in the article we propose the first hypothesis of the study:

The agglomeration of high-tech industries can increase the efficiency of the local industrial environment through scale effects and technological effects [22].

Here we will analyze the impact of the former on the latter in neighboring regions. Economic globalization makes the various actors not isolated in industrial agglomeration, but spatially related through regional networks [23]. Due to geographical proximity and economic association, high-tech industrial agglomeration increases the spillover of knowledge or technology in space, affects the technical level and innovation ability of enterprises in neighboring areas, and further affects the efficiency of the industrial environment in neighboring areas. First of all, the flow of human capital has always been regarded as the most important factor for knowledge spillover. The flow of human capital between industries has promoted the spillover and diffusion of knowledge between vertically related industries, while the flow of external human capital provides the possibility for the introduction of external knowledge and its combination with the original knowledge in the local innovation system. It also facilitates the filling of local technological gaps and the improvement of the overall technical level, which in turn improves local industry environmental efficiency. Secondly, geographical proximity, inter-industry associations, and social and cultural systems have allowed core member companies in regions to engage in interactions intentionally or unintentionally [24]. From the perspective of innovative behavior, this vertical association of enterprises will form an innovative network and provide opportunities for enterprises in gathering areas to learn new knowledge and technologies and enhance the level of knowledge and technology spillover. As a result, high-tech industrial agglomeration enhances the technical level of companies in neighboring areas through the spillover of knowledge and agglomeration, and improves the efficiency of the industrial environment. Based on this, the article proposes the second hypothesis of the study:

Agglomeration of high-tech industries promotes the efficiency of the industrial environment in neighboring regions through the spillover effect of knowledge and technology [25].

2 Methods

2.1 Model settings

In order to effectively verify the industrial environment efficiency of high-tech industrial agglomeration and its externalities (spillover effects), in the article we use the control space panel for analysis. Common spatial panel models include the spatial lag (SAR) model, the spatial error (SEM) model and the spatial Dubin model (SDM). The SAR and SEM take into account the spatial correlation of the interpreted variable and the error term, respectively, while the SDM considers both the spatial correlation of the explained variable and the explanatory variable. The SDM is more representative and meets the requirements of space overflow effect measurement in this article. Therefore, in this research we use the SDM to study. Its specific form is:

$$Y = \rho WY + X\beta + \theta WX + \alpha l_n + \varepsilon \tag{1}$$

in which ρ is the spatial autocorrelation coefficient, β and θ are the regression coefficients, α is the constant term, l_n is a unit matrix of order n × 1; W is the spatial weight, WY and WX are the space of the explanatory variable and the explanatory variable lag item. According to the method of Lesage et al. (2009), the total effect of the model above can be decomposed into a direct effect reflecting the local average impact and an indirect effect reflecting the average impact on other regions, specific as follows:

$$Y = (1 - \rho W)^{-1}\alpha l_n + (1 - \rho W)^{-1}(X\beta + \theta WX) + (1 - \rho W)^{-1}\varepsilon \tag{2}$$

Sorting can get:

Table 1 Industrial environment efficiency measurement index system

	Category	Indicator meaning	Specific indicators
Input	Cost of assets	Energy consumption	Total industrial energy consumption
		Human capital consumption	Industrial employment
		Capital consumption	Industrial capital investment
	Environmental cost	Waste water disposal	Total industrial waste water discharge
		Exhaust emission	Industrial sulfur dioxide emissions
		Solid waste discharge	Industrial solid waste generation
Output	Economic output	Total economic development	Gross industrial production

$$Y = \sum_{r=1}^{k} S_r(W)x_r + V(W)l_n\alpha + V(W)\varepsilon \tag{3}$$

in which $S_r(W) = V(W)(I_n\beta + W\theta_r)$, $V(W) = (1 - \rho W)^{-1}$, I_n is the n-th-order identity matrix. Further conversion into matrix form is:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \sum_{r=1}^{k} \begin{bmatrix} S_r(W)_{11} & S_r(W)_{12} & \cdots S_r(W)_{1n} \\ S_r(W)_{21} & S_r(W)_{22} & \cdots S_r(W)_{2n} \\ & \vdots \ddots \cdots \vdots & \\ S_r(W)_{n1} & S_r(W)_{n2} & \cdots S_r(W)_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} + V(W)\varepsilon \tag{4}$$

The total effect (ATI), direct effect (ADI) and indirect effect (AII) are:

$$\begin{aligned} ATI &= n^{-1}I_nS_r(W)_{In} \\ ADI &= n^{-1}I_ntr(S_r(W)) \\ AII &= ATI - ADI \end{aligned} \tag{5}$$

3 The explained variable

The explained variable studied in this article is the industrial environment efficiency (IEE), measured by Super-DEA model. Compared with the traditional DEA model, the advantage of Super-DEA model is that it can not only judge whether the decision units are effective but also compare the efficiency of them, and rank them according to the result of efficiency calculation. If the measured efficiency value is less than 1, its meaning is the same as the calculation result of the traditional DEA model, indicating that it is relatively invalid. If it is equal to 1, the result is valid. If it is greater than 1, it indicates that the decision units can still maintain a relatively optimal efficiency by expanding a few more on the basis of 1. In the calculation of industrial environmental efficiency, the relevant indicator system has been relatively sound. In the selection of input and output variables, generally speaking, the cost is the input variable, the income is the output variable, and the environmental pollutants can be considered as the cost, which, therefore, can be used as the input variable. Drawing on the relevant research (Jiao Bing et al., 2015; Zeng Xiangang, 2011), the following indicator system can be established (Table 1):

Among them, according to the existing relevant literature, the coal consumption is selected as a specific indicator of industrial energy consumption; industrial capital input is measured by the perpetual inventory method; drawing on the research of Jiao Bing et al. (2015), we regard the difference between the average annual balance of net fixed assets of industrial enterprises above the designated size as new fixed asset investment, and referring to the results of Zhang Jun et al. (2004), select 9.6% as the depreciation rate and use the fixed asset investment price index for deflation; as for the total industrial output value, the year of 2000 is chosen as the base period and the annual industrial ex-factory price index is used for deflation to eliminate the influence of price factors.

3.1 Core explanatory variable

The core explanatory variable in this research is the agglomeration of high-tech industries. The indicators of industrial agglomeration are quite rich, but considering the availability of data and the needs of research, this paper uses location entropy to calculate.

$$HLQ_i = \frac{HP_i/P_i}{HP/P} \tag{6}$$

in which HP_i and P_i represent, respectively, high-tech industry employment in i province and its total employment. HP and P represent, respectively, high-tech industry employment in all provinces and cities and their total employment.

3.2 Spatial weights and control variables

Spatial weight is an important means to reflect the economic and social spatial correlation and spatial dependence in the quantitative analysis. Therefore, the selection of weight is an important part of model establishment. In order to fully reflect the spatial "adjacent" and "adjacent" relations of the research unit, the article selects two geographic weights, namely the geographic queen adjacency weight and the geographic distance weight.[1]Among them, the measurement of the spatial weight of geographic distance is:

$$W_{ij}^d = e^{-\lambda d_{ij}} \tag{7}$$

in whichd_{ij} represents the distance between regional center city i and regional center city j. λ is a constant parameter, usually 1. Considering that the study area is an inter-provincial unit, $\lambda = 0.5$ in this study.

For the control variables, the article selects the following indicators: (1) innovative investment and the improvement of technical level reduce energy consumption and improve energy utilization rate, which are conducive to the improvement of industrial environmental efficiency. In practice, innovative investment is the main driving force for technological progress. The article takes R & D expenditure (LnR&D) as an innovation input indicator and measures it with stock. For the calculation of R&D capital stock, referring to the research method of Xie Lanyun (2010), the perpetual inventory method can be used, that is, $K_t = K_{t-1} + (1-\delta)R_t$, to reflect the cumulative characteristics of technological innovation inputs. Rt means current R&D expenditure. The R&D price index is weighted by the consumer price index and fixed asset price index. The weights are taken as 0.6 and 0.4, respectively, and the depreciation rate δ is taken as 15%. The

[1] The explanatory variable is the industrial environmental efficiency, and the spatial correlation is more from the geographical proximity, so the economic weight or the comprehensive weight of geography and economy is not used to reflect the economic proximity.

Table 2 Descriptive statistics of each variable

Variable	Observations	Mean	variance	Minimum value	Maximum value
IEE	406	0.8224	0.3754	0.2544	2.7188
Hlq	406	0.903	1.118	0.024	4.942
LnR&D	406	15.082	1.454	10.904	18.145
LnFDI	406	12.3040	1.7067	7.3099	15.0897
MS	406	6.302	1.801	2.530	10.920
IND	406	0.4035	0.0704	0.1569	0.5304
URB	406	0.5130	0.1470	0.2570	0.8960

base period R&D stock is determined as $K_0 = \frac{1+g}{g+\delta}E_0$. g is the average growth rate of R&D investment. E_0 is the initial R&D expenditure. (2) Degree of opening up. On the one hand, openness is an important source of technological progress. On the other hand, the "pollution paradise" hypothesis and the "race to the bottom line" argument hold that foreign trade will cause developed countries to relocate polluting enterprises to backward countries or regions. Thus it is an important factor affecting the industrial environment efficiency. In the article we use foreign direct investment (FDI) as a specific indicator, taking the actual use of foreign investment as a percentage of regional GDP; (3) market-oriented development level. For one thing, the degree of marketization can reduce the transaction costs of enterprises. For another, it can stimulate the innovation activities of enterprises. Therefore, it is also an important factor that affects the industrial environment efficiency. This article takes the marketization index (MS) as a specific indicator, which is obtained from the report on China's marketization index prepared by Fan Gang et al. (2010) and Wang Xiaolu et al. (2017) (4) Industrial structure, expressed as the ratio of industrial added value to GDP (IND). (5) Urbanization level. In practice, cities and towns often have more technological advantages over production efficiency and energy utilization than rural areas. Hence, the level of urbanization will also affect the industrial environmental efficiency to a certain extent. In the article, the urbanization rate is used as a specific indicator (URB).

3.3 Data description

Considering the availability and continuity of the data, the article panel data research unit is 29 provinces, municipalities and autonomous prefectures in China (hainan and Tibet are excluded due to missing data), and the research period is from 2003 to 2016. The article data come from "China Statistical Yearbook," "China High-tech Industry Statistical Yearbook," provincial statistical yearbooks and Guotai'an database. The descriptive statistics of each core explanatory variable and control variable are shown in Table 2.

4 Experiment

4.1 Spatial correlation analysis

The article establishes a spatial Durbin model, and the spatial correlation of variables needs to be tested before model analysis. There are many methods for measuring spatial correlation, among which the Moran index is widely used. The global Moran$^{'}$sI is:

Table 3 Spatial correlation test results

Year	W^{0-1}		W^d	
	IEE	*HLQ*	*IEE*	*HLQ*
2003	0.219** (2.231)	0.200** (2.089)	0.009** (2.255)	0.024 (1.019)
2004	0.180** (1.861)	0.161** (1.770)	0.011** (2.080)	0.024 (1.005)
2005	0.037* (1.653)	0.177** (1.905)	0.017* (1.645)	0.021 (1.260)
2006	0.016* (1.648)	0.191** (2.025)	0.020* (1.361)	0.018* (1.506)
2007	0.012 (0.315)	0.190** (2.025)	0.016** (1.832)	0.017* (1.632)
2008	0.012 (0.315)	0. 175** (1.909)	0.016** (1.832)	0.016** (1.704)
2009	0.047** (1.748)	0.171** (1.864)	0.012** (2.071)	0.016** (1.724)
2010	0.017 (1.180)	0.185** (1.995)	0.017** (1.746)	0.014** (1.875)
2011	0.050* (1.510)	0.174** (1.896)	0.020* (1.593)	0.015** (1.813)
2012	0.042** (1.721)	0.172** (1.867)	0.017** (1.920)	0.016** (1.746)
2013	0.039** (1.735)	0.177** (1.933)	0.017** (1.948)	0.015** (1.830)
2014	0.040** (1.845)	0.175** (1.914)	0.017** (1.845)	0.015** (1.806)
2015	0.019** (1.763)	0.176** (1.941)	0.017** (1.724)	0.013** (1.969)
2016	0.003* (1.461)	0.174** (1.953)	0.020* (1.405)	0.012** (2.170)

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(x_i - \bar{x}\right)\left(x_i - \bar{x}\right)}{s^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{8}$$

The calculation of the partial $Moran^{'}sI$ is:

$$I = \frac{\left(x_i - \bar{x}\right)}{S^2}\sum_{j=1}^{n} w_{ij}\left(x_j - \bar{x}\right) \tag{9}$$

in which $\mathrm{s}^2 = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}$ is the sample variance, and w_{ij} is the (i, j) element of the spatial weight. $Moran^{'}sI$ is generally between -1 and 1. Greater than 0 means that the high value is adjacent to the high value and the low value is adjacent to the low value. Less than 0 is the negative correlation between the high value and the low value. If it is equal to 0, there is no spatial correlation.

First, the global spatial correlation between China's industrial environmental efficiency and high-tech industrial agglomeration under two spatial weights is measured, as shown in Table 3.

Table 3 shows that the spatial correlation between China's industrial environmental efficiency and high-tech industrial agglomeration under the two weights is

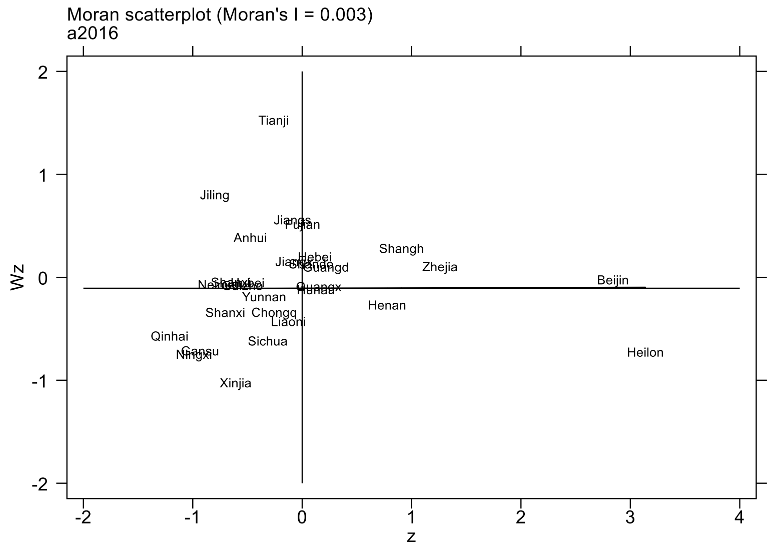

Fig. 1 Moran scatter plot of industrial environmental efficiency in 2016

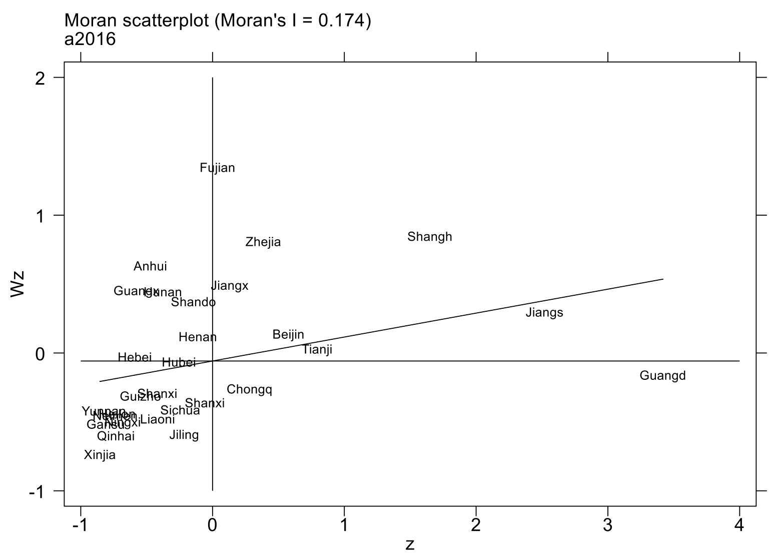

Fig. 2 Moran scatter plot of high-tech industry clusters in 2016

significantly more positive overall, and the spatial correlation of high-tech industrial agglomeration has an increasing trend. It is more obvious under the queen weight.

In order to further explore the industrial environmental efficiency and the spatial distribution of high-tech industrial agglomeration, we made a 2016 Moran scatter plot of industrial environmental efficiency and high-tech industrial agglomeration under the weight of queen, as shown in Figs. 1 and 2. In the figures, the first quadrant is the high–high concentration area, the second quadrant is the low–high concentration area, the third quadrant is the low–low concentration area, and the fourth quadrant is the high–low concentration area. After analyzing Fig. 1, we can easily find that the areas with high–high concentration include Beijing, Shanghai, Zhejiang, Guangdong and Hebei,

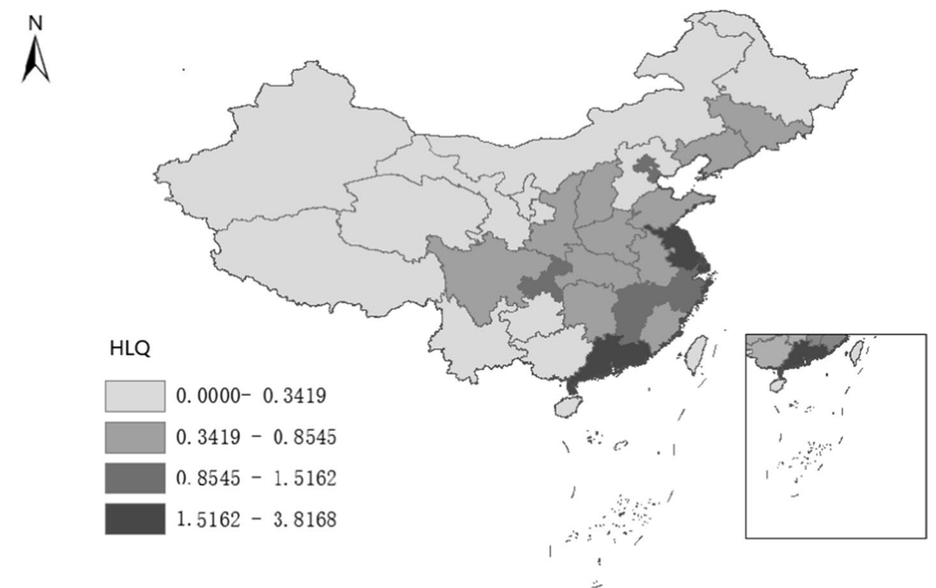

Fig. 3 The spatial pattern of high-tech industry agglomeration in 2016

all of which are eastern regions. The main manifestations of low–low agglomeration are Xinjiang, Qinghai, Gansu, Shaanxi, Yunnan and other western provinces and cities. The remaining provinces and cities, mainly in central provinces and cities, are mostly distributed in high–low agglomeration areas. This result shows that while the industrial environmental efficiency in China is spatially dependent, there is also spatial heterogeneity. In addition, analyzing the spatial distribution of high-tech industrial agglomeration, we can find from the results in Fig. 2 that 6 provinces and cities are distributed in the first quadrant. And there are 18 provinces and cities in the third quadrant, in the distribution state of high–high aggregation and low–low aggregation. The areas with high–high concentration are all eastern provinces and cities except Jiangxi, and 9 provinces and cities are in the second and fourth quadrant. This result also shows that there is a certain spatial correlation and high spatial heterogeneity in the agglomeration of high-tech industries. Further using spatial visualization to show the spatial pattern of high-tech industry agglomeration in 2016 (see Fig. 3), it can be found that the high-value areas of high-tech industry agglomeration are mainly distributed in the east, while the low values are mainly distributed in the west. It is consistent with Moran scatter plot results. To sum up the above analysis results, there is a significant spatial correlation between China's industrial environmental efficiency and high-tech industrial agglomeration. Therefore, it is reasonable to set up a spatial Durbin model. The following article continues to explore and analyze based on the spatial Durbin model.

4.2 Analysis of model results

Using maximum likelihood estimation to estimate the article setting model under two weights, the results are shown in Table 4. From the results of model estimation, the estimated coefficient of the spatial lag term of the explanatory variable (industrial environmental efficiency) is significant under both weights, which shows that the spatial

Table. 4 Model estimation results

Variable	W^{0-1}	W^{d}
HLQ	0.0382* (0.234)	0.0608*** (0.0221)
LnR&D	0.0402 (0.0316)	0.0815* (0.0341)
LnFDI	0.0114 (0.0104)	− 0.0009 (0.0103)
MS	0.0528*** (0.0129)	0.0547*** (0.0108)
IND	− 0.5713*** (0.1480)	− 0.2543* (0.1425)
URB	− 0.3482 (0.2586)	− 1.2265*** (0.3410)
$W \times HLQ$	0.1539*** (0.0450)	0.1991* (0.1101)
$W \times LnR\&D$	0.1965*** (0.0463)	0.4278** (0.1879)
$W \times LnFD\,I$	− 0.0115 (0.0226)	− 0.3345*** (0.0912)
$W \times MS$	− 0.0359** (0.0155)	− 0.0827*** (0.0158)
$W \times IND$	− 0.0937 (0.2365)	− 1.4621*** (0.5455)
$W \times URB$	− 2.4975*** (0.6895)	− 1.7864 (2.4341)
ρ	0.1329** (0.0752)	1.1144*** (0.3252)
like-hood	558.7845	558.7845

spillover effect of industrial environmental efficiency in the vicinity of the ground is significant. The estimated coefficients of the agglomeration of high-tech industries and their spatial lag items also have strong significant levels under the two weights, indicating that the agglomeration of high-tech industries and their externalities has a significant effect on the efficiency of China's industrial environment. In order to analyze the specific situation of its role, the estimation model is further decomposed. The results are shown in Table 5.

Based on the results in Table 5, the impact of high-tech industrial agglomeration on China's industrial environmental efficiency is analyzed. First, under the two weights, the direct effect of high-tech industrial agglomeration on the industrial environmental efficiency is significantly positive. This result shows that the high-tech industrial agglomeration greatly promotes the improvement of the industrial environmental efficiency in the regions. The current high-tech industrial agglomeration does not produce "crowding effect"; therefore, agglomeration is effective. This phenomenon is in line with the promotion of high-tech industrial agglomeration in various parts of China. In order to promote the local economic transformation and industrial structure upgrade, local governments have issued policies to build high-tech industrial parks and formed a certain high-tech industrial agglomeration, which has promoted the growth of the local industrial economy and technological level from both the scale effect and the technical effect and, to a certain extent, improved the efficiency of the local industrial environment. And

Table 5 Test results of direct effect, indirect effect and total effect

	Variable	W^{0-1}	W^{d}
ADI	*HLQ*	0.0395* (0.0240)	0.0674*** (0.0222)
	LnR&D	0.0408 (0.0309)	0.0938*** (0.0338)
	LnFDI	0.0124 (0.0099)	0.0071 (0.0097)
	MS	0.0526*** (0.0124)	0.0575*** (0.0109)
	IND	– 0.5728*** (0.1386)	– 0.2297* (0.1395)
	URB	– 0.3513 (0.3536)	– 1.2147*** (0.3521)
AII	*HLQ*	0.1547*** (0.0432)	0.1313* (0.709)
	LnR&D	0.2013*** (0.0481)	0.2570** (0.1014)
	LnFDI	– 0.0119 (0.0231)	– 0.1618*** (0.0413)
	MS	– 0.0359** (0.0154)	– 0.0704*** (0.0123)
	IND	– 0.1032 (0.2245)	– 0.6000** (0.2626)
	URB	– 2.5786*** (0.7347)	– 0.245 (1.3303)
ATI	*HLQ*	0.1942*** (0.0386)	0.1987* (0.1349)
	LnR&D	0.1605*** (0.0453)	0.1633* (0.0992)
	LnFDI	0.0005 (0.0251)	– 0.1547*** (0.0416)
	MS	0.0167* (0.0094)	– 0.0128** (0.0053)
	IND	– 0.6761*** (0.2184)	– 0.8297*** (0.2304)
	URB	– 2.9299*** (0.6804)	– 1.4597 (1.2644)

as knowledge-based industries, high-tech industrial products are renewed and replaced rapidly replacement, and the efforts that every region makes to develop high-tech industries ensure the relatively sufficient supply of production factors, both of which thus alleviating the "crowding effect" to a certain extent. This result validates the hypothesis 1 studied in the article.

Second, to analyze the indirect effect, that is, the effect of agglomeration of high-tech industries on the efficiency of the industrial environment in neighboring regions through space spillovers. The results in Table 5 show that the agglomeration of high-tech industries has a significant positive spatial spillover effect on the efficiency of the industrial environment. The agglomeration of high-tech industries in a region can help enhance the efficiency of the industrial environment in neighboring regions. Combined with the previous theoretical analysis, the agglomeration of high-tech industries has accumulated a large number of talents, capital and technology. Regional inter-industry associations, cross-regional cooperation of enterprises and the formation of innovation networks have promoted the flow of talents and capital, enhanced the cross-regional spillover of knowledge and technology, improved the technical level of related industries and promoted the development and production efficiency of the overall industry, and to a certain extent, increased the efficiency of the industrial environment in neighboring areas. This result indicates that hypothesis 2 proposed is true.

Based on the above analysis results, we can conclude that the impact of high-tech industrial agglomeration on the efficiency of the industrial environment has a dual effect. The scale effect and the technical effect have promoted the improvement of the local industrial environmental efficiency, while the spatial spillover effect of agglomeration has helped improve the industrial environmental efficiency in neighboring regions. The current concentration of high-tech industries in China is effective.

Analysis of the influence of control variables on the industrial environmental efficiency. The marketization rate has promoted the efficiency of the local industrial environment. From a practical point of view, marketization has reduced the production costs of local enterprises and stimulated local enterprises to innovate, so its direct effect is positive and the efficiency of the local industrial environment has been improved. The spatial spillover effect of the marketization rate is negative. The reason may be that the improvement of marketization promotes the migration of capable enterprises in neighboring regions. This migration reduces the overall industrial technology level of the neighboring regions, which is not conducive to the improvement of the industrial environment efficiency. The direct effect of industrial structure on industrial environmental efficiency is negative, that is, the expansion of industrial production scale is not beneficial to the improvement of local industrial environmental efficiency, and its spatial spillover effect is also negative, indicating that large-scale industrial production will reduce industrial environmental efficiency in neighboring areas. The large-scale production of industries places great pressure on the local area in the input factors and production waste discharge, which thereby reduces the industrial environmental efficiency, and the diffusion of pollutants will also reduce that efficiency in surrounding areas. In the regard of the urbanization rate, it inhibits the improvement of the industrial environment efficiency, whose reasons are as follows. The development of urbanization often relies on the secondary industry. Although the appearance of the city and the living environment of the residents are improved, the increase of the secondary industry and the pollution of the city bring about new problems, which reduce the industrial environment efficiency and also inhibit the improvement of the industrial environment efficiency in surrounding areas.

5 Results

From the perspective of space, this paper theoretically discusses the impact of China's high-tech industrial agglomeration and its spatial spillover effect on industrial environmental efficiency. And based on the panel data of 29 provinces, municipalities and autonomous prefectures from 2003 to 2016, empirical tests were conducted using the spatial Dubin model. The research results show that: (1) There are significant spatial correlations between China's industrial environmental efficiency and high-tech industrial agglomeration, and in the spatial distribution most regions are in high–high agglomeration areas and low–low agglomeration areas. Eastern provinces and cities are located in high–high agglomeration areas, and western provinces and cities in low–low agglomeration areas. (2) The agglomeration of high-tech industries promotes the efficiency of local industrial production and the overall technical level through scale effects and technological effects, thereby improving the efficiency of the local industrial environment. (3) The agglomeration of high-tech industries has enhanced the accumulation of talents, capital and technology. The inter-regional industry associations, the cross-regional cooperation of enterprises and the formation of innovation networks have promoted the flow of factors and further promoted the space overflow of agglomeration, thereby promoting the improvement of the industrial technology level of the neighboring areas and improving its industrial environment efficiency; (4) the marketization rate has significantly promoted the improvement of the industrial environment efficiency in local and neighboring regions, while the industrial structure and urbanization rate have a significant inhibitory effect on the industrial environment efficiency in local and neighboring regions.

6 Discussion

Based on the above analysis and research conclusions, the article draws the following policy implications:

First, promote the development of high-tech industries and focus on supporting the western regions. High-tech industrial agglomeration has a significant promotion effect on industrial environmental efficiency, whether it is from direct effects or indirect effects. However, from the current stage of development, the eastern region is the main gathering place for high-tech industries, while the western region is less concentrated. From the perspective of environmental protection, the western region is a region with weak environment, weak bearing capacity and serious pollution, and it is also an ecological barrier in China. Therefore, increasing the development and agglomeration of high-tech industries in the western region is a feasible move to improve its industrial environment efficiency, improve the ecological environment and promote economic development.

Second, strengthen the construction of inter-regional industrial linkage mechanism. High-tech industrial agglomeration has obvious space spillover effect. From the perspective of overflow channels, regional industry associations and cross-regional cooperation of enterprises provide convenience for this. Strengthening the construction of inter-regional industrial linkage mechanism has many benefits. For one thing, it strengthens the inter-regional industrial links, which is conducive to the spillover and diffusion of knowledge and technology. And then, compared with the spontaneous cooperation seeking of enterprises, the cooperation mechanism construction involves more and wider cooperation, stronger knowledge spillover intensity and is more conducive to gathering space overflow.

Third, deepen the upgrading of industrial structure and enhance the content of science and technology in the industrial structure. At this stage, industrial mass production will significantly reduce the industrial environment efficiency. From one aspect it shows that the current technological content of China's industrial industry is low. From another aspect, accelerating the upgrading of industrial structure is the need to improve China's industrial environment efficiency. Therefore, deepening the upgrading of the industrial structure, increasing the development of the tertiary industry, controlling the scale of the secondary industry and enhancing the content of science and technology in the industrial structure are feasible measures to improve the efficiency of China's industrial environment.

Fourth, promote energy conservation and emission reduction while promoting urbanization. Urbanization has improved the appearance of the city and the living environment of the residents. However, urbanization construction that depends on the secondary industry inevitably has an impact on the environment and reduces the efficiency of the industrial environment. Therefore, in practice, we should pay attention to promote energy conservation and emission reduction and residents' environmental awareness and pay attention to the green development of cities.

Abbreviation
DEA: Data engineering and analytics.

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