Pol. J. Environ. Stud. Vol. 31, No. 4 (2022), 3207-3220
DOI: *10.15244/pjoes/146479* ONLINE PUBLICATION DATE: 2022-05-05

Original Research

Impact of Industrial Agglomeration in Heavily Polluting Industries on Environmental Performance Based on DEA-SBM and Location Quotient in China

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Received: 22 October 2021
Accepted: 7 February 2022

Abstract

With the growth of China's economy, environmental pollution has become more serious. Heavy polluting industries received more attention due to their high pollution and high-energy production methods. This paper studied the impact of industrial agglomeration of heavily polluting industries on the environmental performance, which can help realize the sustainable development of China's economy and environment. In this paper, the employment number of heavily polluting industries in 30 provinces from 2013 to 2017 was selected, and the location quotient method was used to measure the industrial agglomeration of the heavily polluting industries. For the explained variable, environmental performance, this paper used the DEA-SBM method and selected an inseparable undesired output model to measure. In addition, the panel data were chosen for descriptive analysis, and the Z-score method was used to standardize the data. Then the correlation analysis and multiple linear regression analysis were conducted on the standardized data, mainly to study the impact of industrial agglomeration of heavily polluting industries on provincial environmental performance. Research results showed that the agglomeration degree of heavily polluting industries has a U-shaped influence on environmental performance. Finally, this paper proposed viable suggestions from three aspects: government, society, and industry.

Keywords: industrial agglomeration, environmental performance, heavily polluting industry, data envelopment analysis, inseparable undesired output model

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Introduction

As China's economy proliferates and the scale of economic development continues to expand, environmental problems are increasingly severe. Li evaluated the effect of ecological construction in China from 2008 to 2014 and found that China's overall level of ecological construction is still relatively lower [1]. From 1990 to 2014, China's per capita carbon emissions increased by 333% [2]. Although China's per capita carbon emissions are much lower than the US, EU, Japan, and other developed economies when they have reached the level of the peak, according to the "30·60" target proposed by China, no matter how much China's per capita carbon emissions are, and no matter what the cumulative historical amount is, China will achieve net-zero emissions by 2060.

Luo believed that the main culprit of environmental damage is heavily polluting industries [3]. Under the pressure of public opinion and news media, heavily polluting industries have gradually begun to pay attention to environmental performance (EP) [4]. In addition, due to their high energy consumption and high pollution caused by extensive economic development models, China's heavily polluting industries inevitably shoulder environmental and financial responsibilities.

With the division of labour increasingly regionalized and specialized in China, the industrial agglomeration has become a mature phenomenon in current economic activities in China. Industry agglomeration can exchange experience and technology by sharing a high-quality talent market and achieving scale production and energy conservation through horizontal or vertical linkages among industries. Moreover, mutual competition in the industrial aggregation area has enhanced the industry to innovate continuously, thereby increasing the efficiency of the entire industry aggregation area. Therefore, industrial agglomeration is a phenomenon that deserves our attention. Theoretically speaking, the industrial agglomeration of heavily polluting industries significantly impacts EP.

According to experience, it is not difficult to see that if there are no reasonable measures to protect the environment in the agglomeration areas of industries, especially heavily polluting industries, the environmental problems will emerge endlessly. For example, environmental pollution, such as haze, often occurs in some heavy industry cities. Therefore, in areas with a high agglomeration of heavily polluting industries, the destruction of the local environment and the excessive development of resources is also severe. But industrial agglomeration is also one of the essential modes for enterprises to achieve high-level and efficient development. It is incredibly conducive to the rapid development of the industry through the unique economic role of industrial agglomeration. And industrial agglomeration development is also a meaningful way to achieve optimization and advance. Considering this, and in the context of the increasingly acute social and environmental problems, Li's research showed that better EP enterprises have higher excess returns [5]. Moreover, enterprises with higher EP can more effectively resist the environmental opinion of the media [6]. Therefore, it is of great practical significance to discuss whether China's heavy polluting industries can promote environmental protection through the development mode of industrial aggregation and then improve the overall level of environmental quality in China.

By reading the literature of industrial agglomeration review, we can know the historical process of industrial agglomeration research [7]. In the 1890s, Marshall began to pay attention to and study the phenomenon of industrial agglomeration and creatively proposed three reasons for industrial agglomeration in spatial and geographical distance. In the 1930s, Hoover further studied industrial agglomeration. He divided agglomeration into internal scale, localization, and urbanization. In the 1990s, many scholars studied the phenomenon of industrial agglomeration from different perspectives, among which Krugman and Potter were the most famous. For the phenomenon of industrial agglomeration, Chinese scholars also carried out a lot of research. Liu believed that in a narrow sense, industrial agglomeration is a large number of similar enterprises and institutions in a particular space to form an interactive organizational form [8]. Yan believed that industrial agglomeration refers to a high agglomeration of the same industry in a specific geographical region and the agglomeration of industrial capital elements in spatial scope. In terms of state, it generally refers to the same kind of enterprises aggregated in an area [9].

By reading relevant literature on industrial agglomeration research and extensively referring to previous opinions, the connotation of the industrial aggregation to be studied in this paper was as follows: industrial agglomeration refers to the degree of agglomeration of the same or related industries in the geographical distance.

The measurement of regional EP can realize the joint development of the environment, society, and economics, which is conducive to constructing sustainable development in China. Huang believed that eco-environmental performance is a comprehensive benefit that considers the impact of the ecological environment, including economy, society, and environment [10]. Shu put forward integrating environmental with financial performance [11]. In the narrow sense, Jin believed that EP is indicative and quantifiable, such as the emission of three industrial wastes; in contrast, in the broad sense, EP can include the effective use of resources, the reduction of waste, energy consumption, and environmental risks [12].

Through extensive reading and thinking of EP literature, this paper considered that EP should include the comprehensive benefits of both economic and environmental aspects.

Some scholars believed that industrial agglomeration could improve environmental quality in past studies. Hu found industrial agglomeration is negatively correlated with pollution emissions on the whole [13]. The research results of Zeng show that the direct effect of strategic emerging industry agglomeration on green economic efficiency is significantly positive, and the total impact is hugely positive [14]. Other scholars believe that industrial agglomeration leads to increased energy consumption and pollutant emissions in the agglomeration areas, which is not conducive to environmental protection. Miao concluded that improving the agglomeration level of the manufacturing and productive service industry aggravates pollution [15]. Yuan concluded that the interaction between industrial agglomeration patterns and local government competition behaviour intensifies environmental pollution [16]. In addition, some scholars believe that there is a non-linear relationship between industrial agglomeration and EP. Yang found a “U-shaped” relationship between industrial agglomeration and manufacturing EP [17]. Wang and Shen found a U-shaped curve relationship between industrial agglomeration and environmental efficiency [18, 19]. Based on the panel data of 30 provinces in China from 2003 to 2016, Lu concluded a stable inverted U-shaped relationship between industrial collaborative agglomeration and environmental pollution [20].

The review of the current research results, found that many scholars studied the relevance between industrial agglomeration and environment. Still, research perspectives are primarily from the relationship between manufacturing, industry, and pollutant emission intensity agglomeration. Or from the perspective of the relationship between agglomeration of high-tech industry and green innovation efficiency. This paper selected heavily polluting industries to analyze the impact of industrial agglomeration on EP, which is more closely related to environmental issues. The main contributions of this paper are as follows:

(1) Innovatively adopt the inseparable undesirable output model of SBM to measure EP. The DEA method, which can evaluate the efficiency between decision-making units with multiple inputs and outputs, was selected to measure EP comprehensively. Concerning the existence of undesirable outputs in the production process, and undesirable output is inevitably related to input, this paper used the inseparable undesirable output model of SBM for analysis, which can more accurately measure EP.

(2) Analyzed how to improve EP from the perspective of industrial agglomeration. Industrial agglomeration is one of the critical trends in the current regional economic development. Its unique economic role significantly impacted society, the environment, and the economy, so industrial agglomeration became a current research hotspot. This paper discussed the relationship between industrial agglomeration of heavy-polluting industries and EP. It had a specific reference meaning for the heavy-polluting enterprises to adopt industrial agglomeration development models to improve EP and thus improve China's overall environmental quality.

In addition, this paper still had shortcomings. The data in this paper were mainly derived from the statistical yearbook. Because the three industrial waste data in the statistical yearbook had not been published since 2017, we selected 2013-2017 for analysis so that the data may have timeliness issues.

Material and Methods

Theoretical Analysis

Analysis of the Positive Impact of Industrial Agglomeration on the Environment

Economies of the scale can be divided into internal and external aspects. The reduction of production costs and the improvement of efficiency caused by the expansion of internal scale is called internal economies of scale. And the evolution of the scale at the industry or city leads to the increased efficiency and cost savings of a single enterprise without any change in the enterprise’s investment, which is called external economies of scale. Generally speaking, the scale economy benefits of agglomeration refer to the scale economy benefits at the industry, which can improve the production efficiency of the whole industry. That is to say, the same number of products can consume less energy, and the energy efficiency of the enterprise will continue to improve so that the emissions of pollutants in the whole industry can be reduced.

Alfred Marshall divided the external benefits of industrial agglomeration into three parts: the sharing of intermediate inputs, labour, and the spillover of knowledge. First of all, enterprises in the industrial agglomeration area may correlate in terms of business or products, so that enterprises can share raw materials or by-products. Secondly, agglomeration can facilitate the exchange and communication of high-quality talents among the heavily polluting industries, enabling the entire industry to share advanced technology and experience to protect the environment.

In the industry agglomeration area, the advanced environmental protection equipment can be shared in the heavy pollution industry so that the enterprises can efficiently deal with the pollutants, which help to reduce the cost of pollutant treatment and other environmental management in heavily polluting industries and realize the specialization of pollution control. At the same time, the agglomeration of heavily polluting industries can also form a larger community of interests, which can obtain public goods or services of environmental protection from public institutions at a lower cost.

Analysis of the Negative Influence of Industrial Agglomeration on the Environment

In the past, due to the extensive economic development model in China, energy consumption and pollutant emission increased considerably in the areas where heavy polluting industries are agglomerated, which led to the decline of environmental quality. And due to the environment being a typical public good and the environmental quality is challenging to quantify, enterprises may ignore environmental pollution to profit, resulting in external diseconomy and the deterioration of the environmental pollution in the industrial agglomeration of heavily polluting industries.

Suppose there is a lack of reasonable layout in the heavily polluting industries agglomeration areas. In that case, it is challenging to generate the positive effects of industrial agglomeration and very easy to cause the superposition of pollutants in the heavily polluting industries agglomeration areas. Secondly, the industry agglomeration may bring a significant expansion of production scale in the heavy pollution industry, which may cause the excessive use of energy and the considerable increase of pollutant discharge in the area of heavy polluting industry agglomeration.

And in the early stages of the industrial agglomeration, the scale of production may not meet the threshold of the economic benefits of scale; it simply causes an accumulation of pollutants in the aggregation area of the heavy pollution industry. In addition, the introduction and maintenance cost of advanced pollutant treatment equipment is expensive, so it is difficult to put into use in an extensive range at the initial period of heavy pollution industry agglomeration, so it is unable to exhibit the advantages of centrally disposing of pollutants. Secondly, there may be an unreasonable layout and imperfect regulations in the early stage of industrial agglomeration of heavily polluting industries, which cause enterprises in the aggregation area of heavy pollution industries not to take advantage of the relevance of business or products. Moreover, due to the competitive relationship within the heavy pollution industry, stable cooperation may not be formed in a short time, and positive effects are challenging to be realized.

Research Hypothesis

Based on analyzing the positive and negative effects of industrial agglomeration, this paper proposed a hypothesis: there may be a U-shaped relationship between industrial agglomeration of heavily polluting industries and EP.

Sample Source and Research Method

Because the statistical yearbook has not published the three industrial wastes emissions data since 2017, this paper selected the data of 30 provinces from 2013 to 2017 for analysis. A total of 16 industries were classified as heavy polluting according to the classification criteria of the Enterprise Environmental Credit Assessment Method (Trial) published by the Ministry of Environmental Protection. According to the availability and consistency principle of data–and Lin's selection of samples of heavily polluting industries [21], a total of 23 subsectors were selected as the research objects of this paper (see Table 1).

Variable Definitions

Explained Variable

Data envelopment analysis (DEA), created in 1978, is a model that evaluates the efficiency between decision units with multiple inputs and outputs, which scholars widely used to measure EP. Sun proposed an improved DEA model based on the optimal energy input allocation to evaluate EP [22]. Zhu proposed a common-weights DEA model based on "the priority of choosing common weights" to assess the EP [23]. Therefore, this paper selected the DEA method to measure the EP of 30 provinces.

According to the traditional theory of DEA, the primary approach to improving efficiency is increasing output or reducing input. However, inevitably, the undesirable output is related to the input, such as in the production process, the emission of pollutants is closely related to the input of energy. Therefore, how to evaluate the efficiency in the case of undesirable output becomes difficult. The processing methods of the undesirable output had: take the undesirable output as the input or inverse, hyperbolic treatment, linear transformation method, direction distance function method, SBM method, etc. The input method and inverse method violate the essence of production; hyperbola method and linear transformation method are difficult to solve; the direction distance function cannot deal with the relaxation problem, so this paper adopted the inseparable undesirable output model of SBM for analysis. The tool software is DEA-SOLVER 13. If and only if ρ = 1, the DMU is effective, otherwise there is still room for improvement.

$$\rho = min\frac{1-\frac{1}{m}\sum_{i=1}^{m_1}\frac{s_i^{s-}}{x_{i0}^{s}}-\frac{1}{m}\sum_{i=1}^{m_2}\frac{s_i^{NS-}}{x_{i0}^{SN}}-\frac{m_2}{m}(1-\alpha)}{1+\frac{1}{s}\left(\sum_{r=1}^{s_{11}}\frac{S_r^{sg}}{y_{r0}^{Sg}}+\sum_{r=1}^{s_{22}}\frac{S_r^{sb}}{y_{r0}^{Nsb}}+(S_{21}+S_{22})(1-\alpha)\right)} \tag{1}$$

$subject. to.$

$$x_0^s = X^s\lambda + s^{s-}$$

$$\alpha x_0^{NS} = X^{NS}\lambda + S^{NS-}$$

$$y_0^{Sg} = Y^{Sg} - s^{Sg}$$

Table 1. The 23 heavy pollution subsectors.

Number	Heavy polluting industries	Heavy pollution subdivision industry
1	Coal industry	Mining and washing of coal industry
2	Mining industry	Extraction of petroleum and natural gas
3		Ferrous metal mining and beneficiation industry
4		Nonferrous metal mining and beneficiation industry
5		Non-metallic mineral mining and processing industry
6	Brewing industry	Agricultural and sideline food processing industry
7		Food manufacturing industry
8		Liquor, beverage, and refined tea manufacturing industry
9	Textile industry	Textile industry
10	Leather industry	Leather, fur, feather, and their products and footwear industry
11	Building materials industry	Furniture manufacturing industry
12	Paper industry	Papermaking and paper products industry
13	Petrochemical industry	Petroleum, coal, and other fuel processing industries
14	Chemical industry	Manufacturing of chemical raw materials and chemical products
15	Pharmaceutical industry	Pharmaceutical manufacturing
16	Chemical industry	Chemical Fiber Manufacturing
17	Chemical industry	Rubber and plastic products industry
18	Building materials industry	Manufacture of non-metallic mineral products industry
19	Metallurgical industry	The ferrous metal smelting and rolling processing industry
20		The nonferrous metal smelting and rolling processing industry
21		Metal product industry
22	Building materials industry	Other manufacturing industries
23	Thermal power industry	Production and supply of electricity and heat

$$\alpha y_0^{NSg} \leq Y^{NSg}\lambda$$

$$\alpha y_0^{NSg} = Y^{NSg}\lambda + s^{NSb}$$

$$\sum_{r=1}^{s_{11}}\left(y_{r0}^{Sg} + s_r^{Sg}\right) + \alpha \sum_{r=2}^{s_{21}} y_{r0}^{NSg} = \sum_{r=1}^{s_{11}} y_{r0}^{Sg} + \sum_{r=1}^{s_{21}} y_{r0}^{NSg}$$

$$\frac{s_r^{Sg}}{y_{ro}^{Sg}} \leq U(\forall r)$$

$$S^{S-},\ S^{NS-},\ S^{Sg},\ S^{NSb},\ \lambda \geq 0,\ 0 \leq \alpha \leq 1$$

This paper constructed an EP index system (see Table 2). The indicator data mainly came from the statistical data of China Economic Network, China Statistical Yearbook, China Energy Statistical Yearbook, China Population and Employment Statistical Yearbook, etc.

The measured EP of 30 provinces is shown in Table 3, which can be reflected more intuitively in Fig. 1. It could be seen from Table 3 that the EP of Beijing, Tianjin, and Shanghai were efficient. However, the environmental efficiency value of other provinces still had room for improvement. Gansu, Qinghai, Ningxia, and Xinjiang had the lowest ecological efficiency values, which may be due to the relatively backward economic strength of Northwest China and the fragile local environmental environment.

Explanatory Variables

Referring to the practice of Yang [24], this paper selected the location quotient as the measurement of industrial agglomeration degree. Location quotient (LQ) can measure the spatial distribution of certain regional factors and better analyze the degree of industrial agglomeration from the region's perspective. The employment number of heavily polluting industries in 30 provinces was obtained from China Population and Employment Statistical Yearbook. The specific calculation formula of the LQ index is formula (2).

Table 2. EP calculation index system.

Indicator category	Detailed category of indicators	The specific content
Input indicators	The input of fixed assets	Social investment in fixed assets
	The input of human resource	Number of Employment by Region
	The input of the energy	Total regional energy consumption
	The input of water resources	Total regional water use
Output indicators	Desirable output	Gross regional domestic product
	Undesirable output	Discharge of chemical oxygen demand in wastewater
		Sulfur dioxide emissions from the exhaust gas
		General industrial solid waste production

Table 3. EP levels of 30 provinces in China.

Number	Region	2017	2016	2015	2014	2013
1	Beijing	1	1	1	1	1
2	Tianjin	1	1	1	1	1
3	Hebei	0.354516134	0.356560766	0.36150538	0.371757084	0.392074421
4	Shanxi	0.345596482	0.246068582	0.261629336	0.276457923	0.292632023
5	Inner Mongolia	0.316529026	0.39007913	1	1	1
6	Liaoning	0.427904703	0.424427387	0.459427096	0.411847246	0.404835639
7	Jilin	0.388339452	0.417252638	0.428388612	0.418437284	0.428055786
8	Heilongjiang	0.275815568	0.28874777	0.309405914	0.323048761	0.318718086
9	Shanghai	1	1	1	1	1
10	Jiangsu	0.564939939	0.56611756	0.616567756	0.592930528	0.623317612
11	Zhejiang	0.585498283	0.575238241	0.599583687	0.591469953	0.634619741
12	Anhui	0.367152225	0.370231446	0.384959341	0.390534941	0.394646145
13	Fujian	0.45308794	0.463795794	0.480826488	0.47572219	0.471917693
14	Jiangxi	0.32885982	0.332957875	0.340812619	0.359153751	0.37386554
15	Shandong	0.509476493	0.52161299	0.529457253	0.531128363	0.536553086
16	Henan	0.354223619	0.342691394	0.347240093	0.35591922	0.361434355
17	Hubei	0.405831745	0.412769954	0.427608414	0.41942995	0.419076115
18	Hunan	0.452282843	0.464609101	0.480810906	0.467763546	0.463264961
19	Guangdong	0.561878932	0.597297956	0.634488717	0.653030364	0.666609019
20	Guangxi	0.31149939	0.349530598	0.366730103	0.377597935	0.384977431
21	Hainan	0.375941521	0.404647147	0.423672727	0.435054239	0.451983178
22	Chongqing	0.451529123	0.445621265	0.440436689	0.407506488	0.403920412
23	Szechwan	0.368787877	0.364563543	0.380510847	0.372521052	0.364570385
24	Guizhou	0.293517785	0.292179801	0.302792107	0.285112983	0.278493326
25	Yunnan	0.281000268	0.28135729	0.300300358	0.30210977	0.300260697
26	Shaanxi	0.359154657	0.35311779	0.361689724	0.381544579	0.388878613
27	Gansu	0.223556731	0.212263831	0.219424186	0.234890252	0.244745275
28	Qinghai	0.214133332	0.239940855	0.254996273	0.255529535	0.261766628
29	Ningxia	0.233210135	0.237145096	0.23998866	0.24572082	0.258546688
30	Xinjiang	0.177474469	0.179338699	0.19210759	0.212550521	0.218577161

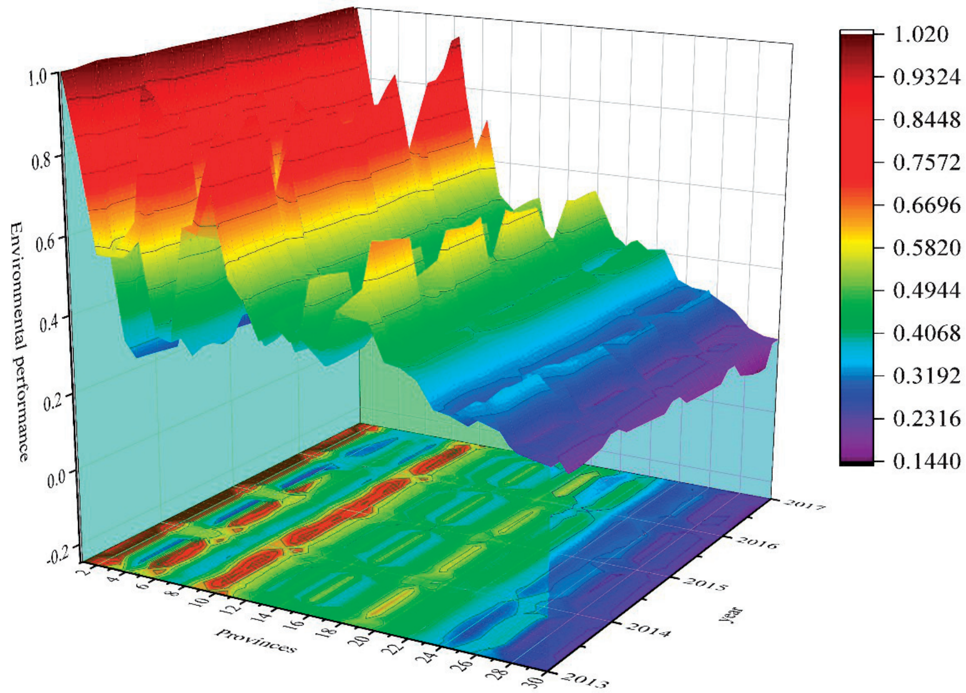

Fig. 1. EP of 30 provinces in China from 2013 to 2017.

$$LQ_{ij} = \frac{m_{ij}/\sum_i m_{ij}}{M_i/\sum_i M_i} \quad (2)$$

The m_{ij} represents the number of employees in the i industry; the j region; The Mi represents the number of employees in the national i industry; LQ = 1 represents uniform distribution. The larger LQ, the higher the degree of industrial agglomeration in the region. The measured results of industrial agglomeration of China's heavily polluting industries are shown in Table 4, which can be reflected more intuitively in Fig. 2.

As shown in Table 4, from the degree of agglomeration, Beijing, Shanghai, Hainan, and Chongqing had a relatively low degree of industrial agglomeration in heavily polluting industries. The agglomeration degree of heavily polluting industries in Tianjin reached its peak in 2015 and then decreased. The LQ index of heavily polluting industries in Shanxi, Inner Mongolia, Fujian, Shandong, Henan, Shanxi, Qinghai, and Ningxia was more significant than 1, indicating that the industrial agglomeration degree of heavily polluting industries in this region was relatively high. The LQ index of heavily polluting industries in Hebei, Liaoning, Heilongjiang, Anhui, Jiangxi, Hubei, Guangdong, Guizhou, Yunnan, Gansu, and Xinjiang was close to 1, indicating that the distribution of heavily polluting industries in these regions was relatively uniform. In the trend of agglomeration development ways, between 2013 and 2017, the industrial agglomeration degree of heavy pollution industry in Beijing, Shanghai, Tianjin, Hebei, Hubei, Hunan, Chongqing, Sichuan, Guizhou was on the decline. The industrial agglomeration degree of heavy pollution industries in Shanxi, Liaoning, Henan, Guangdong, Shanxi, Qinghai, Ningxia was gradually increasing.

Control Variables

The following eight variables were selected as the control variables through reading and thinking about related literature.

(1) Economical: economic development is closely related to environmental issues. A low economic level may lead to the one-sided pursuit of economic growth, resulting in more pollutant emissions, which is not conducive to the improvement of EP. When the economic level is higher, the government has more sufficient investment funds for environmental protection. It is believed that residents living in areas with higher economic levels tend to pursue a better living environment. Therefore, the total consumption level of residents was selected to represent the economic level, and the data came from the CSMAR [25].

(2) Technology: the progress of science and technology is conducive to adopting clean and green production technology in the industry, reducing pollutant emission. Previous studies showed that green innovation behaviour positively impacts EP [26]. The technology index in this paper was measured by the intensity of R&D investment of 30 provinces from 2013 to 2017, and data was derived from China Science and Technology Statistical Yearbook.

(3) Government Intervention: Generally, we believe that the higher the degree of environmental regulation by the government, the better the level of environmental

Table 4. Industrial agglomeration level of heavy polluting industries in China.

Number	Region	2017	2016	2015	2014	2013
1	Beijing	0.299815826	0.304664024	0.31790828	0.345667433	0.359297972
2	Tianjin	0.855429817	0.980569929	1.001735928	1.001622076	0.984961926
3	Hebei	1.060528686	1.077158505	1.079242605	1.09721385	1.097624674
4	Shanxi	1.931223458	1.857681863	1.828531023	1.783946508	1.7539732
5	Inner Mongolia	1.249229834	1.310999912	1.298250755	1.268264281	1.228995074
6	Liaoning	1.096516249	1.045015987	1.040163302	1.041407469	1.029977961
7	Jilin	1.060132631	1.119878802	1.10646751	1.072431016	1.059165462
8	Heilongjiang	1.020584025	1.04019181	1.071712304	1.062591639	1.037085078
9	Shanghai	0.594111795	0.614187951	0.612127338	0.622299812	0.645665887
10	Jiangsu	0.820010293	0.829690228	0.820930933	0.787926187	0.727659342
11	Zhejiang	0.844878762	0.816928133	0.795966609	0.82156802	0.837258615
12	Anhui	0.985439211	0.978284816	0.99494392	1.014837221	1.007131011
13	Fujian	1.139022843	1.157662652	1.156633943	1.171250717	1.163831084
14	Jiangxi	1.029420475	1.068274782	1.069253467	1.065591156	1.013464809
15	Shandong	1.523619963	1.466118461	1.481024166	1.445159466	1.565095264
16	Henan	1.392287384	1.36030816	1.310477736	1.267574258	1.228346922
17	Hubei	0.925342723	0.940816155	0.941968264	0.950969446	0.951617199
18	Hunan	0.844152564	0.855557252	0.899442321	0.914548685	0.913292865
19	Guangdong	1.029134991	1.014762997	1.010118612	0.993333056	0.97959792
20	Guangxi	0.785723424	0.82950797	0.821476554	0.839055412	0.85498573
21	Hainan	0.496139449	0.477156461	0.492549313	0.504169358	0.504566829
22	Chongqing	0.529535054	0.564329844	0.59256411	0.611592463	0.603663027
23	Szechwan	0.841073078	0.847172524	0.882407485	0.963246203	0.963827532
24	Guizhou	0.893288435	0.953046849	1.001790573	1.059169801	1.100212513
25	Yunnan	1.037038814	1.030539774	1.025570289	1.049730479	1.089038389
26	Shanxi	1.110602276	1.072280609	1.055428041	1.018133158	1.01297328
27	Gansu	1.050292971	1.042803765	1.05253486	1.076130198	1.011044672
28	Qinghai	1.361945771	1.324353865	1.321376077	1.328461833	1.302650099
29	Ningxia	1.616340195	1.548396639	1.528501212	1.509579599	1.438067791
30	Xinjiang	0.959399908	0.948484054	0.921853061	0.949389692	0.888104841

quality in the region. In this paper, the proportion of investment in environmental pollution control of GDP from 2013 to 2017 was used to represent the degree of Government Intervention. The data was obtained from China Environmental Statistics Yearbook.

(4) Education: the improvement of education level is closely related to the enhancement of environmental consciousness, and it is believable that college students have a more vital awareness of environmental protection. In this paper, the proportion of the population with a college degree and above of the local population aged six and above in 30 provinces from 2013 to 2017 was used to measure the regional education level. Data came from China Statistical Yearbook.

(5) Population: The more people there are, the more resources they use and the more pollution they emit, so we generally consider that the population harms EP. This paper selected the population of 30 provinces at the end of the year from 2013 to 2017. The population data at the end of 30 provinces came from China Population and Employment Statistical Yearbook.

(6) Foreign direct investment (FDI): Foreign direct investment is essential for EP. In general, we believe that foreign-invested enterprises have relatively higher

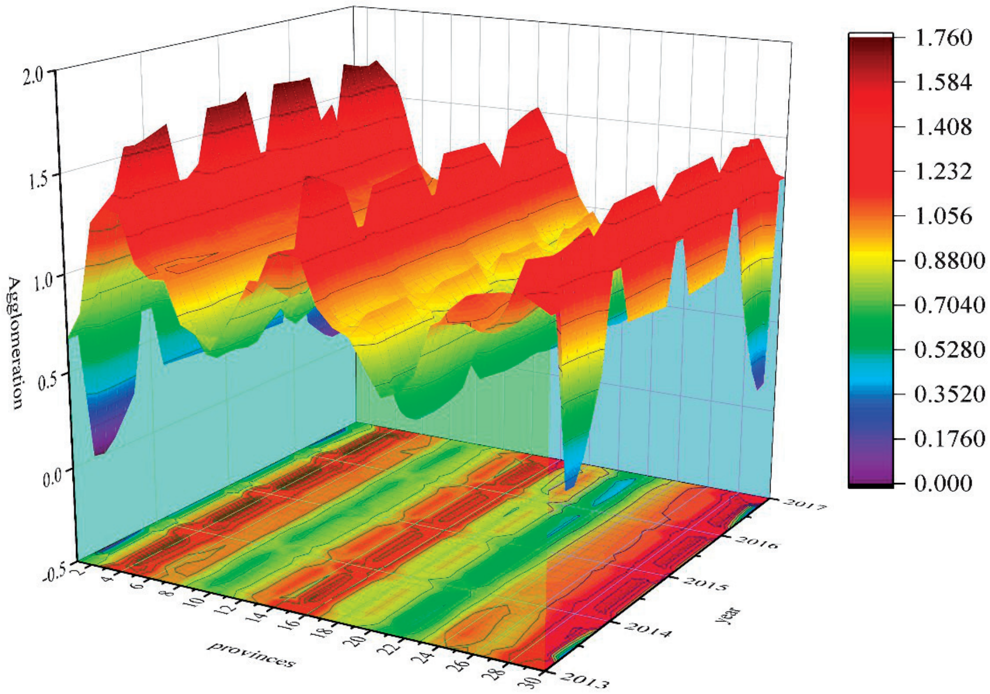

Fig. 2. Agglomeration level of heavy pollution industries in 30 provinces of China.

environmental concepts and advanced production and environmental protection technology, which can improve the efficiency of energy utilization and reduce the emission of pollutants. But the foreign investment can also bring about a "pollution haven" effect. In this paper, the proportion of gross industrial output value of the foreign investment in heavily polluting industries to GDP from 2013 to 2017 was used to measure the level of foreign direct investment. Data were from China Statistical Yearbook, China Trade, and Foreign Economic Statistical Yearbook.

(7) Industrial structure: Different industrial systems have different impacts on EP. In general, we believe that the environmental quality is lower in regions with a more significant proportion of the secondary industry. In contrast, areas with a higher proportion of tertiary industry in industrial structure have higher EP. The proportion of the industrial added value to the local GDP was selected as the index of the regional industrial system. The data was obtained from China Statistical Yearbook.

(8) Traffic levels: Traffic levels dramatically impact the region's economic development and environmental characterization. This paper selected the cargo turnover from 2013 to 2017 to represent the regional transportation level. The data of cargo turnover of 30 provinces were obtained from China Statistical Yearbook.

Econometric Model Construction

This paper constructed a multiple regression equation for factors that influence EP based on the above. The variables and their calculation methods are shown in Table 5, and the basic model is shown in formula (3).

$$EP_{ij} = \alpha_{ij} + \beta_1 agglo_{ij} + \beta_2 agglo^2{}_{ij} + \beta_3 ec_{ij} + \beta_4 tech_{ij} + \beta_5 edu_{ij} + \beta_6 pop_{ij} + \beta_7 fdi_{ij} + \beta_8 struct_{ij} + \beta_9 gi_{ij} + \beta_{10} traf_{ij} \quad (3)$$

The EP_{ij} represents the EP indicators of the j region in the i year. And i =2013, 2014, 2015, 2016, 2017, j represents 30 provinces (excluded Hong Kong, Macau, Taiwan, and Tibet).

Results and Discussion

Descriptive Statistics Results and Discussion

Descriptive statistics were carried out on the variable data, as shown in Table 6, and Z-score standardization was applied to process the data. As shown from Table 6, the mean value of 0.458 for EP was greater than the median value of 0.389, indicating that the EP of more than half of the provinces in China has not reached the national average level. The median of the industrial agglomeration level of heavily polluting industries was equal to the mean, indicating that the distribution of this index data was symmetrical. The median economic level of 16,732 was less than the mean of 19,835, and the standard deviation was significant, indicating that the economic development

Table 5. Variable definition and calculation method.

Define	Symbol	Variable	Calculation method
Explained variable	ep	Environmental performance	Measurement of DEA-SBM inseparable undesirable outputs
Explanatory variables	agglo	Industrial agglomeration (first power)	A location quotient of employment in heavily polluting industries
	agglo2	Industrial agglomeration (second power)	The square of the location quotient of the number of people employed in heavily polluting industries
Control variables	ec	Economics	The total level of household consumption
	pop	Population	Year-end population
	edu	Education	The proportion of the population aged six and above with a college degree or above
	tech	Science and technology	The intensity of research and experimental development funds
	fdi	Foreign direct investment	The proportion of gross industrial output value of the foreign investment in heavily polluting industries to GDP
	struct	Industrial structure	The proportion of the added value of the industry in the GDP
	gi	Government intervention	The proportion of investment in environmental pollution control in GDP
	traf	Traffic	The volume of cargo turnover

degree of 30 provinces in China varied greatly, and the economic level of more than half of the provinces did not reach the national average level. The median FDI of 0.192 was less than the average of 0.346, indicating that more than half of the provinces received less FDI. The median for education of 0.120 was less than the average of 0.139. The median for the technology of 1.28 was less than the average of 1.632, indicating that more than half of the provinces did not reach China's education and technology level. The government still need to strengthen investment in technology and education. The median of government intervention of 1.29 was lower than its mean of 1.458, indicating that the environmental controls in some provinces were not high enough and needed to be further strengthened. The standard deviation of population and traffic level was substantial, indicating significant differences in population and transportation conditions among the 30 provinces. The median of the regional industrial structure was 0.390, which was greater than the mean of 0.364, indicating that the proportion of secondary industry in some provinces was small, so the industrial added value was low, making the mean value of this index more minor than the median.

Correlation Analysis Results and Discussion

Correlation analysis was conducted on the Z-score standardized data of 30 provinces in China from 2013 to 2017, and the results are shown in Table 7. It can be seen from Table 7 that, for the industrial agglomeration index of the heavily polluting industries, the coefficient

Table 6. Descriptive statistics of each variable.

VARIABLES	N	MEAN	MEDIAN	SD	MIN	MAX
ep	150	0.458	0.389	0.227	0.177	1
agglo	150	1.016	1.016	0.303	0.3	1.931
ec	150	19,835	16,732	9,081	9,541	53,617
pop	150	4,560	3,834	2,727	578	11,169
edu	150	0.139	0.120	0.0722	0.0681	0.476
tech	150	1.632	1.28	1.117	0.46	6.01
fdi	150	0.346	0.192	0.348	0.0473	1.759
gi	150	1.458	1.29	0.798	0.3	4.24
struct	150	0.364	0.390	0.0819	0.118	0.496
traf	150	5,494	3,757	5,139	445.6	27,920

Table 7. Correlation analysis of major variables.

	Zep	Zagglo	Zagglo2	Zec	Zpop	Zedu
Zep	1					
Zagglo	-0.422***	1				
Zagglo2	-0.357***	0.972***	1			
Zec	0.801***	-0.423***	-0.337***	1		
Zpop	-0.029	0.118	0.055	-0.036	1	
Zedu	0.711***	-0.425***	-0.306***	0.826***	-0.313***	1
Ztech	0.766***	-0.460***	-0.361***	0.818***	0.106	0.835***
Zfdi	0.680***	-0.482***	-0.393***	0.853***	-0.106	0.659***
Zstruct	-0.039	0.466***	0.350***	-0.256***	0.436***	-0.389***
Zgi	-0.163**	0.277***	0.333***	-0.183**	-0.359***	0.096
Ztraf	0.342***	-0.065	-0.095	0.443***	0.518***	0.12

	Ztech	Zfdi	Zstruct	Zgi	Ztraf
Ztech	1				
Zfdi	0.648***	1			
Zstruct	-0.171**	-0.346***	1		
Zgi	-0.108	-0.300***	-0.063	1	
Ztraf	0.343***	0.505***	0.280***	-0.288***	1

of the first power was -0.422, and the coefficient of the second power was -0.357, which indicated that both the first power and the second power of industrial agglomeration of heavily polluting industries had a significant negative correlation with EP, indicating that industrial agglomeration of heavily polluting industries had an inverted U-shaped relationship with EP. The coefficients of economics, education, technology, traffic, and foreign direct investment in 30 provinces were all positive. They passed the significance test, indicating that the above indicators had a significant positive effect on EP. The reasons may be that the improvement of household consumption and education level makes residents have higher requirements for environmental quality, and the advancement of technology can improve the level of green production technology, energy efficiency, and pollutant treatment technology to promote the improvement of EP. The coefficient of FDI was 0.680 and passed the significance test. The positive correlation between FDI and EP indicated that China did not become the pollution haven of foreign countries but effectively utilized the advanced technology of foreign-owned enterprises, which promoted economic development and environmental protection in China. The coefficient of government intervention was -0.163, which had a significant negative correlation with EP. This may be due to the immediate increase in environmental costs caused by the government's environmental regulations, such as ecological fines, which caused the decline of corporate cash flow. As a result, the investment decreased in the green innovation of enterprises. Hence, government intervention harms EP, or the lag of the positive impact of environmental investment inhibited the improvement of EP. As mentioned in the study of Jin, only 11% of China's listed companies could make profitable environmental investments between 2012 and 2016 [27].

Multiple Regression Results and Discussion

Multiple regression analysis was conducted on the data after Z-score standardization, and the results are shown in Table 8. In both the fixed-effect model and random effect model, the quadratic power index of industrial agglomeration is a significantly positive correlation, indicating the U-shaped relationship between industrial agglomeration of heavily polluting industries and EP, and passing the significance test at the degree of 5% and 10%, indicating that the hypothesis in this paper is valid. After the Hausman test, the p of 0.0043 is less than 0.01, so the fixed-effect model should be selected.

In previous studies, most of them focused on the relationship between manufacturing, industrial agglomeration and environmental pollution. Or from the Angle of the relationship between high-tech industrial agglomeration and green innovation efficiency. Most of the results are linear; that is, the industrial agglomeration has a positive or negative impact on the environment, and there are few non-linear

Table 8. Results of Multiple Linear Regression.

Variables	Fixed effect model	Random effects model
	Zep	Zep
Zagglo	-1.538**	-0.963*
	(-0.638)	(-0.505)
Zagglo2	1.450**	0.739*
	(-0.623)	(-0.434)
Zec	0.16	0.267
	(-0.146)	(-0.202)
Zpop	0.322	-0.24
	(-1.983)	(-0.171)
Zedu	-0.392	-0.265
	(-0.324)	(-0.26)
Ztech	-0.109	0.593***
	(-0.205)	(-0.0974)
Zfdi	-0.000533	0.032
	(-0.0681)	(-0.0719)
Zstruct	0.262	0.365**
	(-0.173)	(-0.151)
Zgi	-0.0125	-0.00832
	(-0.0337)	(-0.0757)
Ztraf	-0.0125	-0.036
	(-0.075)	(-0.0696)
Constant	0	0
	(-4.14E-10)	(-0.0975)
Observations	150	150
Number of regions	30	30
R-squared	0.237	

Note: Robust t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

results. This paper concludes a U-shaped relationship between industrial agglomeration and environmental performance in heavy pollution industries, which enriches the research perspective and research results in this field.

When industrial agglomeration of heavily polluting industries is on the left side of the U-shaped relationship to environmental performance in the early stage, it may be due to the following reasons

(1) In the past, China's extensive economic development model led to a sharp increase in energy consumption and pollutant emission of heavily polluting industries in the agglomeration area and a decline in environmental quality.

(2) Due to the lack of scientific and reasonable planning and unreasonable industrial layout, the industrial agglomeration areas of heavy pollution industries will lead to excessive expansion of production scale, which may lead to a significant increase in energy consumption and pollutant emission heavy pollution industries.

(3) As the environment is a typical public good, and its quality is difficult to quantify, in the past, enterprises in some heavily polluting industrial agglomeration areas ignored environmental pollution to make profits, resulting in external uneconomy. And the environmental pollution in the heavy pollution industrial agglomeration area is aggravated.

In the later period, industrial agglomeration of heavily polluting industries is on the right side of the U-shaped relationship to environmental performance, which may be due to the following reasons.

(1) With the promotion of the concept of environmental protection and the sharing of advanced green technologies in industrial clusters, the development concept of heavily polluting industries is also changing, and pollution emissions and energy consumption are gradually reduced in the industrial agglomeration.

(2) To achieve the efficiency and technological progress brought by the labour force, infrastructure and information sharing in industrial agglomeration, heavy pollution industrial agglomeration require a certain period of communication and cooperation. When the internal cooperation mode of heavy pollution industrial agglomeration becomes mature, industrial agglomeration can significantly positively impact EP. In addition, advanced equipment that can realize the large-scale centralized treatment of pollutants in industrial agglomeration areas also needs time to be used. Therefore, the positive impact of industrial agglomeration of heavy pollution industries on EP may be time-delayed, forming a U-shaped relationship.

Conclusions

Taking heavy polluting industries in 30 provinces in China from 2013 to 2017 as examples, this paper studied the impact of industrial agglomeration of heavily polluting industries on provincial EP and concluded that there was a U relationship between industrial agglomeration of heavily polluting industries and EP. According to the conclusion, this paper analyzed and proposed the following suggestions.

First, we put forward suggestions for the national government level.

According to the above analysis of the U-shaped relationship between industrial agglomeration and environmental performance, if industrial agglomeration of heavily polluting industries is to have a positive impact on environmental performance, it is suggested that the government should make policies in the following aspects:

(1) Promoting research institutions to carry out innovative research on environmental protection technologies. The government may set up special funds for environmental protection to increase investment in research and development of environmental protection for heavily polluting industries. Through green technology innovation, energy consumption and pollution emissions can be reduced, pollutant treatment efficiency can be improved, and the production and development mode of heavy pollution industry can be optimized and upgraded so that the positive effect of technology and knowledge spillover of industrial agglomeration can play a more significant role.

(2) Establish incentive and punishment policies for environmental performance in industrial agglomeration of heavily polluting industries. Preferential tax policies will be given to energy-efficient enterprises, meet pollutant discharge standards, or deal with pollutants professionally. For enterprises that discharge many pollutants and consume many resources, government policies should be combined with the market economy to eliminate backwards productive forces and save energy. In this way, advanced enterprises can drive out inferior enterprises, thus making industrial agglomeration of heavily polluting industries positively impact environmental performance.

(3) Strictly regulate the principle of environmental access and rationally arrange industrial clusters of heavily polluting industries. The government should strengthen the support for industrial agglomeration of heavy pollution industries and strengthen the horizontal and vertical relationship between industries. Heavy pollution industry, therefore, enterprises can make full use of the advantage of industrial agglomeration, a practical guide to enhancing the efficiency of the allocation of resources, by sharing intermediate input, by-product recycling or waste, reducing costs and waste of resources, sharing of advanced environmental protection equipment and infrastructure, realize the mass concentration of pollutants governance or pollution control of pollutants to the professional company, It can reduce the marginal cost of unit pollutant treatment and realize the regularization and specialization of pollution treatment.

(4) Strengthen the environmental audit of areas where heavy polluting industries gather. The government may audit the ecological management strategies of heavily polluting industries, the implementation of environmental protection actions and the effectiveness of environmental protection. The government should conduct an environmental audit comprehensively and accurately from energy utilization efficiency, green and clean technology, pollutant discharge, and professional treatment of pollutants to restrain the negative impact of heavy pollution industrial agglomeration on EP.

(5) Give full play to the regulating role of market economy, improve the market-oriented reform of enterprise environmental protection, eliminate backward enterprises in EP, and promote the positive externality of industrial agglomeration to environmental performance.

Secondly, suggestions from the public level:

(1) Giving full play to the role of social institutions. Social structure can help regulate industry environmental information disclosure standards and can be held with heavy pollution industry-related environmental seminars, to promote the exchanges of heavy pollution industry gathering area high-quality talent, strengthen the industrial concentration area of environmental protection knowledge education and propaganda, improve production efficiency and energy utilization efficiency, to reduce emissions, guiding the improvement of the EP of heavy pollution industry.

(2) Give play to the supervisory role of social media. Under the pressure of media and the public on environmental protection, enterprises in heavy pollution industries must adopt ecological protection strategy and actively develop green and clean production technology, which can promote the positive development of environmental protection industry in heavy pollution industrial agglomeration areas.

Finally, suggestions at the internal industry level:

Cultivate a high-quality personnel team. Enterprises may set up research groups of professionals related to environmental protection and management, set up specialized departments for green technology innovation and pollution control, optimize the organizational structure of enterprises, fulfil the people-oriented responsibility for environmental protection, and promote the improvement of ecological pollution in heavily polluting industrial clusters.

Acknowledgments

The work was supported by the Fundamental Research Funds for the Central Universities (2017MS199). The authors gratefully acknowledge the reviewers and editors for their fruitful comments.

Conflict of Interest

The authors declare no conflict of interest.

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