Environmental Science and Pollution Research (2023) 30:55485–55497
https://doi.org/10.1007/s11356-023-26186-z

RESEARCH ARTICLE

Analysis on spatial effect of environmental regulation on upgrading of industrial structure in China

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Received: 4 August 2022 / Accepted: 24 February 2023 / Published online: 9 March 2023

Abstract

Transformation and upgrading of industrial structure is the key link to achieve high-quality economic development in China. In recent years, China has begun to eliminate some industries with high energy consumption and high pollution through environmental regulation policies and promote transformation and upgrading the industrial structure. Under multiple pressures such as the shortage of industrial structure and the decline in the demographic dividend, environmental regulation as a binding force will have an significant impact on ecological protection and economic structure adjustment. With the promotion of the inter-regional integration strategy, the links between various regions are becoming closer and closer. Therefore, the environmental regulation policies implemented by the government will not only affect the region, but can also impact neighboring regions. So, how will environmental regulation affect the optimization of industrial structure in the local and surrounding areas and the mechanism and pathways of its impact are theoretical topics worthy of in-depth study, which have important practical significance for exploring the win–win sustainable development path of industrial structure optimization and ecological protection. This paper selects the data of 30 provinces and cities in China from 2009 to 2019, analyses their spatial distribution characteristics, and establishes a spatial Dubin model to explore the spatial effect of environmental regulation intensity on the upgrading of local and adjacent regional industrial structure. The research results show that: (1) China's environmental regulation policy is not developed independently, but has certain relevance in space, that is, regions with higher environmental regulation intensity are adjacent to each other, and regions with lower environmental regulation are adjacent to each other; (2) The intensity of environmental regulation does not directly promote or inhibit the transformation and upgrading of the local industrial structure, but has a positive spatial spillover effect on the upgrading of the industrial structure in the surrounding areas; (3) The impact of environmental regulation policies on the upgrading of industrial structure is mainly reflected through indirect effects.

Keywords Environmental regulation · Industrial structure upgrading · Spatial autocorrelation · Spatial Dubbin model · Spatial spillover decomposition

Introduction

Since the reform and opening up in 1978, driven by industrialization and urbanization processes, China has maintained a trend of rapid development for many years. In 2021, China's total GDP reached 114.37 trillion yuan, an increase of 209.11 percentage points 1978. However, with the rapid growth of China's economic aggregate, the dependence on high energy consumption and high pollution industries is also increasing day by day in order to continue to maintain the continuous expansion of industrial scale. Under such a development mode, some ecological and environmental problems continuously emerge, which not only have a great impact on the quality of life of the people, but also pose challenges to the green development of China's economy. According to the Environmental Performance Index (EPI) Report for the past decade, China's EPI score has always been in a relatively backward position. In the current situation, it is urgent to regulate environmental pollution.

Responsible Editor: Philippe Garrigues

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The Report of the 19th National Congress of the Communist Party of China clearly pointed out that "China's economy has changed from a stage of high-speed development to a stage of high-quality development, requiring the transformation of the mode of economic development and the optimization of the structure of economic development in the process of development." Industrial structure is an important factor affecting China's economic development. By adjusting the transformation and upgrading of industrial structure, we can promote the transformation of some high energy consumption and high pollution industries and increase the proportion of clean energy industries and high-tech industries, so as to control the source of pollution. Therefore, it is an important way to green development and improve economic efficiency. At present, China is in a critical period of economic structure transformation. Ecological protection and the upgrading and transformation of industrial structure will become a major issue affecting the high-quality development of China's economy. How to coordinate the relationship between ecological environment protection, industrial structure adjustment and economic development, and under the current situation that various regions in China are increasingly closely linked, clarifying its mechanism will provide important theoretical significance and practical guidance for the policy-making of China's environmental regulation and the realization of the goal of high-quality development.

Literature review

In the process of economic development, China has made great strides in industrialization, but at the same time, the contradiction between ecological environment and economic development is also growing (Peng and Bao 2006). At present, the problem of environmental pollution has become the research focus of all countries in the world. In response to this problem, many countries have put forward a series of environmental regulation policies in order to alleviate environmental problems while developing economy (Elgin and Mazhar 2012). At present, scholars have not completely agreed on the definition of environmental regulation. Some scholars believe that environmental regulation policy is a means for the government to adjust environmental problems. Environmental regulation can not only effectively alleviate environmental pollution, but also promote the development of green innovation in the economy (Frondel et al. 2007). Some scholars pointed out that environmental regulation policy is not only a government action, but also requires the active cooperation of enterprises and the public, so as to play the greatest role (Arfaoui 2018). Although the concept of environmental regulation has not been agreed, it is certain that environmental regulation has great practical significance for protecting the ecological environment and promoting high-quality economic development.

In terms of the connotation of industrial structure, Rostow (2001) puts forward the stage theory of economic growth, divided the process of economic growth into six development stages, and pointed out that in different development stages, the productivity level of each industry has certain differences, and the fast-growing industry can use its driving effect to promote the development of other industries. The upgrading of industrial structure is reflected in the reduction of production activities with labor as the main body and the transfer to production acquisition with high-tech technology as the main body (Yoo and Heshmati 2019). The optimization and upgrading of industrial structure can be explored from two aspects: output and employment. No matter which aspect, the proportion of the tertiary industry is increasing, and the proportion of the primary industry is decreasing (Guo et al. 2017). Some scholars also believe that the optimization and upgrading of the industrial structure is the unity of the rationalization and high degree of the industrial structure after the harmonious development (Salant 1976). The rationalization of industrial structure is reflected in the promotion of proper matching of resources among industries and the realization of stable, orderly, and scheduled development of regional economy on the basis of resource endowment and scientific and technological development level in order to obtain higher economic benefits. The upgrading of industrial structure describes the complex process of the transformation of the leading industry from the primary industry with low added value or rough processing to the tertiary industry with high-tech content through the secondary industry that fails to make efficient use of capacity (Zeng et al. 2020).

The current literature on the impact of environmental regulation policies on the optimization and upgrading of industrial structure is mainly discussed from the micro and macro aspects. The micro impact is mainly reflected in enterprises. Some scholars believe that environmental regulation will lead to higher prices of production factors and higher emission costs in enterprises (Jaffe and Palmer 1997), squeezing out the funds originally used to upgrade technology (Jorgenson and Wilcoxen 1990a), which is not conducive to the upgrading of industrial structure (Xu and Dong 2009). In Jorgenson and Wilcoxen's (1990b) empirical analysis, when environmental regulation is implemented, the gross national product decreases by 2.59%, which hinders industrial development. Liao and Xia (2015) observed the implementation intensity of the government's environmental regulation and the correlation effect of foreign direct investment by simulating the imperfect competitive market and found that the negative impact of foreign capital inflow on the environment was greater than the benefits of technology spillover to enterprises. Other scholars believe that environmental regulation policies encourage enterprises to carry out technological innovation and promote the transformation of large-scale industry (Yang and Li 2019; Michael and Linde 1995), which can promote local green development and promote the transformation and upgrading of industrial structure (Xepapadeas and Zeeuw 1998; Korhonen et al. 2015). Berman and Bui (2001) collected relevant data of oil refining enterprises subject to environmental regulations and other local unregulated enterprises of the same type. The production efficiency of unregulated enterprises in the same period was lower than that of regulated oil refining enterprises, indicating that the implementation of environmental regulation policies was beneficial. Lu Jing (2007) found that Chinese honey import and export companies would change the traditional enterprise development model, absorb the nutrition of scientific and technological innovation, and promote industrial transformation under the strict entry standards of the importing countries and the corresponding trade policies of China. From a macro perspective, it is mainly reflected in the effect of environmental regulation on the transfer of industries between regions. Shen et al. (2012) and others selected the Pearl River Delta region as the research object, believing that the intensity of environmental regulation will vary greatly due to different pollution industries. A considerable number of scholars believe that in recent years, due to the increase in the intensity of environmental regulation, some pollution-intensive industries have gradually shifted from eastern China to the central and western regions and from coastal areas to inland areas (Tian et al. 2018; Zhou et al. 2017; Wu et al. 2019; Yang et al. 2018).

From the relevant content of previous literature, although the policies related to environmental regulation and industrial structure upgrading have been implemented very early, there are still different opinions. The measurement of environmental regulation and industrial structure upgrading has not reached a completely unified indicator system. And some scholars, when analyzing the impact of environmental regulation on the upgrading of industrial structure, only limited to a certain region, did not consider a spillover effect of the policy, and could not elaborate the relationship between the two. Based on the above research deficiencies, this paper focuses on the emission standard when measuring the environmental regulation variables, selects three types of pollutants, and uses the comprehensive index method to calculate the intensity of environmental regulation. Select the proportion of the added value of the tertiary industry in the added value of the secondary industry to measure the level of industrial structure upgrading. When examining the nexus between environmental regulations and industrial structure, this paper not only scrutinizes the influence of environmental regulations on industrial structure, but also delves into the spillover effect of policies.

Introduction and setting of model theory

Analysis of spatial autocorrelation theory

Spatial autocorrelation analysis is to express or define the relationship between regions by establishing a spatial weight matrix with spatial correlation degree. Among them, the global spatial autocorrelation is to determine the spatial correlation significance of each indicator in the whole region, while the local autocorrelation is to determine the strength of the correlation degree of each sub-interval.

Setting of spatial weight matrix

The premise of spatial weight setting is the "first law of geography," that is, the closer the distance is, the more similar it is. The closer the distance is, the closer the connection is, and the higher the similarity in all aspects is. There are usually three kinds of spatial weight matrix settings, namely, adjacent spatial weight, geographical distance weight, and economic distance weight.

The condition of judging spatial correlation by the weight of adjacent space is that there are similar edges. Let the regional relationship between region i and region j be recorded as W_{ij}; if i and j have a common boundary, then $W_{ij} = 1$; otherwise, $W_{ij} = 0$.

The geographical distance weight takes into account the actual distance between the two regions and believes that the correlation decreases with the increase of distance. The weight of the two regions is equal to the reciprocal of the square of the spherical distance between the two regions. Assuming d is the spherical distance between regions, it can be expressed as follows:

$$w_{ij} = \begin{cases} 1/d^2, \neq j \\ 0, i = j \end{cases} \tag{1}$$

The economic distance weight takes into account the geographical distance, takes into account the economic factors, and mainly uses the per capita real GDP indicator, so its value is equal to the geographical distance weight matrix multiplied by an economic matrix E; E is a diagonal matrix, expressed as follows:

$$E_{ij} = \begin{cases} \frac{1}{|\overline{y}_i - \overline{y}_j|}, i \neq j \\ 0, i = j \end{cases} \tag{2}$$

where $\overline{y}_i$ and $\overline{y}_j$ represent the per capita real GDP of i and j provinces in N years respectively.

Moran index and Moran scatter

Moran index is used to measure whether there is correlation between regions, and its value range is [– 1, 1]. The calculation formula is as follows:

$$I = \frac{n\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i \sum_j w_{ij}(x_i - \bar{x})^2} = \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{\bar{x}})}{s^2 \sum_i \sum_j w_{ij}} \quad (3)$$

Moran scatter map can clearly depict the local Moran index of each region in the coordinate map, so as to obtain the size, significance, and agglomeration type of Moran value. As shown in Fig. 1, high-high concentration (HH) indicates that the observed value at position *i* and the observed value around it are high value areas; high-low concentration (HL) indicates that the observed value at position *i* is greater than that around it. Low-low concentration (LL) and low–high concentration (LH) are opposite to the above respectively.

Setting of spatial regression model

According to the existing literature, there are three spatial econometric models: spatial Dobbin model (SDM), spatial lag model (SLM), and spatial error model (SEM). The difference between these three models is mainly reflected in the different setting methods of their spatial interaction effects. The complete model with all types of spatial interaction effects is as follows:

$$\begin{aligned} Y &= \delta WY + X\beta + WX\theta + u \\ u &= \lambda Wu + \varepsilon, \varepsilon \sim N(0, \delta^2 I_n) \end{aligned} \quad (4)$$

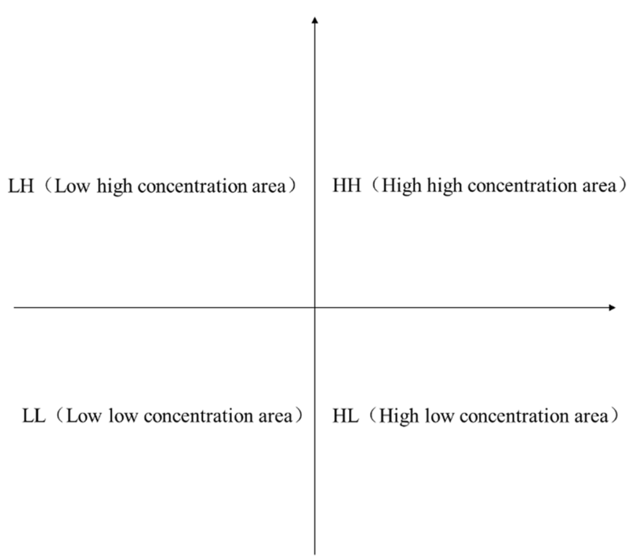

Fig. 1 Moran scatter map

When an explained variable is affected not only by the explained variable, but also by the explained variables in other regions of the space, the model needs to be set as a spatial lag SLM model, in the form of:

$$Y = \delta WY + X\beta + u, u \sim N(0, \delta^2 I_n) \quad (5)$$

When the disturbance term has spatial effect, that is, the disturbance term in one space will affect the explained variables in other spaces, the model needs to be set as the spatial error SEM model, in the form of:

$$\begin{aligned} Y &= X\beta + u \\ u &= \lambda Wu + \varepsilon, \varepsilon \sim N(0, \delta^2 I_n) \end{aligned} \quad (6)$$

When the explained variables in a region are affected by the explained variables in this region and other regions, and also by the explained variables in other regions, that is, there is a double interaction effect, the model needs to be set as a spatial Dobbin SDM model, in the form of:

$$Y = \delta WY + X\beta + WX\theta + u, u \sim N(0, \delta^2 I_n) \quad (7)$$

Decomposition method of spatial spillover effect

Spillover effect refers to a variable, that is, the explained variable that acts on this region also affects the explained variables in other regions in the space. SDM model can split and test the direct and indirect influence effects of variables through partial differential decomposition. The main difference between spillover effect and indirect effect is that spillover effect is the impact of local environmental regulation policies on the upgrading of industrial structure in surrounding areas. Intermediary effect means that local environmental regulation policies affect the upgrading level of local industrial structure through some other factors.

According to the partial differential method of spatial regression model, the formula is sorted out:

$$y = \sum_{r=1}^{k} S_r(W)x_r + V(W)I_n\alpha + V(W)\varepsilon \quad (8)$$

Among them,

$$V(W) = (I_n - \rho W)^{-1} = I_n + \rho W + \rho^2 W^2 + \rho^3 W^3 + \ldots$$

$$S_r(W) = V(W)(I_n \beta_r + W\theta_r)$$

$$y_i = \sum_{r=1}^{k} [S_r(W)_{i1}x_{1r} + S_r(W)_{i2}x_{2r} + \ldots \_S_r(W)_{in}x_{nr}] + V(W)I_n\alpha + V(W)_i\varepsilon$$

Find the partial derivative and get the formula:

$$\frac{\partial y_i}{\partial x_{jr}} = S_r(W)_{ij} \tag{9}$$

This is the indirect effect.

$$\frac{\partial y_i}{\partial y_{ir}} = S_r(W)_{ii} \tag{10}$$

This is the direct effect. The two together constitute the total effect.

Measurement and analysis of key variables

Key variable measure

Environmental regulation refers to the determination of technical standards and pollutant emission standards by the government through formulating laws, regulations and relevant policies on environmental pollution control. It mainly relies on the compulsory intervention of the government departments and the regulatory role of the market to restrict the production activities of the economic entities and guide the economic entities to develop towards the goal of low emissions and low consumption in the process of production. Scholars generally divide environmental regulation into three types: command and control type, market incentive type, and public voluntary type. In this paper, the order-control environmental regulation is selected to measure the intensity of environmental regulation.

Command and control environmental regulation are generally enforced by enterprises through the issuance of relevant policies and decrees by the government and the formulation of corresponding technical standards and emission standards. Therefore, the intensity of regulation is generally measured by the emission of various pollutants. This section uses the comprehensive index method to measure the intensity of environmental regulation. Three indicators, namely, industrial smoke emission, industrial sulfur dioxide emission, and industrial wastewater emission, are selected for comprehensive calculation.

First, these three indicators need to be standardized to eliminate the influence of dimension. The standardized formula is as follows:

$$R_{ij}^s = \frac{R_{ij} - \min R_j}{\max R_j - \min R_j} \tag{11}$$

where R_{ij} represents the emission of class j pollutants in the i-th region; min R_j represents the minimum value of the emission of the j-th pollutant; maxR_j represents the maximum emission of the j-th pollutant; and R_{ij}^s represents the standardization result of the emission of class j pollutants in the i-th region.

Secondly, determine the weight of various pollutants:

$$W_j = R/\overline{R}_{ij} \tag{12}$$

$\overline{R}_{ij}$ represents the average level of class j pollutant emissions in 30 provinces in each year.

Finally, determine the comprehensive index of environmental regulation:

$$ER = \frac{1}{3}\sum_{j=1}^{3} W_j \times R_{ij}^s \tag{13}$$

Based on the availability of data and referring to the literature of scholars, the upgrading level of industrial structure is expressed by the proportion of the added value of the tertiary industry in the added value of the secondary industry (Wang et al. 2022).

Space character analysis

Global autocorrelation analysis

Based on the previous analysis, this section selects the adjacent space weight matrix to conduct spatial autocorrelation analysis. Table 1 shows the Moran index of environmental regulation intensity variables in 30 provinces in China from 2009 to 2019. Except for a few years, most years are significant. In other words, China's environmental regulation policy is not developed independently, but has a certain relevance in space, that is, regions with high environmental regulation intensity are adjacent to each other, and regions with low environmental regulation are adjacent to each other.

Table 1 Spatial Moran index of environmental regulation intensity in China from 2009 to 2019

Variables	I	$E(I)$	$sd(I)$	z	p Value*
2009	0.104	– 0.034	0.109	1.263	0.103
2010	0.122	– 0.034	0.109	1.430	0.076
2011	0.078	– 0.034	0.098	1.151	0.125
2012	0.212	– 0.034	0.110	2.240	0.013
2013	0.082	– 0.034	0.099	1.181	0.119
2014	0.129	– 0.034	0.107	1.528	0.063
2015	0.113	– 0.034	0.100	1.478	0.070
2016	0.127	– 0.034	0.101	1.596	0.055
2017	0.136	– 0.034	0.101	1.690	0.045
2018	0.131	– 0.034	0.101	1.631	0.051
2019	0.133	– 0.034	0.101	1.652	0.049

Table 2 shows the Moran index of environmental regulation intensity variables of 30 provinces in China from 2009 to 2019. All years are significant at the 5% significance level, and the spatial Moran index from 2009 to 2019 shows an upward trend year by year, indicating that this correlation is strengthening year by year with the passage of time. That is, with the closer relationship between regions, the upgrading level of industrial structure in various regions is also gradually enhanced.

Local autocorrelation analysis

The global Moran index reflects the spatial correlation between variables in the whole region of the country, but it cannot reflect the spatial aggregation characteristics of specific provinces. In order to further analyze the spatial characteristics of each province, this paper uses Stata software to the local Moran index in the region to be calculated, and the Moran scatter diagram is drawn to analyze the spatial aggregation characteristics of the region. Due to space limitations, only the Moran scatter diagram of 2019 is given here.

As shown in Figs. 2 and 3, the Moran scatter diagram of environmental regulation intensity is mainly shown as "HH type" and "LL type." The main provinces and cities located in HH type are Beijing, Xinjiang, Zhejiang, Hainan, and other provinces and cities, and the main provinces and cities located in LL type are Heilongjiang, Qinghai, Hebei, Sichuan, and other provinces and cities. The Moran scatter chart of the upgrading level of industrial structure is mainly "LL type." Representative provinces and cities include Qinghai, Ningxia, Gansu, Xinjiang, and other provinces and cities, mostly in the western region.

Table 2 Spatial Moran index of China's industrial structure upgrading level from 2009 to 2019

Variables	*I*	*E*(*I*)	*sd*(*I*)	*z*	*p* Value*
2009	0.144	– 0.034	0.106	1.677	0.047
2010	0.154	– 0.034	0.107	1.768	0.039
2011	0.153	– 0.034	0.107	1.759	0.039
2012	0.156	– 0.034	0.107	1.775	0.038
2013	0.158	– 0.034	0.107	1.795	0.036
2014	0.161	– 0.034	0.107	1.823	0.034
2015	0.168	– 0.034	0.107	1.892	0.029
2016	0.173	– 0.034	0.107	1.938	0.026
2017	0.167	– 0.034	0.107	1.888	0.030
2018	0.175	– 0.034	0.107	1.952	0.025
2019	0.178	– 0.034	0.107	1.985	0.024

Empirical analysis

Variable selection and data description

Explained variable

This section explores the impact of environmental regulation on the upgrading of industrial structure. The upgrading level of industrial structure (*IS*) is the explanatory variable, which is expressed by proportion of added value of the tertiary industry in added value of the secondary industry.

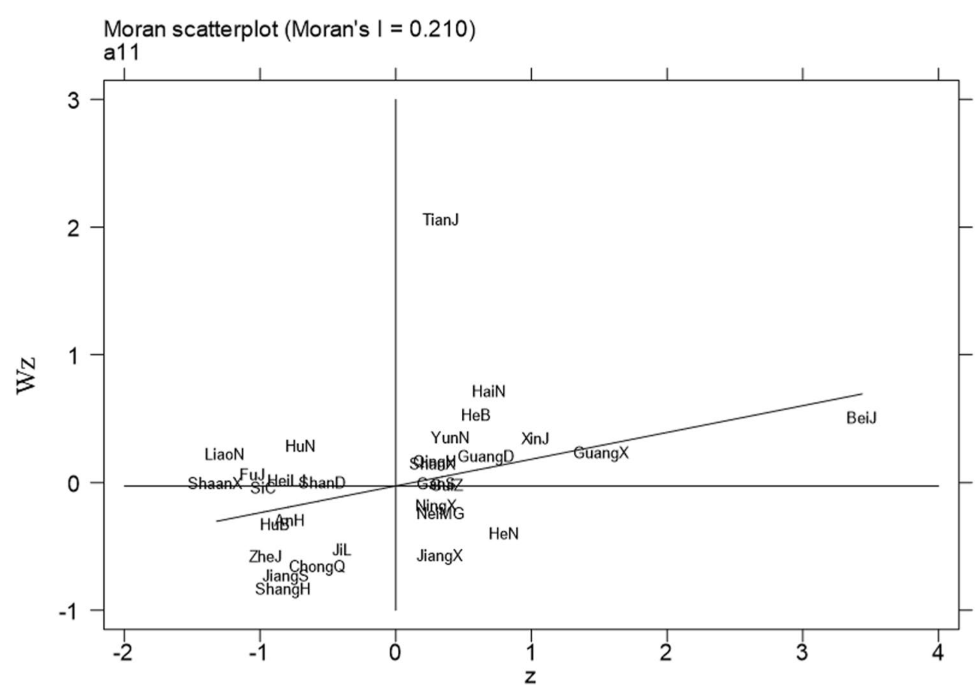

Fig. 2 Moran scatter chart of environmental regulation intensity in 2019

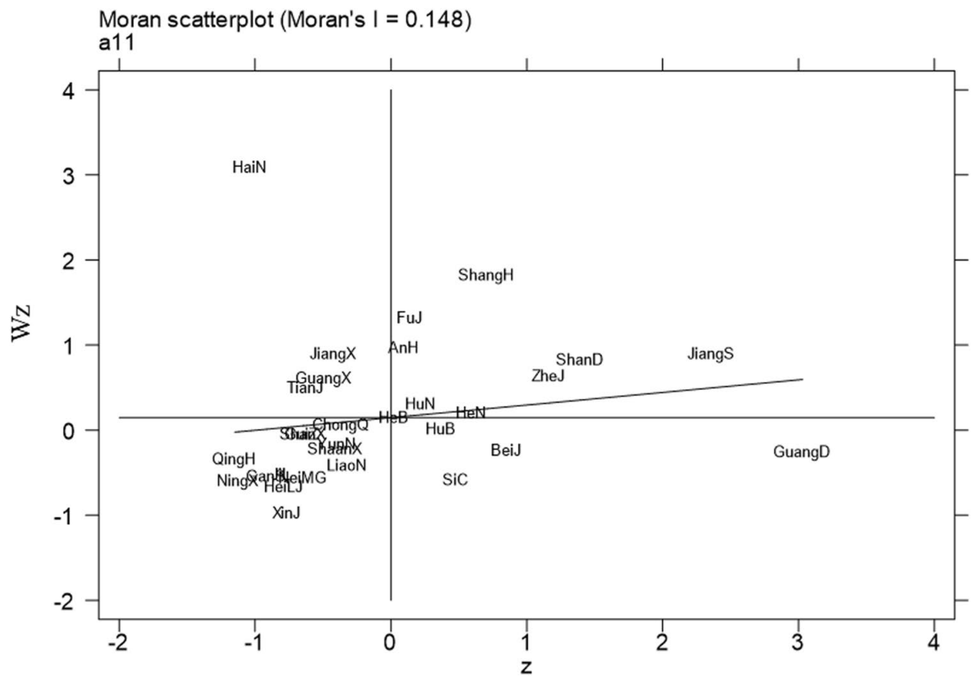

Fig. 3 Moran scatter chart of industrial structure upgrading level in 2019

Explanatory variable

The indicator of environmental regulation intensity (ER) is expressed by comprehensive index of industrial smoke emission, industrial sulfur dioxide emission, and industrial wastewater emission.

Control variable

In addition to the impact of environmental regulation on the efficiency of green innovation, there are other variables. The following variables are selected as the control variables of the model.

Government support (GS**)** If a region wants to upgrade its industrial structure, it must rely on the support of the government. The more funds the government invests, the more funds it spends on new product development and innovation, which will promote the technological transformation and upgrading of some industries. This paper chooses proportion of fiscal expenditure in GDP of each region to express the degree of government support.

GDP per capita ($PGDP$**)** The upgrading of industrial structure is the key factor to promote high-quality economic development. Regional economic development can also promote the upgrading of industrial structure to a certain extent. This paper selects GDP per capita variable to measure the level of regional economic development.

Capital labor ratio ($Ln(K/L)$**)** Enough capital and manpower must be invested in the upgrading of industrial structure. This index reflects the most basic resource allocation in production, and the more advanced technology is. Generally, the higher the capital labor rate, thus promoting the transformation and upgrading of industrial structure.

Degree of openness (OP**)** On the one hand, opening to the outside world can promote the exchange of advanced technology between enterprises and foreign countries, improve the production efficiency of enterprises, and absorb foreign advanced enterprise management ideas; on the other hand, it can also attract foreign capital through opening up. In the big competition in the domestic market, it "forces" the competition of local companies and improves the production efficiency of the industry. This paper selects ratio of total import and export trade to GDP to measure the degree of opening-up of a region.

Urbanization level (UR**)** The level of urbanization reflects the process of rural population migration and agglomeration to cities and towns, which leads to the migration of labor and other production factors between cities and villages. In recent years, with the advancement of urbanization, the corresponding industrial structure is also gradually changing. This paper selects the urbanization rate of each region as an indicator to express the level of maturity. The selected variables are shown in Table 3.

Table 3 Description of main variables

Character of variables	Variable name	Symbol	Select indicators
Explained variable	Upgrading level of industrial structure	*IS*	Proportion of added value of the tertiary industry in added value of the secondary industry
Explanatory variables	Intensity of environmental regulation	*ER*	Comprehensive index of environmental regulation
Control variable	Government support	*GS*	Proportion of fiscal expenditure in GDP of each region
	Per capita GDP	*PGDP*	GDP per capita
	Capital labor ratio	$Ln(K/L)$	Logarithm of total capital divided by total labor
	Degree of openness	*OP*	Ratio of total import and export trade to GDP
	Urbanization level	*UR*	Urbanization rate

This paper selects the relevant data of 30 provinces and cities in China (incomplete data in Tibet) and uses the China Statistical Yearbook, China Environmental Statistical Yearbook, China Industrial Economic Statistical Yearbook, and the official website of national and provincial statistical bureaus to supplement the missing data with the average growth rate method. At the same time, this paper also deals with the logarithm of the non-proportional variables used to prevent heteroscedasticity in the regression process.

Regression of spatial regression model

Model selection

In the selection of measurement model, this paper takes three steps. The first step is to test the constraints and screen out SLM, SEM, and SDM respectively; The second step is to comprehensively consider the size of log likelihood and R^2 based on Hausman test, test the coefficient significance of the two models, and then choose to establish fixed effect or random effect models. The third step is to determine whether SDM model needs partial differential decomposition according to the significance of Rho value.

First, use Stata software to perform Wald and LR tests on spatial lag and spatial error. The results are shown in Table 4. From the above two aspects, it can be seen that the constraints of SLM and SEM models are insufficient, so it is more accurate to use SDM model for regression.

Secondly, Hausman test preliminarily judged the fixed effect model and the random effect model. The test results showed that the Chi^2 value was far greater than the critical value, with a *p* value of 0.001, which passed the significance test of 1%, and it was considered that the fixed effect model was more suitable for this regression analysis (see Table 5).

Analysis of spatial measurement results

As shown in Table 6, environmental regulation has a completely different impact on the transformation and upgrading of industrial structure in this region and adjacent regions. The intensity of environmental regulation has no significant impact on the upgrading of local industrial structure, but has a significant positive effect on the upgrading level of industrial structure in adjacent regions, indicating that the spillover effect between regions is the main driving force of national environmental regulation on the high-end industrial structure. This shows that the government's environmental regulation can adjust the internal structure of the industry and realize the coordinated development between industries. Therefore, it is believed that the environmental regulation policies implemented by the Chinese government have a positive spillover effect on the improvement of the industrial structure of surrounding regions.

Although the impact of China's environmental regulation policy on the upgrading of local industrial structure is not significant, the empirical results show that the environmental regulation policy has a positive spatial spillover effect on

Table 4 Wald and LR test results of SAR and SEM models

Test	Adjacency space weight		Geographical distance weight		Economic distance weight	
	Fixed	Random	Fixed	Random	Fixed	Random
Wald test spatial lag	111.66***	113.56***	131.70***	131.33***	153.16***	171.70***
LR test spatial lag	110.33***	108.65***	134.02***	133.11***	182.4***	180.41***
Wald test spatial error	123.45***	105.71***	126.65***	133.15***	155.51***	176.25***
LR test spatial error	153.53***	148.33***	133.61***	134.12***	176.85***	175.32***

***, **, and * respectively represent the significance level of 1%, 5%, and 10%

Table 5 Hausman test results

Test	Adjacency distance	Geographical distance	Economic distance
Chi-square test value	– 12.404	– 18.32	– 32.631
p Value	0.001	0.001	0.001

the upgrading of industrial structure in surrounding regions. This also means that the upgrading of industrial structure in this region can get a “free ride” effect from the environmental policy effects in other regions. There may be the following reasons: (1) environmental policy competition between local governments. After the implementation of decentralization in 1994, local governments gradually gained financial autonomy, thus forming an economic development model with “GDP growth” as the main goal. Due to the differences in geographical location, the competitive behavior of local governments can be divided into “race-to-the-bottom” and “race-to-the-top.” This paper believes that environmental regulation policy can promote the innovation of production technology and the flow of industrial factors in adjacent regions, so as to achieve the optimization of resources between regions. Thus, local governments are encouraged to follow the environmental regulation strategy, and then form the environmental regulation effect of “race-to-the-top” in the competition between local governments, so as to “force” the industrial development of all regions in the region. (2) Because many pollutants diffuse in space, environmental regulation can reduce regional pollution, and adjacent regions will also benefit from environmental regulation, thereby promoting industrial development.

In terms of control variables, government support, economic development level, capital labor ratio, opening up, and urbanization level all play a positive role in promoting the optimization and upgrading of industrial structure. However, in the analysis of adjacent regions, the level of economic development and urbanization are not significant under a weight matrix respectively. Moreover, the coefficient

Table 6 Estimation results of fixed and random effects of SDM model under three spatial weights

Variable	Adjacency space weight		Geographical distance weight		Economic distance weight	
	Fixed effect	Random effect	Fixed effect	Random effect	Fixed effect	Random effect
ER	0.043 (0.027)	0.040 (0.026)	0.037 (0.023)	0.035 (0.023)	0.019 (0.020)	0.017 (0.020)
GS	0.112* (0.048)	0.109* (0.047)	0.154** (0.58)	0.150** (0.057)	0.126* (0.051)	0.125* (0.051)
LnPGDP	0.401** (0.152)	0.359* (0.150)	0.300* (0.120)	0.256* (0.118)	0.230* (0.101)	0.169* (0.088)
$Ln(K/L)$	0.400** (0.140)	0.404** (0.148)	0.335** (0.102)	0.340** (0.109)	0.282*** (0.076)	0.284*** (0.080)
OP	0.373* (0.152)	0.374* (0.157)	0.319* (0.125)	0.322* (0.130)	0.217* (0.093)	0.215* (0.094)
UR	0.217*** (0.057)	0.219*** (0.057)	0.241*** (0.057)	0.243*** (0.057)	0.202*** (0.036)	0.190*** (0.036)
$W * ER$	0.425** (0.155)	0.400** (0.154)	0.539** (0.188)	0.512** (0.192)	0.112 (0.133)	0.037 (0.154)
$W * GS$	0.129** (0.048)	0.127** (0.047)	0.184** (0.059)	0.181** (0.058)	0.128** (0.048)	0.127** (0.047)
$W * LnPGDP$	0.048 (0.036)	0.052 (0.035)	0.077 (0.058)	0.078 (0.059)	0.078*** (0.019)	0.080*** (0.019)
$W * Ln(K/L)$	0.283* (0.153)	0.294* (0.157)	0.821** (0.296)	0.826** (0.306)	0.056 (0.103)	0.057 (0.102)
$W * OP$	0.395* (0.157)	0.397* (0.161)	0.667** (0.213)	0.666** (0.219)	0.257** (0.095)	0.258** (0.097)
$W * UR$	– 0.150* (0.063)	– 0.146* (0.061)	– 0.248 (0.157)	– 0.239 (0.159)	– 0.320* (0.139)	– 0.345* (0.146)
Rho	0.136	0.141	– 0.288	– 0.294	– 0.050	– 0.075
_cons	-	3.840 (0.959)	-	7.100 (2.212)	-	6.407 (1.180)
Likelihood	581.0930	493.2650	576.7371	490.0074	577.5429	492.6201
R^2	0.6565	0.6557	0.6535	0.6524	0.6526	0.6521

of urbanization level in adjacent regions is significantly negative, indicating that urbanization level has a significant negative spillover effect on the upgrading of industrial structure in surrounding regions, which may be because the enhancement of local urbanization level will promote some industries to transfer locally, which is not conducive to the upgrading of industrial structure in adjacent regions.

Rho value indicates that the spatial spillover effect is significant. See Table 7 for the spatial decomposition results of fixed effects under the three weight matrices.

In the analysis of the impact of the intensity of environmental regulation on the upgrading and transformation of industrial structure, the direction of direct effect and spillover effect are not exactly the same, while the overall effect depends on the joint influence of direct effect and indirect effect. The coefficients of indirect effect and total effect show a significant positive correlation, while the results of direct effect are not significant. This shows that environmental regulation is mostly promoted through indirect influence in the process of upgrading the regional industrial structure. This is mainly because the original purpose of environmental regulation is to achieve sustainable economic and social development, so the government will strictly control the emission standards of various pollutants and limit the emission of various pollutants. In this case, enterprises must strictly comply with the emission standards, or they will be severely punished. Therefore, either some enterprises will reduce pollution by improving technology or using some high-tech machines, or some heavily polluting enterprises will directly transform and upgrade, and consider moving the production focus to some less polluting industries, which has promoted the rationalization process of industrial structure. Therefore, environmental regulation plays a more indirect role in the process of affecting the upgrading and transformation of industrial structure. The effects of other control variables on the upgrading of industrial structure are both direct and indirect, as shown in Table 7.

Discussion

Give play to synergy of regional policies

Today, with the increasingly close spatial correlation, environmental regulation has a significant spillover effect on the improvement of regional industrial structure. In recent years, the exchanges between regions are increasing day by day, and the continuous strengthening of environmental regulation will also lead to the transformation of local governments from "race-to-the-bottom" to "race-to-the-top." Therefore, China must pay attention to the spatial spillover effect of environmental regulation on the upgrading of industrial structure.

(1) We should establish and improve regional cooperation mechanisms and strengthen the control and management of environmental pollution. By establishing the competition and compensation mechanism of environmental regulation, we can promote the benign competition of environmental protection policies between

Table 7 SDM model spatial effect decomposition results

Effect	Variable	Adjacency space weight	Geographical distance weight	Economic distance weight
Direct effect	*ER*	– 0.027 (0.019)	0.039 (0.030)	0.020 (0.019)
	GS	0.395*** (0.053)	0.355*** (0.056)	0.286*** (0.056)
	LnPGDP	0.364*** (0.040)	0.335*** (0.042)	0.223*** (0.044)
	Ln(K/L)	0.024* (0.036)	0.012* (0.038)	0.010* (0.038)
	OP	0.001 (0.009)	0.004 (0.009)	0.005 (0.010)
	UR	– 0.012 (0.008)	– 0.004 (0.009)	0.014* (0.008)
Indirect effect	*ER*	0.059*** (0.015)	0.050 (0.064)	0.073* (0.029)
	GS	0.264* (0.115)	0.742*** (0.148)	0.072 (0.088)
	LnPGDP	0.394*** (0.078)	0.614*** (0.093)	0.265*** (0.063)
	Ln(K/L)	0.133* (0.053)	– 0.015 (0.093)	0.160** (0.052)
	OP	0.005 (0.013)	– 0.010 (0.022)	0.025* (0.014)
	UR	– 0.006 (0.011)	– 0.029* (0.012)	– 0.036*** (0.010)
Overall effect	*ER*	0.086* (0.050)	0.089 (0.063)	0.093** (0.033)
	GS	– 0.131 (0.113)	0.387** (0.149)	– 0.214* (0.092)
	LnPGDP	0.031 (0.074)	0.279** (0.090)	0.042 (0.058)
	Ln(K/L)	0.157** (0.048)	– 0.003 (0.091)	0.170*** (0.041)
	OP	0.006 (0.017)	– 0.006 (0.023)	0.030* (0.016)
	UR	– 0.018* (0.009)	– 0.034*** (0.009)	– 0.022** (0.007)

local governments, so as to realize the environmental regulation between different regions. Reach an agreement on environmental protection to avoid the occurrence of "free riding" and maximize the accumulation of environmental regulations in the industrial structure.

(2) According to the specific conditions of different regions, fully investigate the advantages of different regions, and formulate the industrial layout that meets the requirements of local development. Promote the rational flow of production factors in various regions, promote the rational division of labor between regions, and promote the industrial development of various regions. In terms of industrial transfer, we should pay attention to technological innovation and technological innovation, and use technological spillover to promote industrial transformation and upgrading.

(3) Comprehensively and objectively evaluate the resources and ecological carrying capacity of each region, so as to coordinate the industry, economy, and ecological environment of the undertaking area. Reasonably formulate investment policies to promote the optimization of industrial structure. At the same time, we should strengthen the ecological compensation mechanism. For some serious regions, financial and other policy support can be adopted to reduce the environmental pollution caused by their responsibility. Losses caused by spillover effects.

Formulate differentiated regional environmental regulation policies

From the national level, environmental regulation has a positive effect on China's economic and social development, so it can "force" the local government to improve and change the intensity of environmental regulation. However, due to the structural differences in the development of the Eastern and Western, when implementing environmental protection management, we should not "cut across the board." We should formulate environmental control policies suitable for different regions according to the specific situation and regional development characteristics and adopt differentiated methods to deal with various problems.

(1) Continuously improve the environmental protection system. The central government should formulate and improve relevant laws and regulations from a macro perspective. By regulating the environment of local governments, they can be included in the assessment of local political achievements and cooperate with local governments at the same level to form a coordination mechanism of environmental regulation so that the environmental regulation of adjacent regions can be coordinated and unified so that it can better play its role.

(2) The government should take the innovation and optimization of environmental regulation means as the focus of its work. After implementing environmental regulation policies for many years, the role of environmental policy tools of administrative and command regulation is increasingly limited, but many studies have shown that market-oriented environmental regulation tools have been widely used in many occasions in recent years. Therefore, we can learn from the positive role of the "invisible hand" in environmental protection and industrial upgrading in policy-making, such as collection of emission taxes and tradable emission permits.

(3) Strengthen the monitoring of the public and public opinion on the environment. Today, with the informatization of the whole society, the supervision of the society and the public can effectively urge the government and enterprises to pay attention to the environmental protection needs of the society and avoid development measures that are not conducive to environmental protection. Therefore, public opinion such as the public and the media is also an effective means of supervision, and the use of public opinion can also help the environmental protection work to be effectively implemented.

Improve distribution efficiency of regional production factors

To promote the upgrading of industrial structure, we should be good at using innovative thinking and accelerating the optimization of resource allocation. In terms of China's industrial development, for a long time, the allocation of industrial production factors in China mostly depends on the management of the government, rather than relying on market forces for production, which makes the allocation of factor resources between industries inefficient. We must promote the optimization of technology, system, environment, and other aspects from the perspective of improving the efficiency of resource allocation, so as to promote the upgrading of industrial structure.

(1) Ensuring the decisive role of the market in resource allocation is a prerequisite for adjusting the structure and realizing industrial upgrading. Market allocation of resources is a universal rule. Only on the basis of market entry and exit mechanism can we effectively improve the production enthusiasm of all subjects in the market and take the initiative to break through the free circulation of various factors in the market, which is conducive to improving the use efficiency of production factors. At the same time, some measures that can stimulate the market, such as simplifying administrative power, can promote the upgrading of industrial structure.

(2) To achieve the purpose of improving the efficiency of resource allocation, we must innovate in the existing system and break through the existing factor circulation barriers; at the same time, preferential measures such as taxes and subsidies should be taken to speed up the circulation of production factors among departments.

Author contribution The first draft of the manuscript was written by Guoan Zeng. Material preparation, data analysis, and revision were performed by Tingyi Liu. Both authors have read and agreed to the published version of the manuscript. Both authors read and approved the final manuscript.

Funding This work was supported by the Key Program of the National Philosophy and Social Science Foundation of China (Grant No. 21ATJ003).

Data availability Although the data used in this paper are from various publicly available yearbooks in China, some yearbooks are not freely available. The data for each variable can be obtained from the corresponding yearbook provided in the paper. And the datasets used in this paper are available from the corresponding authors on reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Both authors agreed with the submitted content and gave explicit consent to publish the manuscript if it is accepted.

Competing interests The authors declare no competing interests.

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