Spatial Spillover Effect of Heterogeneous Environmental Regulation On Ecological Welfare Performance in China

guo bing nan (1107033980@qq.com)
Jiangsu University of Science and Technology
tang li
Jiangsu University of Science and Technology
jia ru
University of Leeds
lin ji
Zhejiang University of Finance and Economics

Research Article

Keywords: heterogeneous environmental regulation, ecological welfare performance, spatial spillover

Posted Date: September 21st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-698369/v1

Spatial spillover effect of heterogeneous environmental regulation on ecological welfare performance in China

GUO Bing-nan[1], TANG Li[1], JIA Ru[2],LIN Ji[3]

1.School of Humanity & Social Science, Jiangsu University of Science and Technology, Zhenjiang Jiangsu 212003, China；

2.School of Sociology and Social Policy, University of Leeds, Leeds LS2 9JT, United Kingdom

3. School of Finance, Zhejiang University of Finance and Economics, Hangzhou 310018, China

Corresponding author：200600002509@just.edu.cn (B. Guo)

E-mail addresses: 200600002509@just.edu.cn (B. Guo); 192090001@stu.just.edu.cn (L. Tang);evelynkimjia@163.com(R. Jia)； linji1221@zufe.edu.cn:（J.Lin）

Abstract: This paper constructs a theoretical model to deduce the mechanism of environmental regulation on ecological welfare performance, selects the panel data of 30 provinces in China from 2005~2019, uses the Super-SBM model to measure the ecological welfare performance of China, and the influence of heterogeneous environmental regulation on ecological welfare performance in China is empirically tested by spatial Durbin model. The results show :(1) there are regional differences in the ecological welfare performance of different provinces in China, which illustrates an unbalanced spatial distribution ;(2) there is significant positive spatial correlation between market incentive, command -control and voluntary participation environmental regulation and ecological welfare performance ;(3) The impact of different types of environmental regulations on the performance of ecological welfare in China is heterogeneous. Command-control and market incentive environmental regulations can improve the performance of ecological welfare, while voluntary participation environmental regulations have no significant impact on the performance of

ecological welfare ;(4) From the perspective of spatial spillover effect, command-control environmental regulation is not conducive to the ecological welfare performance of neighboring regions, while market incentive environmental regulation is conducive to the improvement of ecological welfare performance of adjacent areas. The spatial spillover effect of voluntary participation environmental regulation on ecological welfare performance in adjacent areas is not significant.

Keywords: heterogeneous environmental regulation; ecological welfare performance; spatial spillover

1. Introduction

Since the reform and opening, the economy of China has grown rapidly. At the same time, the extensive economic development mode of "high energy consumption, high pollution and high emission" have led to increasingly prominent problems such as excessive utilization of resources, serious environmental pollution and the mismatch between economic growth and social welfare growth. Therefore, how to promote the coordinated development of economy, environment and social welfare and improve the performance level of ecological welfare has become an urgent need of high-quality economic development. The environment belongs to public goods, and environmental regulation is the main means to reduce environmental pollution and protect the environment. Based on the heterogeneity of the environmental regulation tools, this paper theoretically explains the effect mechanism of different environmental regulation tools on the ecological welfare performance, and empirically analyzes the impact and spatial spillover effect of heterogeneous environmental regulation on ecological welfare performance in China.

2. Literature Review

Ecological welfare performance refers to the ratio of social welfare value to ecological consumption, which is derived from Daly's (2005) overview of the "full world" theory. He believes that human beings have entered a "full world" where natural capital is scarce, and then the economic growth at this time may not necessarily bring about the improvement of the welfare level. Relevant research on ecological welfare performance started relatively late but attracted much attention, etc. Existing literature can be roughly divided into three categories: The first type focuses on the connotation and measurement of ecological welfare performance (Zhu et al., 2014; Feng et al., 2016; Long et al., 2019); The second type of literature focuses on influencing factors affecting ecological welfare performance (Xiao et al., 2018; Du et al.; 2020).The research shows that technological development, greening level, urbanization are the main factors affecting the performance of ecological welfare; and the third literature studies the convergence and spatial effect of ecological welfare performance (Xu et al., 2019; Du et al., 2019; Fang et al., 2019; Xiao et al., 2020).

With the continuous improvement of national governance level and management system, the environmental regulation tools are constantly improved, and the domestic and foreign scholars on the economic impact of environmental regulation has carried on the related research. There are three most representative views: the first kind of view support "porter hypothesis", thinking appropriate environmental regulation will encourage enterprise innovation and improve the economic efficiency (Sinn,2008;Hoel,2010;Edwin et al., 2012; Zhang et al., 2012; Yang et al., 2012); The second type of view supports the "follow cost hypothesis" that environmental regulation increases enterprise production costs, occupies innovative investment and has negative impact (Lanoie et al., 2011; Hancevic et al., 2016; Xu et al.; 2017); The third view believes that the impact of environmental regulation on economic performance is uncertain, and different environmental regulation tools, time and space differences have on economic performance (Li et al., 2016; Cai et al., 2017).Most of the above literature studies focus on the relationship between environmental regulation and ecological efficiency, green economic efficiency and green development efficiency, while there are relatively few research on environmental regulation and ecological welfare performance, and regard environmental regulation as a whole, not considering the different influence of different environmental regulation tools.

To sum up, the existing literature still has the following shortcomings: first, it lacks the theoretical influence mechanism of environmental regulation on ecological welfare performance; second, the heterogeneity of environmental regulation is not considered. In fact, the impact of different environmental regulation tools may be different; Third, the lack of discussing the impact of environmental regulation on ecological welfare performance from a spatial perspective. Based on this, this paper makes the following expansion on the basis of the existing studies: (1) Theoretical systematically explains the action mechanism of environmental regulation on ecological welfare performance; (2) The heterogeneity of the impact of different environmental regulation tools on ecological welfare performance was investigated; (3) The spatial spillover effect of heterogeneous environmental regulation tools on ecological welfare performance was discussed.

3. Theory Analysis and Hypothesis

This article draws from Copeland and Taylor Thinking (Copeland and Taylor;1994), building the production model of the two departments, incorporating environmental regulation into the production function, deducing the analysis framework of industrial structure optimization and technological innovation as the basic path, and draw the research hypothesis that environmental regulation can promote the improvement performance of ecological welfare.

Suppose that the two production departments A and B respectively produce products a, b. a is a non-clean product, which will discharge e unit of pollutants during production. b is a clean product whose input elements are capital (K) and labor (L), and the C-D functions of the product a, b is:

$$F_a(K_a, L_a) = K_a^{\alpha} L_a^{\beta}, \;\; \alpha + \beta = 1 \tag{1}$$

$$F_b(K_b, L_b) = K_b^{\delta} L_b^{\gamma}, \;\; \delta + \gamma = 1 \tag{2}$$

In the absence of environmental regulation, pollutant emission is in a fixed proportion to the output of product A. To reduce pollutant emission, another factor of a certain proportion should be input into the equation (1). The simultaneous production function equation of product A is constructed as follows:

$$a(K_a, L_a) = F\big((1-\theta)K_a, (1-\theta)L_b\big) = (1-\theta)K_a^{\alpha} L_a^{\beta} \tag{3}$$

$$e = \varphi(\theta) K_a^{\alpha} L_a^{\beta} \tag{4}$$

Among them, $\varphi(\theta)$is the environmental regulation effect. With the enhancement of the intensity of environmental regulation θ pollutants a gradually reduce, the $\varphi(\theta) = (1-\theta)^{\frac{1}{\omega}}$,$\omega \epsilon (0,1)$. According to the product b cost minimizing condition, the total cost function of product b is:

$$c^b(r,w) = \left(\frac{rw}{\delta}w\right)\left(\frac{\delta r}{rw}\right)^{\gamma} F_b(K_b, L_b),\ \ \delta + \gamma = 1 \tag{5}$$

Where, r and w are the factor prices of capital and labor respectively. Therefore, the marginal cost of product b is:

$$mc^{Fb}(r,w) = \frac{\delta^{-\delta}}{\gamma^{\gamma}} r^{\gamma} w^{\delta} \tag{6}$$

Similarly, in the absence of environmental regulation, the marginal cost of producing products a is:

$$mc^{Fa}(r,w) = \frac{\beta^{-\beta}}{\alpha^{\alpha}} r^{\alpha} w^{\beta} \tag{7}$$

Assuming the government charges A pollutant discharge fee of τ units per unit pollutant discharge, by constructing the first-order condition of the Lagrange equation, the pollutant discharge produced by A sector can be calculated as:

$$\lambda = \frac{e}{a} = \frac{\omega}{\tau} \tag{8}$$

The profit functions of A and B are respectively:

$$\pi^a = a - rK_a - wL_a - \tau e \tag{9}$$

$$\pi^b = b - rK_b - wL_b \tag{10}$$

The sewage charge is related to product pricing, and equation (3) and (8) are substituted into equation (9) to obtain:

$$\pi^a = (1-\omega)(1-\theta)F_a(K_a, L_a) - rK_a - wL_a - \tau e \tag{11}$$

Let $P^{Fa} = (1-\omega)(1-\theta)$ and in a perfectly competitive market, the marginal cost of enterprise profit maximization = product price, i.e., $mc^{Fa}(r,w) = P^{Fa}$, $mc^{Fb}(r,w) = 1$. Substitute the maximization of enterprise profit into Equations (6) and (7), and the factor prices are respectively solved:

$$r=\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{\gamma-1}{\alpha-\gamma}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{1-\alpha}{\alpha-\gamma}}(P^{Fa})^{\frac{1-\gamma}{\alpha-\gamma}} \tag{12}$$

$$w=\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{-\gamma}{\gamma-\alpha}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{\alpha}{\gamma-\alpha}}(P^{Fa})^{\frac{\gamma}{\gamma-\alpha}} \tag{13}$$

According to Shepherd theorem, the total endowment of two factors of A country can be obtained from the demand of capital and labor for unit output of A and B sectors:

$$\overline{K}=K_aF_a+K_bF_b \tag{14}$$

$$\overline{L}=L_aF_a+L_bF_b \tag{15}$$

Substituting Equations (1), (2), (12) and (13) into Equations (14) and (15), it can be concluded that the equilibrium output of A and B department is:

$$a(P^{Fa},\overline{K},\overline{L})=\frac{\alpha\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{-\gamma}{\gamma-\alpha}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{\alpha}{\gamma-\alpha}}(P^{Fa})^{\frac{\gamma}{\gamma-\alpha}}\overline{L}-(1-\alpha)\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{\gamma-1}{\alpha-\gamma}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{1-\alpha}{\alpha-\gamma}}(P^{Fa})^{\frac{1-\gamma}{\alpha-\gamma}}\overline{K}}{\alpha-\gamma} \tag{16}$$

$$b(P^{Fa},\overline{K},\overline{L})=\frac{(1-\gamma)\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{\gamma-1}{\alpha-\gamma}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{1-\alpha}{\alpha-\gamma}}(P^{Fa})^{\frac{1-\gamma}{\alpha-\gamma}}\overline{L}-\gamma\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{-\gamma}{\gamma-\alpha}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{\alpha}{\gamma-\alpha}}(P^{Fa})^{\frac{\gamma}{\gamma-\alpha}}\overline{K}}{(1-\omega)(\alpha-\gamma)} \tag{17}$$

To the $R=\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{-\gamma}{\gamma-\alpha}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{\alpha}{\gamma-\alpha}}$、$X=\left(\frac{\beta^{-\beta}}{\alpha^{\alpha}}\right)^{\frac{\gamma-1}{\alpha-\gamma}}\left(\frac{\delta^{-\delta}}{\gamma^{\gamma}}\right)^{\frac{1-\alpha}{\alpha-\gamma}}$, The effect of environmental regulation on the equilibrium output of the two products is observed by taking the derivative of equation (16) and equation (17) with respect to pollution control cost τ respectively:

$$\frac{\partial a(P^{Fa},\overline{K},\overline{L})}{\partial\tau}=\frac{\partial a(P^{Fa},\overline{K},\overline{L})}{\partial P^{Fa}}\frac{\partial P^{Fa}}{\partial\tau}=-\frac{\alpha\gamma R(P^{Fa})^{\frac{\alpha}{\gamma-\alpha}}\overline{L}+(1-\alpha)(1-\gamma)X(P^{Fa})^{\frac{1-\alpha}{\alpha-\gamma}}\overline{K}}{(\gamma-\alpha)^2}\frac{\partial P^{Fa}}{\partial\tau}>0 \tag{18}$$

$$\frac{\partial b(P^{Fa},\overline{K},\overline{L})}{\partial\tau}=\frac{\partial b(P^{Fa},\overline{K},\overline{L})}{\partial P^{Fa}}\frac{\partial P^{Fa}}{\partial\tau}=\frac{(1-\gamma)^2X(P^{Fa})^{\frac{1-\gamma}{\alpha-\gamma}}\overline{K}+\gamma^2R(P^{Fa})^{\frac{\alpha}{\gamma-\alpha}}\overline{L}}{(1-\omega)(1-\theta)}\frac{\partial P^{Fa}}{\partial\tau}<0 \tag{19}$$

Since the α、β、γ、δ、ω、$\theta\epsilon(0,1)$、$P^{Fa}=(1-\tau e)(1-\theta)$, the yield of non-clean product A will decrease when the environmental regulation intensity is high, i.e., the greater τ. On the contrary, the output of cleaning product B will increase, and the industrial structure will be continuously optimized and upgraded. According to "Porter Hypothesis", the increase of environmental regulation intensity will increase the innovation input of enterprise production, promote enterprise innovation, and encourage the greening of industrial structure, thus leading to the improvement of ecological welfare performance level. Ecological welfare performance is the ratio of social welfare value to the consumption of ecological resources, which can be expressed as:

$$EP = \frac{\sum w_i y_i}{\sum u_v e_v} \tag{20}$$

Whereinto,y_i、 e_v are the pollution emission in the ith output and v ,$w_i and\ u_v$ are the proportion of their input factors, the molecular part of output is the sum of output a and output b, recorded as $Y(P, \tau, \overline{K}, \overline{L})$, and the denominator part is pollution output, denoised as $e^a(\overline{K}, \overline{L})$. Then equation (20) can be rewritten as:

$$EP = \frac{Y(P, \tau, \overline{K}, \overline{L})}{e^a(\overline{K}, \overline{L})} = \frac{a(P^{Fa}, \overline{K}, \overline{L}) + b(P^{Fa}, \overline{K}, \overline{L})}{\varphi^a(\theta)(P^{Fa}, \overline{K}, \overline{L})} \tag{21}$$

Among them, $\frac{\partial a(P^{Fa}, \overline{K}, \overline{L})}{\partial \tau} > 0$、 $\frac{\partial b(P^{Fa}, \overline{K}, \overline{L})}{\partial \tau} < 0$. Environmental regulation mainly shows the "structural" and "technological" effects. Among them, the technological effect is manifested as the improvement of technological level. On the one hand, the improvement of technological level can bring about the improvement of productivity, reduce the energy consumption per unit output, and thus reduce pollution emissions. On the other hand, the improvement of technology level can improve the environmental governance technology and environmental optimization. The structural effect is the upgrading of industrial structure, the reduction of polluting industries and the reduction of environmental pollution. The core connotation of ecological welfare performance includes environmental optimization, sustainable economic development, improvement of social welfare and other indicators.

Therefore, this paper proposes theoretical hypothesis 1: environmental regulation helps to improve ecological welfare performance.

With the increase of the types of environmental regulatory tools, the heterogeneity of different types of environmental regulatory tools has also attracted the attention of scholars. Zhang J X et al. (2015) found in their research that market incentive environmental regulations significantly improved the industrial green growth index, while command-control and public participation environmental regulations had a relatively weak impact. Yu

W et al. (2016) found in their study that command-control and market incentive environmental regulations have no significant impact on industrial operation performance. Li X P et al. (2020) found in their study that market incentive environmental regulations have the greatest promoting effect on carbon productivity, followed by command-control environmental regulations. Wei W et al. (2020) found that both punitive environmental regulation and incentive environmental regulation have significant promoting effects on industrial environmental efficiency, and the effect of punitive environmental regulation decreases in intensity while that of incentive environmental regulation increases in intensity.

Therefore, this paper proposes theoretical hypothesis 2: there is heterogeneity in the impact of different environmental regulation tools on ecological welfare performance.

4. Methodology and variables

4.1 Model

Based on the theoretical mechanism analysis and hypothesis, and by referring to the research of Li X P (2020), a spatial econometric model is constructed to empirically analyze the spatial impact of heterogeneous environmental regulations on ecological welfare performance. The model is as follows:

$$EP = \alpha + \beta ER + \theta_i X + \rho W * ep + \varphi_i W * X + \eta_i + \delta_t + \mu_{it}$$

$$\mu_{it} = \lambda W * \mu_{it} + \nu_{it} \tag{22}$$

In the formula (22), W represents the spatial weight matrix, EP represents the ecological welfare performance, ER represents different environmental regulation tools, X represents other control variables, η_i, δ_t, and μ_{it} represent individual effect, time effect and random disturbance items respectively. When ρ≠0, φ=0 and λ=0, it is a spatial lag model. When ρ≠0, φ≠0 and λ=0, it is a spatial Durbin model. When ρ=0, φ=0 and λ≠0, it is a spatial error model.

4.2 Variable description

(1) Ecological welfare performance (EP). How to accurately measure the performance of ecological welfare is the starting point of this analysis. Most of the existing literature uses

data envelopment analysis method to construct the measurement index of ecological welfare performance to measure the performance of ecological welfare. This paper uses the Super-SBM method proposed by Tone (2001) to measure ecological welfare performance according to its connotation and uses the indicator system of Long et al (2017) for reference. The selected input indexes include energy consumption (per capita standard coal consumption), land resources (per capita urban construction land area) and water resources consumption (per capita water consumption). Output indicators include both desired output and non-desired output. Desired output is expressed by the human development index, which includes the level of health care (life expectancy), the level of education (average years of schooling) and the level of economic development (per capita GDP). Undesired outputs include wasting water (total industrial wasting water emissions per capita), waste gas (industrial waste gas emissions per capita) and solid waste (industrial solid waste emissions per capita).

(2) Environmental Regulation (ER). Reference Li X P(2020) research, environmental regulation tools can be divided into command and control, market incentives and voluntarily participated in three types, among them, the command control type (ER1) is mainly refers to the government mandatory intervention activities of drainage measures, adopt various provinces and cities "three simultaneity" environmental protection investment ratio as GDP region; Market incentive type (ER2) refers to the influence of market forces on the environmental behavior of the parties, which is measured by the ratio of resource tax to local fiscal revenue. Voluntary participatory environmental regulation (ER3) refers to a non-legal agreement that is expected to be established between the government, enterprises or non-profit organizations with the purpose of improving environmental quality or resource utilization, which is represented by the total number of environmental letters in each province or city.

(3) Control variables. Technical level (Tc), which is represented by the number of authorized patent applications and treated logarithmically. Industrial structure (Ind),which is expressed as the proportion of the total output value of the tertiary industry in GDP. The

degree of opening to the outside world (Open) is expressed as the proportion of total imports and exports of each province in GDP. The level of economic development (Pgdp) is expressed by GDP per capita and treated logarithmically. This paper takes the panel data of 30 provinces from 2005 to 2019 as the research object (the data of Tibet is missing, so it is excluded, and Hong Kong, Macao and Taiwan regions of China are not included), and the data are all from EPS database.

5. empirical analysis

5.1 Descriptive Analysis

As can be seen from Table 1, the maximum value of ecological welfare performance is 1.88, and the minimum value is 0.26. The large difference between the maximum value and the minimum value indicates that there are inter-provincial differences in the ecological welfare performance of provinces in China, showing the characteristics of unbalanced spatial distribution. At the same time, the maximum and minimum values of different environmental regulation tools in different provinces also have great differences, indicating that there are regional differences in environmental regulation tools in different provinces.

Table 1 Descriptive statistics of the sample data

Variables	Definition	Means	Std.	Max	Min
EP	Ecological welfare performance	0.663	67.338	1.880	0.260
ER1	Market incentive-type	2.645	73.223	21.470	0.001
ER2	Command control-type	1.338	54.672	4.240	0.270
ER3	Voluntary participatory type	0.087	0.011	0.063	0.113
Open	Opening degree	0.131	0.221	1.163	0.000
Tc	Technological progress	9.393	1.640	13.176	4.369
Pgdp	Economic development level	10.461	0.654	13.176	8.528
Ind	Industrial structure	0.435	0.099	0.835	0.000

5.2 Spatial Distribution

Figure 1 shows the geographical distribution of the mean value of ecological welfare performance of all Chinese provinces during the sample period. The darker the color, the higher the level of ecological welfare performance. There are four provinces whose ecological welfare performance value is greater than 1, namely Beijing, Tianjin, Hainan and Qinghai, accounting for about 13% of the whole country. From the perspective of geographical distribution, the regions with high ecological welfare performance are mainly concentrated in the eastern coastal areas, such as Jiangsu, Shanghai, Zhejiang, etc., which may be caused by the relatively high level of economic development, medical and health care level, education level and ecological and environmental protection level in the eastern coastal areas.

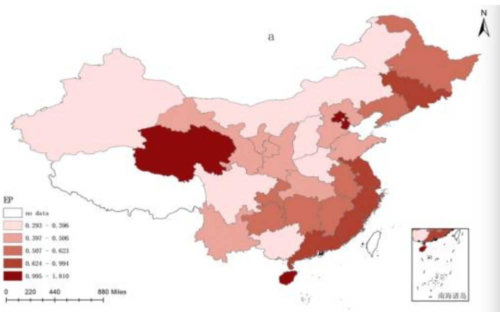

Figure 1 Spatial distribution of ecological welfare performance in various Chinese provinces

Fig. 2, Fig. 3 and Fig. 4 respectively show the spatial distribution of the annual mean value of environmental regulation intensity of command-control type, market incentive type and voluntary participation type. From the figure, we can intuitively see the differences in the geographical distribution of the three types of environmental regulations, and the implementation intensity of different types of environmental regulation tools in the same region is also different, which also indicates that there may be differences in the impact of heterogeneous environmental regulations on ecological welfare performance. Specifically, the high value regions of command-control environmental regulation are mainly distributed in Northwest China and Northeast China. The regions with high value of market incentive environmental regulation are mainly distributed in the eastern and northwestern regions, while the regions with low value are mainly concentrated in the western regions such as

Yunnan, Guizhou and Sichuan. The regions with high values of voluntary participatory environmental regulations are mainly concentrated in Shanghai, Jiangsu, Zhejiang and other eastern regions, while the regions with low values are mainly concentrated in Xinjiang, Qinghai, Shanxi and other northwestern regions.

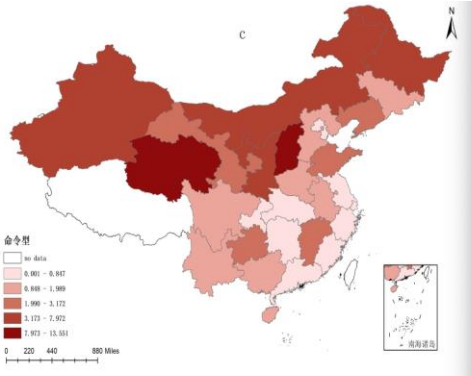

Figure 2. Spatial Distribution of Command Control the Market Environment Regulation

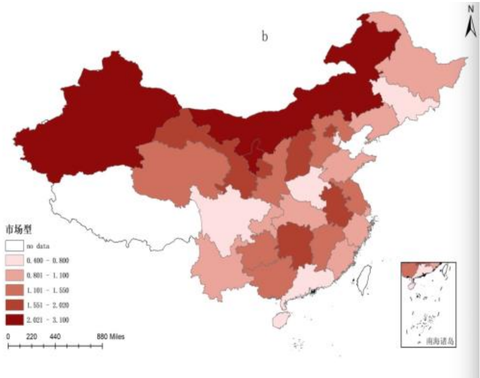

Figure 3 The Spatial Distribution of Incentive Environment Regulation

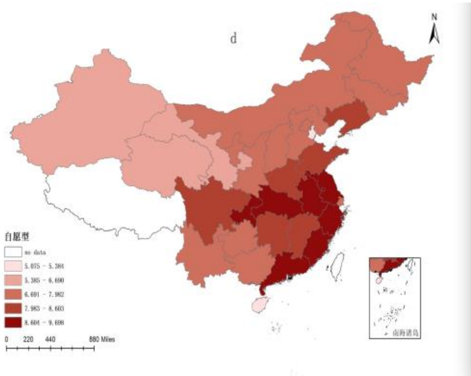

Figure 4. Spatial Distribution of voluntary participating Environment Regulation

5.3 Spatial correlation analysis

In order to verify whether there is a spatial correlation between environmental regulations and ecological welfare performance in each province, the global Moran index was used to analyze the spatial correlation between market incentive, command-control, voluntary participation environmental regulations and ecological welfare performance, so as to judge whether there are spatial correlation characteristics. Table 2 shows the results of China's ecological welfare performance and the global Moran index test of the three environmental regulations under the economic-geographic nested weight matrix from 2005 to 2019. The results in Table 2 show that the Moran' I value of ecological welfare performance is greater than 0, and the P values all pass the significance level test of 10%. The Moran' I value of market incentive, command control and voluntary participation environmental regulation is greater than 0, and the P value has passed the significance level test of 10%, which indicates that there is a significant positive spatial correlation between the ecological welfare performance of different provinces and different types of environmental regulation tools in China.

Table 2 Moran's I test results of heterogeneous environmental regulation and ecological welfare performance

year	EP		Market incentive		Command-control		Voluntary participation	
	Moran's I	P	Moran's I	P	Moran's I	P	Moran's I	P
2005	0.278***	2.332	0.383***	3.047	0.060**	2.170	0.030***	2.781
2006	0.280***	2.357	0.433***	3.308	0.089***	2.782	0.033**	2.011
2007	0.288***	2.395	0.457***	3.495	0.104***	3.125	0.011***	2.868
2008	0.248**	2.101	0.423***	3.328	0.095***	2.970	0.038**	2.010
2009	0.331***	2.679	0.354***	3.108	0.067***	2.480	0.033*	1.934
2010	0.298***	2.438	0.536***	4.559	0.064***	2.407	0.037**	2.004
2011	0.317***	2.589	0.642***	5.306	0.091***	3.033	0.034*	1.812
2012	0.306***	2.540	0.559***	4.436	0.084***	2.767	0.054***	2.308
2013	0.307***	2.593	0.507***	3.941	0.085***	2.755	0.088***	3.174
2014	0.321***	2.695	0.431***	3.450	0.069***	2.400	0.089***	3.244
2015	0.276***	2.327	0.398***	3.234	0.047*	1.917	0.098***	3.448
2016	0.269**	2.236	0.335***	2.819	0.032*	1.770	0.091***	3.272
2017	0.313***	2.569	0.346***	2.945	0.040*	1.775	0.088***	3.184
2018	0.190**	2.012	0.395***	3.286	0.055**	2.129	0.091***	3.264
2019	0.140*	1.878	0.385***	3.250	0.051**	2.049	0.090***	3.262

Note：*P<0.1,**P<0.05,*** P<0.001 in the double tail test.

5.4 Analysis of the spatial regression results

In order to test the rationality of the model, the spatial lag model, the spatial error model and the spatial Durbin model were regression respectively in this paper, and the regression results are shown in Table 3. For the command-control type, market incentive type and voluntary participation type, the spatial Durbin model has the largest degree of fitting, the logarithmic likelihood function has the largest value, and the AIC and BIC have the smallest value. Therefore, the spatial Durbin model is determined to be the optimal model.

It can be seen from the regression results that command-control, market incentive and voluntary participation environmental regulations all have a positive impact on China's ecological welfare performance, which verifies hypothesis 1 that environmental regulations are conducive to the improvement of ecological welfare performance. In Models (3), (6) and (9), the estimated coefficient of ρ is significantly positive, indicating that there is a positive spillover effect on ecological welfare performance among provinces, that is, there is mutual influence on ecological welfare performance among neighboring provinces, showing the characteristic of "one flourishing, one losing". From the perspective of the impact of different types of environmental regulations, different types of environmental regulations have different impacts on ecological welfare performance. Proposition 2 can be verified that heterogeneous environmental regulations have different impacts on ecological welfare performance. Specifically, the regression coefficient of command-control environmental regulations in Model (3) is significantly positive, with a coefficient of 0.004, indicating that an increase of 1 unit of command-control environmental regulations can promote an increase of 0.004 unit of ecological welfare performance. In Model (6), the regression coefficient of market incentive environmental regulation is significantly positive, with a coefficient of 0.012, indicating that increasing 1 unit of market incentive environmental regulation can promote the improvement of ecological welfare performance by 0.012 units. By contrast, the promoting effect of market incentive environmental regulation is greater than that of command-control environmental regulation. This may be because market incentive environmental regulation gives enterprises the free choice of technological innovation and production and operation, which can reduce the execution cost. With the continuous improvement of China's environmental monitoring system and legal system, the effect of market incentive environmental regulation on the protection of China's environment is increasingly strengthened. In Model (9), voluntary and participatory environmental regulations have a positive but insignificant role in promoting ecological welfare performance, which is consistent with the conclusion of Li X P(2020). This may be because voluntary participatory environmental regulation depends on the public's conscious awareness of environmental protection. However, there are still many problems in voluntary participatory environmental regulation in China, such as the mismatch of public conscious awareness of environmental protection and the low level of public participation, which leads to the insignificant promotion effect of voluntary participatory environmental regulation on ecological welfare performance.

Table 3 Test results of the influence of heterogeneous environmental regulation on ecological welfare performance and space overflow effect in China

Variables	Command-control (ER1)			Market incentive (ER2)			Voluntary participation (ER3)		
	SAR（1）	SEM（2）	SDM（3）	SAR（4）	SEM（5）	SDM（6）	SAR（7）	SEM（8）	SDM（9）
ER	0.004**	0.005***	0.004**	0.015**	0.017**	0.012**	0.003	0.002	0.005
	(2.22)	(2.62)	(2.24)	(2.01)	(2.31)	(2.16)	(1.48)	(1.14)	(1.20)
Tc	0.012*	0.015*	0.371***	0.016*	0.021**	0.404***	0.016*	0.018*	0.015***
	(1.76)	(1.86)	(2.69)	(1.79)	(1.88)	(2.66)	(1.89)	(1.66)	(2.88)
Ind	0.044	0.074	0.047	0.028	0.043	0.005	0.058	0.077	0.028
	(0.66)	(1.07)	(0.70)	(0.41)	(0.67)	(0.06)	(0.86)	(1.16)	(0.39)
Open	0.030	0.032**	0.036*	0.049*	0.052*	0.040*	0.035	0.040	0.028
	(0.92)	(2.16)	(1.96)	(1.74)	（1.73）	(1.94)	(1.08)	(1.27)	(0.80)
Pgdp	-0.020	-0.030	0.027***	-0.019	-0.02	0.018*	-0.020	-0.028	-0.014

	(-1.02)	(-1.58)	(2.53)	(-0.95)	(-1.42)	(1.79)	(-1.02)	(-1.38)	(-0.38)
W ER			-0.421** (-2.21)			0.241*** (2.96)			0.181 (0.35)
W Tc			0.442*** (2.68)			0.519*** (3.07)			0.512*** (2.97)
W Ind			0.905 (0.13)			0.324 (0.38)			0.694 (0.96)
W Open			-0.225 (-0.61)			-0.223 (-0.57)			-0.574 (-0.15)
W Pgdp			-1.131*** (-3.74)			0.962*** (3.05)			1.059*** (3.39)
ρ/λ	0.079** (1.99)	0.155** (2.27)	0.199*** (3.33)	0.088** (2.38)	0.140** (2.15)	0.207*** （2.99）	0.062** （2.10）	0.102** （1.97）	0.112*** (2.89)
R2	0.149	0.174	0.218	0.134	0.158	0.254	0.160	0.130	0.229
Log L	591.152	592.821	628.496	590.7267	592.085	603.020	589.011	589.658	600.602
AIC	-968.304	-971.642	-1004.164	-967.453	-970.170	-982.040	-966.022	-961.315	-977.204
BIC	-939.539	-942.877	-954.853	-938.689	-941.405	-932.729	-935.257	-936.551	-967.893
N	450	450	450	450	450	450	450	450	450

Note：*P<0.1,**P<0.05,*** P<0.001, with t statistics in parentheses.

From the spatial spillover effect model (3), the region command-control type of the strengthening of environmental regulation performance against adjacent regional ecological welfare level of ascension, to increase 1 unit type command-control the intensity of environmental regulation can reduce welfare performance 0.421 units in the adjacent regions, this may be because in the management system of fiscal decentralization on our region to take strict environmental regulation. Adjacent areas will become the transfer and receiving places of polluting enterprises, resulting in increased pollution emissions in adjacent areas and increased pressure on emission reduction, thus showing negative spatial spillover effect, which further confirms the research conclusion of Shen K R(2017). In Model (6), the increase in the intensity of market incentive environmental regulations in this region is conducive to the improvement of the ecological welfare performance of neighboring regions, which is manifested as that the increase of 1 unit of market incentive environmental regulations in this region will improve the ecological welfare performance of neighboring regions by 0.241 unit. This may be because market incentive environmental regulations promote technological progress by promoting technological progress. The "learning effect" and "competition effect" promote the technological innovation and stimulate the "Porter effect" in the neighboring areas, and then produce positive spatial spillover effect on the ecological welfare performance in the neighboring areas. In Model (9), the spatial spillover effect of voluntary and participation environmental regulations on ecological welfare performance is not significant, which may be because voluntary and participation environmental regulations in China are still in the development stage and the public's environmental awareness is weak, so the spatial effect on ecological welfare performance is not significant.

5.5 Robustness test

The empirical analysis mainly reported the regression results of the economy - geographical matrix. However, considering the spatial econometric analysis of spatial weight matrix of sensitivity, this paper further report based on adjacency matrix and geographic distance matrix in SDM model the heterogeneity of the spatial effect of environmental regulation on Chinese ecological benefits performance regression results, as shown in table 4. It can be seen from Table 4 that market incentive and command-control environmental regulations have a significant promoting effect on China's ecological welfare performance, and there is a significant spatial spillover effect on ecological welfare performance, but the size of the spillover effect is different, and the direction of the spillover effect is consistent with the above results. Therefore, the estimation results of the impacts of three different types of environmental regulations on China's ecological welfare performance and the spatial spillover effects are robust.

Table 4. Robustness test results

Var	the adjacent matrix			the geographical distance matrix		
	ER1	ER2	ER3	ER1	ER2	ER3
ER	0.002**	0.012**	0.005	0.005***	0.013**	0.002
	(2.27)	(1.99)	(1.08)	(2.64)	(2.12)	(0.40)
Tc	0.002	0.004	0.001	0.011	0.017	0.013
	(0.19)	(0.28)	(0.09)	(0.96)	(1.37)	(1.09)
Ind	0.089	0.097	0.068	0.027	0.036	0.022
	(1.12)	(1.20)	(0.84)	(0.33)	(1.37)	(0.27)
Open	0.023	0.040	0.021	0.014	0.039	0.027
	(0.63)	(1.09)	(1.41)	(0.37)	(1.04)	(0.75)
Pgdp	0.081**	0.038	0.052	0.010	0.021	0.022
	(2.27)	(1.09)	(1.41)	(0.33)	(0.67)	(0.69)
W ER	0.011***	0.043***	0.007	0.149***	0.073***	0.202
	(3.03)	(3.17)	(1.15)	(2.44)	(2.77)	(0.70)
W Tc	0.073***	0.079***	0.076***	0.044	0.756	0.120
	(3.19)	(3.48)	(3.29)	(0.07)	(0.39)	(0.58)
W Ind	0.220	0.213	0.142	0.226	0.157	0.022
	(1.17)	(1.17)	(1.07)	(0.20)	(1.33)	(0.27)
W Open	-0.042	-0.042	-0.019	-0.437	-0.413*	-0.371*
	(-0.79)	(-0.82)	(-0.36)	(-1.03)	(-1.87)	(-1.65)
W Pgdp	-0.159***	0.133***	0.151***	-0.980	0.102	0.701
	(-3.87)	(3.40)	(3.86)	(-0.31)	(0.03)	(0.22)
ρ/λ	0.095***	0.077***	0.046***	0. 087***	0.071***	0.085**
	(2.55)	(3.24)	(2.74)	(2.57)	(2.70)	(2.48)
R2	0.206	0.212	0.114	0.181	0.087	0.077

Log L	610.816	601.158	604.742	607.606	605.836	604.472

Note: as Table 3.

6. conclusions and recommendations

This paper theoretically explains the action mechanism of environmental regulation on ecological welfare performance. Based on the panel data of 30 provinces in 2005 ~2019, the spatial Durbin model constructed to test the spatial spillover effect of heterogeneous environmental regulation on ecological welfare performance in China. The study found: (1) there are regional differences in ecological welfare performance in Chinese provinces and unbalanced regional spatial distribution. (2) Market incentive, command-control and voluntary participation environmental regulation and ecological welfare performance has significant positive spatial correlation. (3) The impact of different types of environmental regulations on China's ecological welfare performance is heterogeneous. Command-control and market incentive environmental regulations can improve China's ecological welfare performance, but the promotion effect of market incentive environmental regulations is stronger than that of command-control environmental regulations. The effect of voluntary participatory environmental regulation is not significant. (4) From the perspective of space spillover effect, the command-control environmental regulation is not conducive to the improvement of ecological welfare performance in neighboring areas, while market incentive environmental regulation is conducive to the improvement of ecological welfare performance in neighboring areas, and voluntary participation environmental regulation has no significant spatial spillover effect on ecological welfare performance in neighboring areas.

The above conclusions have important policy implications: (1) To establish a collaborative mechanism for environmental regulation. In this paper, the study found that environmental regulation and the ecological welfare performance were presented significant spatial correlation, thus to build a targeted interest compensation mechanism, to avoid the transfer of pollution across regions, build environment of local government cooperative governance mechanism, a "zone spreading across the region is a common environmental governance responsibility, break the local market segmentation, Eliminate local protectionism and "free rider" behavior, optimize resource allocation, and improve the performance of ecological welfare. (2) Choose appropriate environmental regulation tools according to local conditions. This study found that different environmental regulation tools have different impacts and spatial spillover effects on ecological welfare performance, and the impact of market incentive environmental regulation is stronger than that of command-type environmental regulation. Therefore, local governments should continue to be encouraged to adopt market-oriented environmental regulation policies, such as investment in pollution control and resource tax, to promote technological innovation of enterprises through market means, also to improve ecological welfare performance. At the same time, we should strengthen the positive impact of command-control environmental regulations, prevent pollution transfer caused by command-control environmental regulations, and reduce the negative impact of command-control environmental regulations on the ecological welfare performance of neighboring areas. (3) Establish and improve the policy of voluntary participation in environmental regulation. This study shows that the impact of voluntary participatory environmental regulation is not significant. Therefore, to actively establish and improve public participation in environmental management laws and regulations, establish perfect and transparent government information publicity system, strengthen the enterprise information disclosure, give full play to the supervision of the media initiative, intensify propaganda and education, encourage the public to actively participate in environmental protection, promote the voluntary participation environmental regulation of ecological benefits are significant impact performance.

Declarations

1. Ethics approval and consent to participate

I certify that this manuscript is original and has not been published and will not be submitted elsewhere for publication while being considered by Environmental Science and Pollution Research. And the study is not split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time. No data have been fabricated or manipulated (including images) to support your conclusions. No data, text, or theories by others are presented as if they were our own. The submission has been received explicitly from all co-authors. And authors whose names appear on the submission have contributed sufficiently to the scientific work and therefore share collective responsibility and accountability for the results.

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent was obtained from all individual participants included in the study.

Conflict of Interest: The authors declare that they have no conflict of interest.

2. Consent for publication

Not applicable.

All data generated or analysed during this study are included in this published article.

3.Competing interests

The authors declare that they have no competing interests.

4.Funding

Not applicable.

5.Authors' contributions

Guo Bingnan checked the rationality of the article. Tang li analyzed and interpreted the data and established the model, and was a major contributor in writing the manuscript. Jia ru proofread the article. Lin Ji provided reliable advice for writing the article. All authors read and approved the final manuscript.

References

Cai, W.G., Zhou, X.L.,2017. Dual effect of Chinese environmental regulation on green total factor productivity. Economist. (9):27-35.

Copeland, B. R., and M. S. Taylor.,1994. North-south trade and the environment. Quarterly Journal of Economics. 109(3):755-787.

Daly H.E.,2005. Economics in a full world. Scientific American. (3),100-107.

Du, H.B., Huang, L.J., Zhang, C., He, J. J.,2019. Research on the regional differences decomposition and convergence mechanism of ecological well-Being performance. Ecological Economy. 29(03):1-10.

Edwin, Van, Der, et al.,2021. Imperfect environmental policy and polluting emissions: the green paradox and beyond. International Review of Environmental and Resource Economics. 6(2):153-194.

Fang, S.J., Xiao Q.,2019. Research on regional ecological well-being performance and spatial effect in China. China population， resources and environment. 29(3):1 - 10.

Feng, J. F., Yuan, J. H., 2016. On Chinese regional ecological well-being performance and its influence factors. China Science and Technology Forum. (03):100-105.

Hancevic I P.,2016. Environmental regulation and productivity: the case of electricity generation under the CAAA-1990. Energy economics. 60: 131-143.

Hoel M.,2010. Is there a green paradox? CESifo Working Paper Series. 100(11):1999-2030.

Lanoie P, Laurent-lucchetti J, Johnstone N, et al.,2011. Environmental policy, innovation and performance: new insights on the Porter Hypothesis. Journal of economics & management strategy. 20(3):803-842.

Li B, Wu S S.,2016. Effects of local and civil environmental regulation on green total factor productivity in China: a spatial Durbin econometric analysis. Journal of Cleaner Production. 153:342-353.

Li, C.Y., Zhang, S.Q., Zhang, W. et al., 2019. Measurement and influencing factors of inter-provincial ecological well-being performance in China. Scientia Geographica Sinica. 39(12): 1875-1883.

Li, X. P., Yu, D. S., Yu, J. J.,2020. Spatial spillover effect heterogeneous environmental regulations on carbon productivity-spatial Durbin model. China Soft Science. (04):82-96.

Long, L. J., 2019. Evaluation of urban ecological well-being performance of Chinese major cities based on two-stage super-efficiency network SBM Model. China population， resources and environment. 29(7): 1 - 10.

Sinn H.,2008. Public policies against global warming: a supply side approach. International Tax Public Finance. (4):360-394.

Tone, K.,2001. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research. (3):498-509.

Wei, W.,2020. Heterogeneous environmental regulation, clean technology structure and improvement of regional industrial environmental efficiency. Technology and Economy. 39(06):119-130+140.

Xiao, L.M., Xiao, Q.L.,2021. Study on the differentiation and spatial convergence of urban ecological welfare performance patterns in the Yellow River Basin. Soft Science. 35(02):46-53.

Xu, Y.D., Qi, P., Tong, L.F.,2017. Spatial-temporal differentiation of Chinese provincial ecological well-being performance. Regional Economic Review. (04):123-131.

Xu, Y. K.,2017. Re-evaluate the impact of environmental regulation on enterprise productivity and its mechanism. Finance & Trade Economics.38(6):147-161.

Yang, C. H., Tseng, Y. H., Chen, C. P.,2012. Environmental regulations, induced R&D, and productivity: evidence from Taiwan's manufacturing industries. Resource & energy economics.34(4):514-532.

Yu, W., Chen, Q., Chen, H.,2016. Analysis of the impact of different environmental policy instruments on technology innovation: evidence from China's 30 provinces' panel data from 2004-2011. Management Review. 28(1):53-61.

Zhang, C. H., Liu, H. Y., Bressers, H. T. A., et al.,2011. Productivity growth and environmental regulations-accounting for undesirable outputs: analysis of China's thirty provincial regions using the Malmquist-Luenberger Index. Ecological economics.70(12):2369-2379.

Zhang, J.X., Cai, N., Yang, C.,2015. Impact of environmental regulation on green growth index of industry in China. China population， resources and environment. 25(1):24-31.

Zhu, D. J., Zhang, S.,2014. Research on ecological wellbeing performance and its relationship with economic growth. China Population, Resources and Environment. 24(09):59-67.